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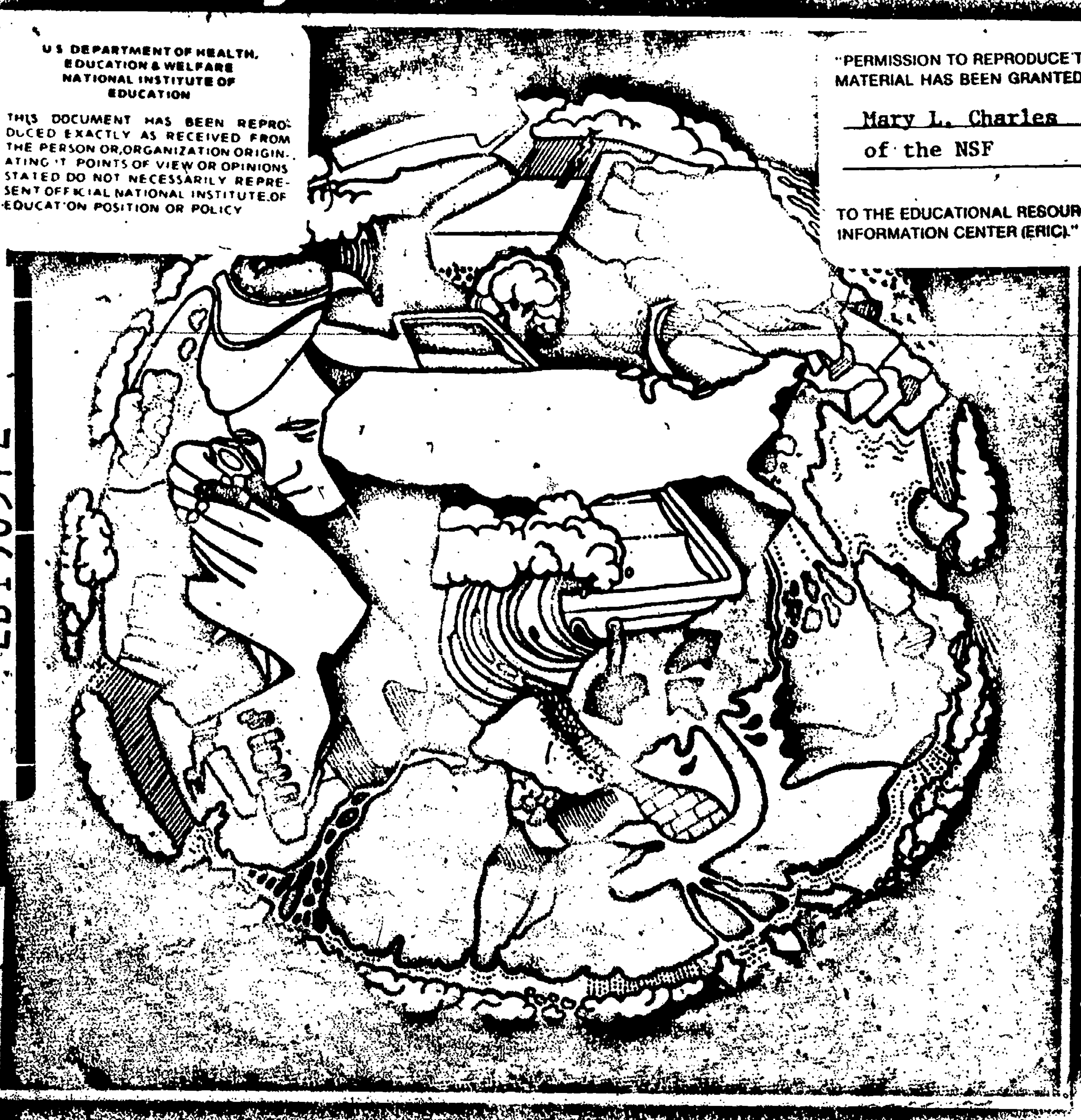
ABSTRACT

This is the student's text for one of the units of the Intermediate Science Curriculum Study (ISCS) for level III students (grade 9). The chapters contain basic information on the processes that shape the earth, activities related to the subject, and optional excursions. A section of introductory notes to the student discusses how to use the book and how the class will be organized. Illustrations accompany all instructions and the students are encouraged to select proper equipment based on the illustrations. (SA)

# Crusty Problems









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INTERMEDIATE SCIENCE CURRICULUM STUDY

# Crusty Problems

## Probing the Natural World / Level III

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# Foreword

A pupil's experiences between the ages of 11 and 16 probably shape his ultimate view of science and of the natural world. During these years most youngsters become more adept at thinking conceptually. Since concepts are at the heart of science, this is the age at which most students first gain the ability to study science in a really organized way. Here, too, the commitment for or against science as an interest or a vocation is often made.

Paradoxically, the students at this critical age have been the ones least affected by the recent effort to produce new science instructional materials. Despite a number of commendable efforts to improve the situation, the middle years stand today as a comparatively weak link in science education between the rapidly changing elementary curriculum and the recently revitalized high school science courses. This volume and its accompanying materials represent one attempt to provide a sound approach to instruction for this relatively uncharted level.

At the outset the organizers of the ISCS Project decided that it would be shortsighted and unwise to try to fill the gap in middle school science education by simply writing another textbook. We chose instead to challenge some of the most firmly established concepts about how to teach and just what science material can and should be taught to adolescents. The ISCS staff have tended to mistrust what authorities believe about schools, teachers, children, and teaching until we have had the chance to test these assumptions in actual classrooms with real children. As conflicts have arisen, our policy has been to rely more upon what we saw happening in the schools than upon what authorities said could or would happen. It is largely because of this policy that the ISCS materials represent a substantial departure from the norm.

The primary difference between the ISCS program and more conventional approaches is the fact that it allows each student to travel at his own pace, and it permits the scope and sequence of instruction to vary with his interests, abilities, and background. The ISCS writers have systematically tried to give the student more of a role in deciding what he should study next and how soon he should study it. When the materials are used as intended, the ISCS teacher serves more as a "task easer" than a "task master." It is his job to help the student answer the questions that arise from his own study rather than to try to anticipate and package what the student needs to know.

There is nothing radically new in the ISCS approach to instruction. Outstanding teachers from Socrates to Mark Hopkins have stressed the need to personalize education. ISCS has tried to do something more than pay lip service to this goal. ISCS' major contribution has been to design a system whereby an average teacher, operating under normal constraints, in an ordinary classroom with ordinary children, can indeed give maximum attention to each student's progress.

The development of the ISCS material has been a group effort from the outset. It began in 1962, when outstanding educators met to decide what might be done to improve middle-grade science teaching. The recommendations of these conferences were converted into a tentative plan for a set of instructional materials by a small group of Florida State University faculty members. Small-scale writing sessions conducted on the Florida State campus during 1964 and 1965 resulted in pilot curriculum materials that were tested in selected Florida schools during the 1965-66 school year. All this preliminary work was supported by funds generously provided by The Florida State University.

In June of 1966, financial support was provided by the United States Office of Education, and the preliminary effort was formalized into the ISCS Project. Later, the National Science Foundation made several additional grants in support of the ISCS effort.

The first draft of these materials was produced in 1968, during a summer writing conference. The conferees were scientists, science educators, and junior high school teachers drawn from all over the United States. The original materials have been revised three times prior to their publication in this volume. More than 150 writers have contributed to the materials, and more than 180,000 children, in 46 states, have been involved in their field testing.

We sincerely hope that the teachers and students who will use this material will find that the great amount of time, money, and effort that has gone into its development has been worthwhile.

Tallahassee, Florida
February 1972

*The Directors*
INTERMEDIATE SCIENCE CURRICULUM STUDY

# Contents

# Notes to the Student

The word *science* means a lot of things. All of the meanings are "right," but none are complete. *Science* is many things and is hard to describe in a few words.

We wrote this book to help you understand what science is and what scientists do. We have chosen to show you these things instead of describing them with words. The book describes a series of things for you to do and think about. We hope that what you do will help you learn a good deal about nature and that you will get a feel for how scientists tackle problems.

**How is this book different from other textbooks?**

This book is probably not like your other textbooks. To make any sense out of it, you must work with objects and substances. You should do the things described, think about them, and then answer any questions asked. Be sure you answer each question as you come to it.

*The questions in the book are very important.* They are asked for three reasons:

1. To help you to think through what you see and do.
2. To let you know whether or not you understand what you've done.
3. To give you a record of what you have done so that you can use it for review.

**How will your class be organized?**

Your science class will probably be quite different from your other classes. This book will let you start work with less help than usual from your teacher. You should begin each day's work where you left off the day before. Any equipment and supplies needed will be waiting for you.

Your teacher will not read to you or tell you the things that you are [illegible]

Try to work ahead on your own. If you have trouble, first try to solve the problem for yourself. Don't ask your teacher for help until you really need it. Do not expect him to give you the answers to the questions in the book. Your teacher will try to help you find where and how you went wrong, but he will not do your work for you.

After a few days, some of your classmates will be ahead of you and others will not be as far along. This is the way the course is supposed to work. Remember, though, that there will be no prizes for finishing first. Work at whatever speed is best for you. *But be sure you understand what you have done before moving on.*

Excursions are mentioned at several places. These special activities are found at the back of the book. You may stop and do any excursion that looks interesting or any that you feel will help you. (Some excursions will help you do some of the activities in this book.) Sometimes, your teacher may ask you to do an excursion.

**What am I expected to learn?**

During the year, you will work very much as a scientist does. You should learn a lot of worthwhile information. More important, we hope that you will learn how to ask and answer questions about nature. *Keep in mind that learning how to find answers to questions is just as valuable as learning the answers themselves.*

Keep the big picture in mind, too. Each chapter builds on ideas already dealt with. These ideas add up to some of the simple but powerful concepts that are so important in science. If you are given a Student Record Book, do all your writing in it. *Do not write in this book.* Use your Record Book for making graphs, tables, and diagrams, too.

From time to time you may notice that your classmates have not always given the same answers that you did. This is no cause for worry. There are many right answers to some of the questions. And in some cases you may not be able to answer the questions. As a matter of fact, no one knows the answers to some of them. This may seem disappointing to you at first, but you will soon realize that there is much that science does not know. In this course, you will learn some of the things we don't know as well as what is known. Good luck!

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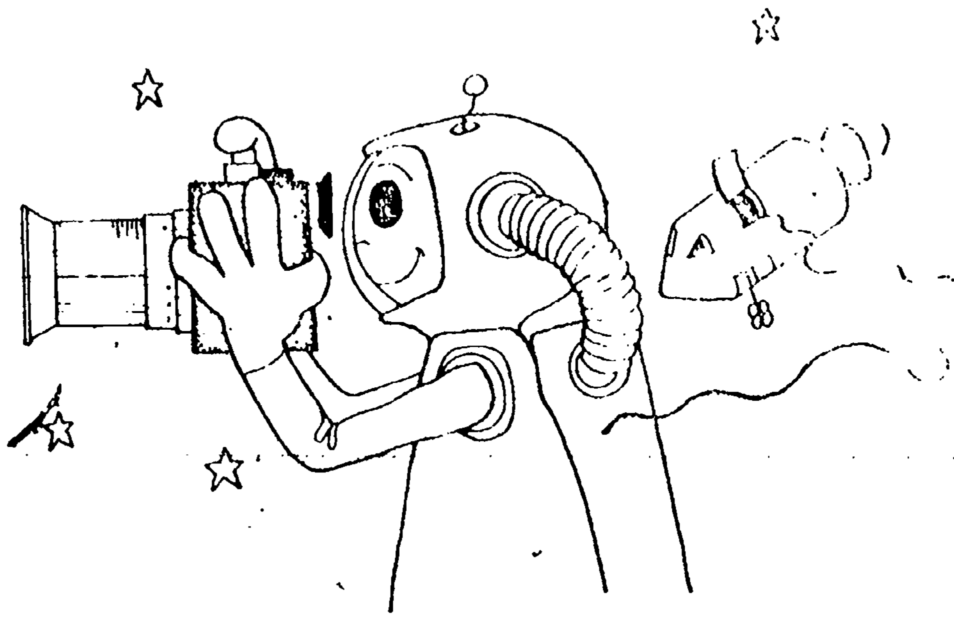
# A First Look at Earth



Just a few years ago the photograph you see on the facing page could not have been taken. Isn't it rather awesome to think you were walking around on that planet the day the photograph was taken? In this unit, you will be asked to solve many problems concerning the planet you are looking at, to make observations of features that you may see, and to determine how those features were formed and what might happen to them in the future.

Although you have lived on the earth all your life, there is a good chance that you have wondered about one or more of the following.

1. How old is the earth?
2. Has the earth always looked the way it does on the facing page?
3. Has the land that your school rests on always been there?
4. Is the earth changing in any way?
5. Do the continents actually drift?
6. What causes an earthquake, a volcano, or a landslide?

Have you ever thought about any other questions related to the earth? If so, why don't you write them in the space provided in the Record Book, and then as you study this unit, or when you finish, check back and see if you've answered them.

Before moving in and getting a closer look at the earth, examine the chapter opening picture once again.

☐ **1-1.** If you were an observer from outer space, how would you describe the planet before you?

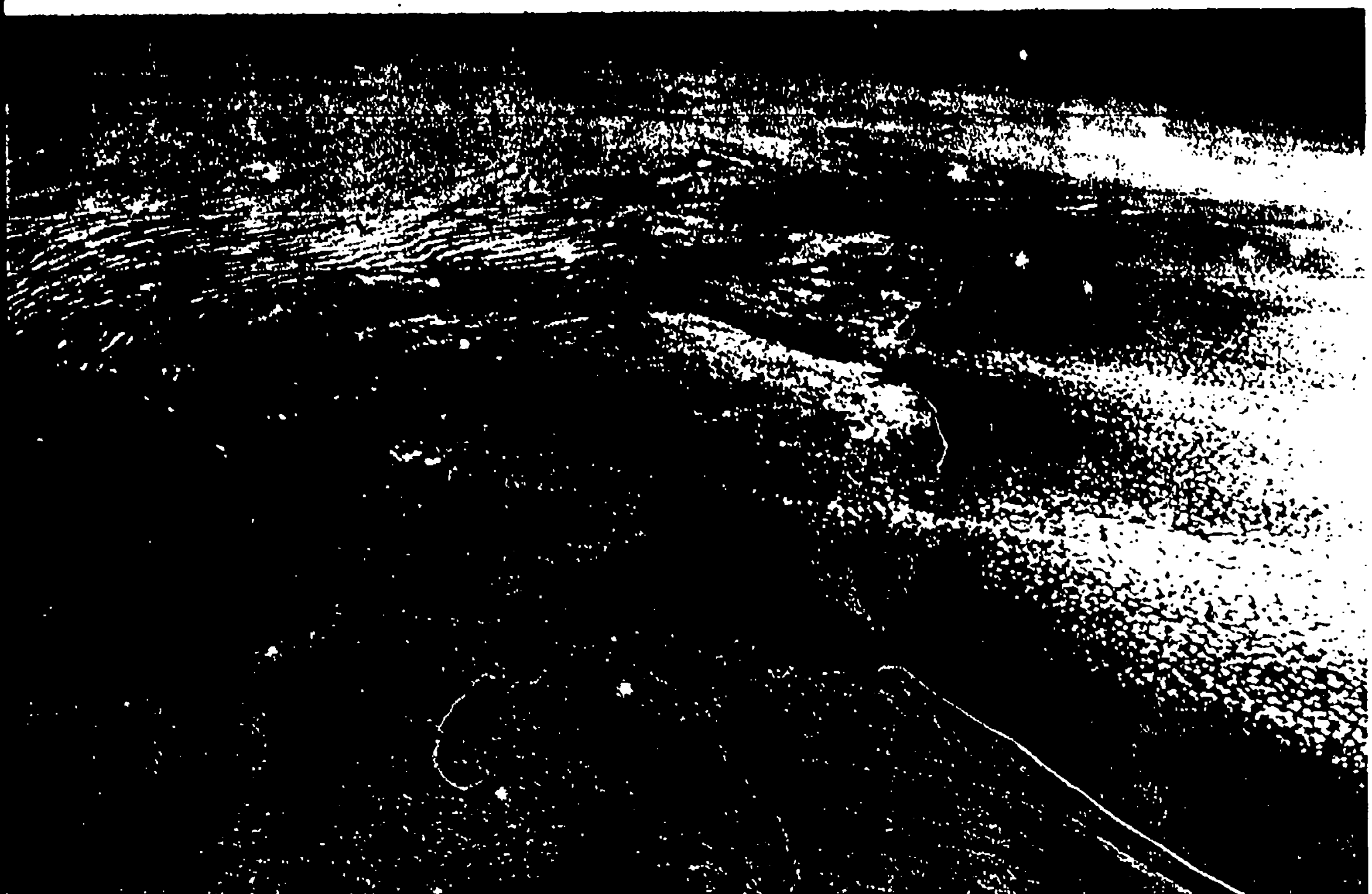


**Figure 1-1**

Figure 1-1 shows a portion of the planet as seen from about 150 miles above the surface.

☐ **1-2.** List the important features you see in the photograph.

☐ **1-3.** In the photograph, do you see any evidence of motion or change?

Figure 1-2

DOWN TO EARTH

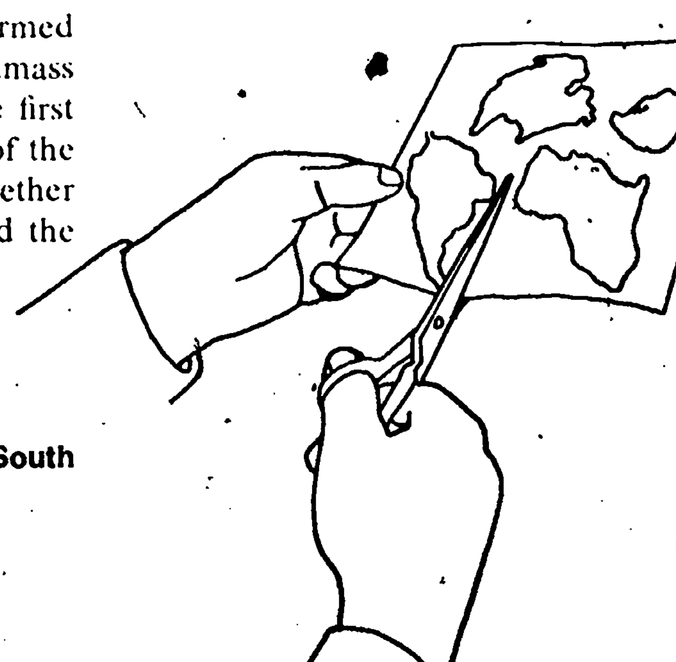
If you said No in response to question 1-3, your answer is correct, based on the evidence in the picture.

[ ]1-4. What would you say if asked the same question about Figure 1-2? If you decided that change is shown in the photograph, list the evidence you used to make that choice.

From the evidence in Figure 1-2, there's no doubt that at least that part of the earth is active and changing. One of the exciting areas of study a geologist encounters is the study of the ways the earth has changed through time and what might have caused the change.

DRIFTING CONTINENTS

For a moment let's consider the subject of change on a grand scale. In 1915 Alfred Wegener, a German scientist, proposed that all the continents were once joined together and formed one super landmass. He also proposed that this landmass later broke apart into separate continents. One of the first lines of evidence to suggest such an idea is the shape of the continents. Try your hand at fitting the continents together as you would a puzzle. For the activity, you will need the following materials:



1 pair of scissors.
1 map of the world

**ACTIVITY 1-1. Cut out the continents of North America, South America, Eurasia, Africa, Australia, and Antarctica.**

**ACTIVITY 1-2.** Piece the continents together in such a way that you get the best fit possible.

If you were successful you probably were able to put the pieces of the puzzle together to form a supercontinent. Now suppose someone were to ask you if the continents were really together once. What would you say? What kind of information would you need to support the idea?

Now you have a problem on your hands, don't you? Whenever we have a problem to solve, we need information (call it data if you wish) to help us solve the problem. In this unit, the source of that information will be in the set of accompanying resources. In some cases, you will not only have a problem posed, but you will also have to search for the resource or resources to help you solve the problem. For the first problem, we'll give you some direction in terms of which specific resource you might study.

The problem you have here is this: *What kind of evidence will support (or reject) the idea that the continents were once joined together?* Read through Resources 1 and 2 very quickly and decide which one you would like to do.

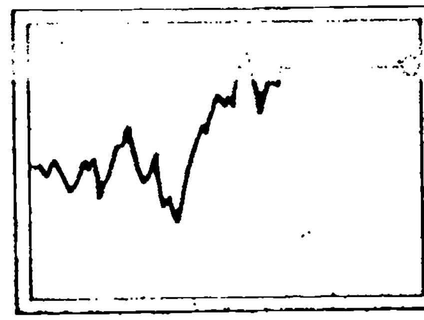
[ ] **1-5.** Which resource did you do?

[ ] **1-6.** Did the resources support, or reject, the idea that the continents might have been joined together? Explain your response.

## THE QUAKING EARTH

Let's continue our examination of the earth. You probably have never experienced the shock waves produced by an earthquake. But you probably have read in the newspaper or seen on television the destruction of property and loss of lives due to these tremors of the earth. You might think earthquakes are rare events on the earth, especially if you have never experienced one. But this is not true. Hundreds of tremors occur daily all around the earth, many too small to be reported. Now and then, however, one occurs that is powerful enough to destroy cities and towns and kill thousands of people.

Let's consider what has been said. If there are many quakes occurring daily, why would [illegible] have experienced them? Where do they occur? How deep in the earth do they originate? How powerful are they?



Let's consider the first two questions. Where on the earth and how deep below the surface do earthquakes occur? To find out, you will need the following materials.

- 3 different-colored pencils
- 1 map, in Record Book
- 1 epicenter data table, in Record Book

Below is a sample epicenter data table, which gives you information regarding the date, time, location, depth, and magnitude of earthquakes.

**Table 1-1**

| PRELIMINARY DETERMINATION OF EPICENTERS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| February 1971 Origin Time (GMT) | | | | Geographic Coordinates | | Region and Comments | Depth (Km) | Magnitude (CGS) |
| Day | Hr | Mn | Sec | Lat | Long | | | |
| 1 | 01 | 12 | 26.8 | 37.2 N | 30.2 E | Turkey | 35 | 4.5 |
| 1 | 02 | 47 | 51.6 | 7.0 N | 73.1 W | Northern Colombia | 140 | 4.3 |
| 1 | 03 | 51 | 45.4 | 5.1 S | 151.7 E | New Britain Region. Felt (III) at Rabaul. | 110 | 5.0 |
| 1 | 05 | 19 | 23.4 | 51.7 N | 172.9 W | Andreanof Islands, Aleutian Is. Mag. 6 (Pas). | 40 | 5.5 |
| 1 | 06 | 14 | 50.2 | 25.5 S | 176.8 W | South of Fiji Islands | 44 | 5.4 |
| 1 | 07 | 36 | 54.4 | 51.9 N | 172.9 W | Andreanof Islands, Aleutian Is. | 48 | 3.9 |
| 1 | 07 | 50 | 10.7 | 38.7 N | 14.1 E | Sicily | N | 4.3 |
| 1 | 11 | 56 | 29.8 | 5.4 S | 146.0 E | East New Guinea Region | 73 | |
| 1 | [illegible] | 26 | 55.6 | 44.6 N | 7.5 E | Northern Italy. Felt (III) in Côte d'Azur. | 18 | 4.4 |
| 1 | 12 | 48 | 32.8 | 56.2 S | 27.4 W | South Sandwich Islands Region | 17 | 5.1 |
| 1 | 14 | 21 | 42.9 | 42.3 N | 85.3 E | Northern Sinkiang Prov., China | N | 4.8 |
| 1 | 14 | 43 | 26.6 | 2.9 S | 139.1 E | Near N. Coast of West New Guinea | 46 | |
| 1 | 14 | 56 | [illegible] | 6.2 S | 154.6 E | Solomon Islands | 103 | 5.4 |
| 1 | 14 | 59 | 12.6 | 62.3 N | [illegible] W | Central Alaska | 15 | 4.6 |

Notice that if you read across a single line in Table 1-1, you will obtain information about a single earthquake.

**1-7.** To make sure you can read the table, determine the following for the first earthquake listed.

**a.** Date earthquake occurred
**b.** General location
**c.** Depth (km)
**d.** Latitude
**e.** Longitude

How did you do? If you were successful, continue on. If not, go back and study the table.

Using the data from the table, you are to plot the location and indicate the depth of each earthquake. To indicate the depth, utilize the following chart in plotting your earthquakes.

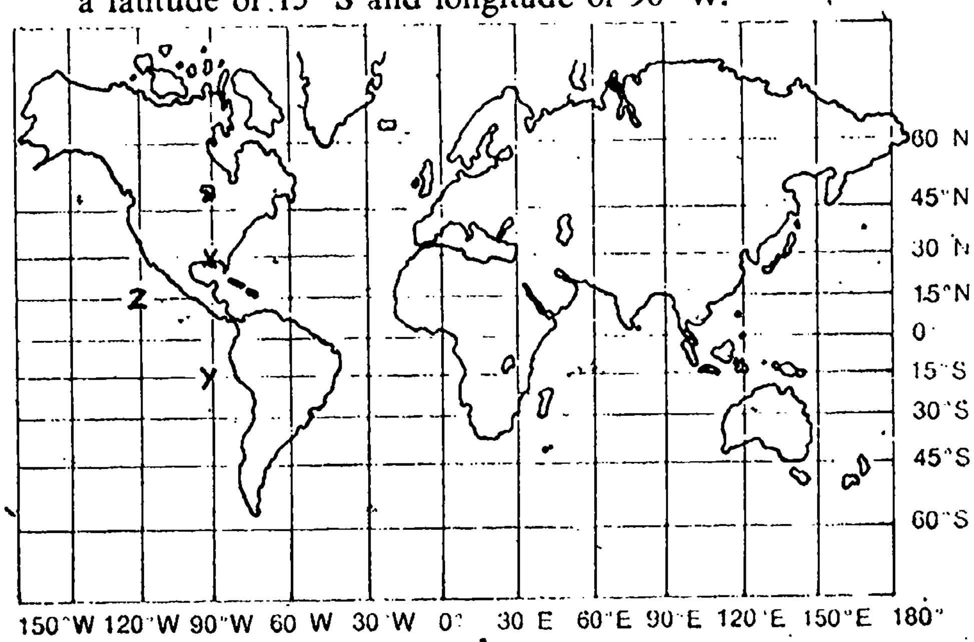
| Earthquake | Depth (km) | Symbol or Color |
|---|---|---|
| Shallow | 0-69 | + blue |
| Moderate | 70-299 | ■ red |
| Deep | More than 299 | □ yellow |

**Table 1-2**

To locate the position of the earthquake on the map requires the use of two coordinates. You're familiar with locating a point on a graph, using X- and Y-coordinates; on a map, latitude and longitude are used.

For example, in Figure 1-3, point X has the coordinates of latitude 30° N, and longitude 90° W. Look at point Y, with a latitude of 15° S and longitude of 90° W.

**Figure 1-3**



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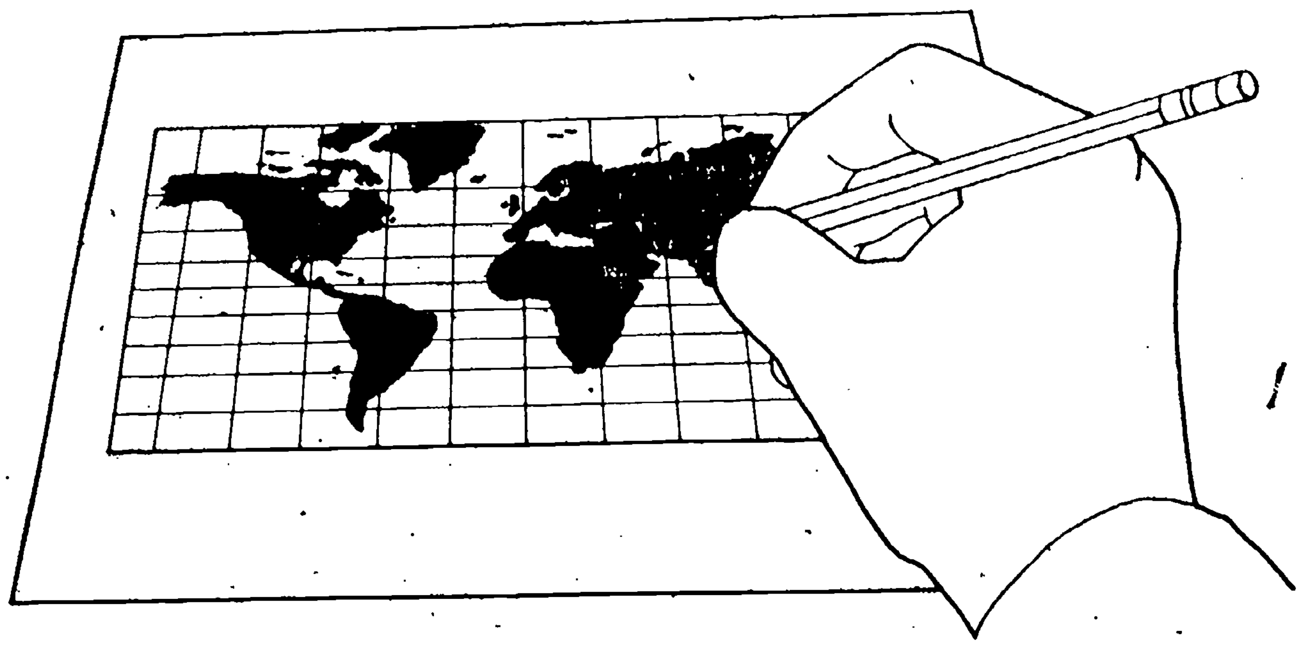
☐1-8. What are the coordinates of point 2?

Did you get latitude [illegible] N and longitude [illegible] W?

**ACTIVITY 1-3. The first earthquake on the sample epicenter data table has the coordinates 37.2° N and 30.2° E and is located as shown on the map. Find this location on your map and use an appropriate symbol or color to mark it. Now, using the epicenter data table on page 3 in your Record Book, plot all the earthquakes in this manner.**



☐**1-9.** On the basis of the earthquakes you have just plotted, list the regional locations of the earthquakes.

☐**1-10.** Would you say that earthquakes are randomly distributed over your map, or are they concentrated in zones?

Look over your completed map again but, this time, focus on the depth of the earthquakes.

☐**1-11.** Can you find any zones on your map where there are concentrations of shallow, moderate, or deep earthquakes? If so, where?

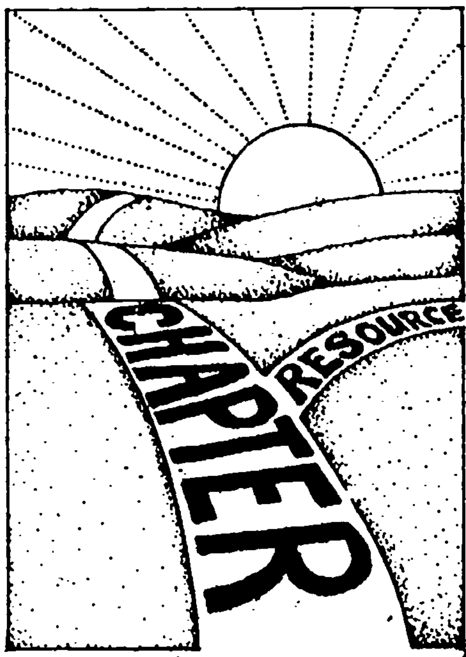
You now know that earthquakes do occur in zones and that some places on the earth have more shallow earthquakes than other places.

[ ]1-12. How can you explain this pattern of earthquake location? Why are there zones of shallow earthquakes and zones of deep earthquakes?

[ ]1-13. Refer to Resources 3 and 4. Does either resource provide you with an adequate explanation of the two observations concerning earthquakes?

[ ]1-14. Can you describe another model that might explain these observations?

At this point in Chapter 1, you have taken a first, large-scale look at the planet on which you live, and you also have a general model from which to view the earth. Like any model that you have developed in this course, it is temporary and subject to change as new data and evidence are gathered.




**More about resources**

In this unit, you will be asked to solve problems by answering questions posed about geologic features and events. To make it clear to you when you should consult the resources, we'll use either this symbol,

**RESOURCE** ➡ or this.

⬅ **TO CLUSTER**

When this occurs, you should turn to the resource section at the end of the chapter. Everything you need to answer all the problems will be somewhere among the resources.

**Important Note** *The resources follow each chapter and those following Chapters 2, 3, and 4 are further arranged into clusters.*

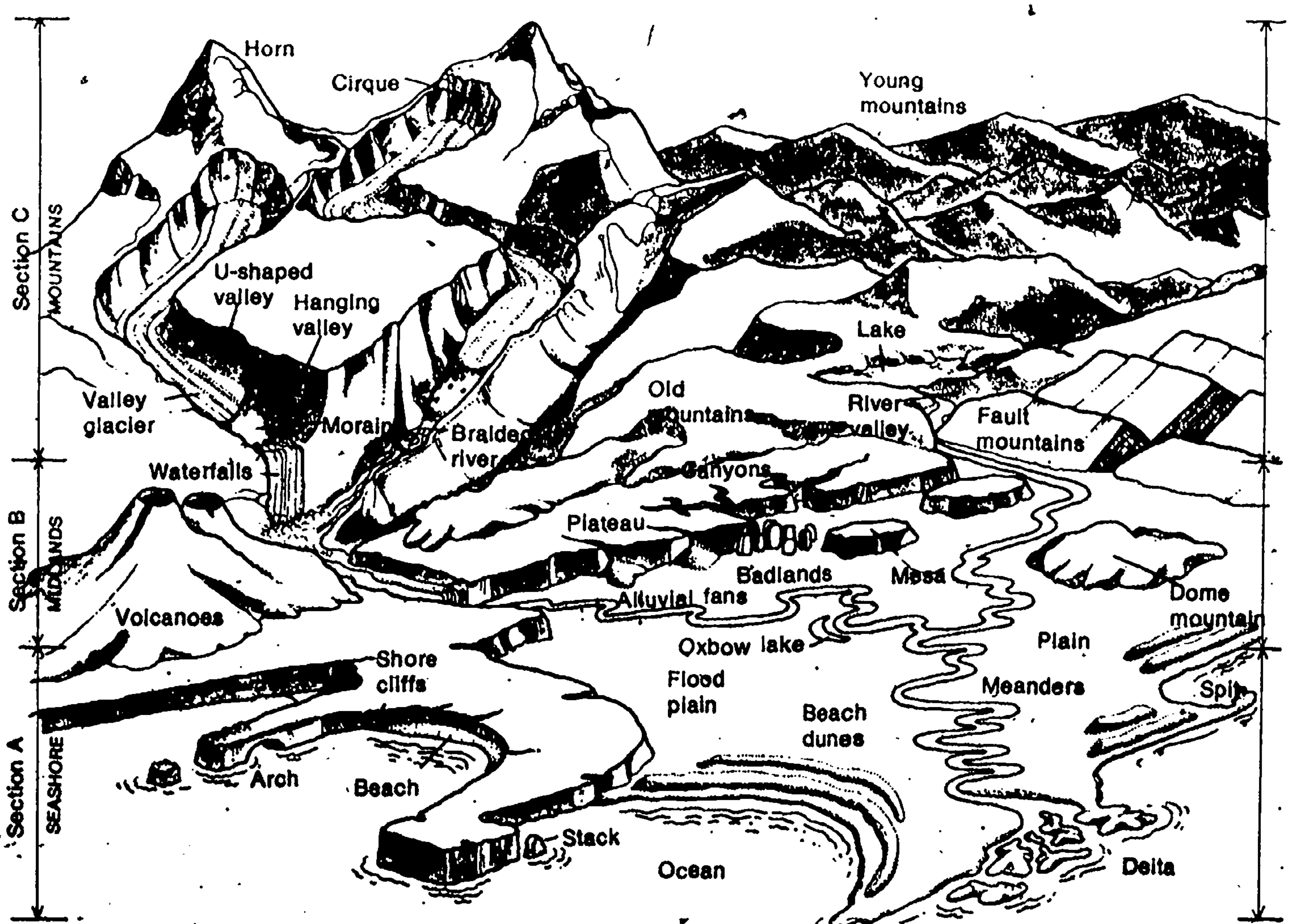
For example, if you are working in Chapter 2, for each resource problem in that chapter, you will be directed to a cluster of resources indicated as Cluster A, Cluster B, and so forth.

Remember, resource implies support, and that's what you get. Each resource contains information that you can fall back on to fill gaps in your knowledge. Unlike excursions, however, they are not arranged in the order you will need them, even though they are grouped by chapter. It is up to you to find and use the ones you think will be helpful.

## HOW THE UNIT IS ORGANIZED

Take a look at the general geology chart (the composite diagram, shown in Figure 1-4 below). If you look closely, you should find that part of the diagram contains features somewhat like those near you. Students all over the United States will find this to be true because the drawing includes most of the important landforms found in this country.

Figure 1-4



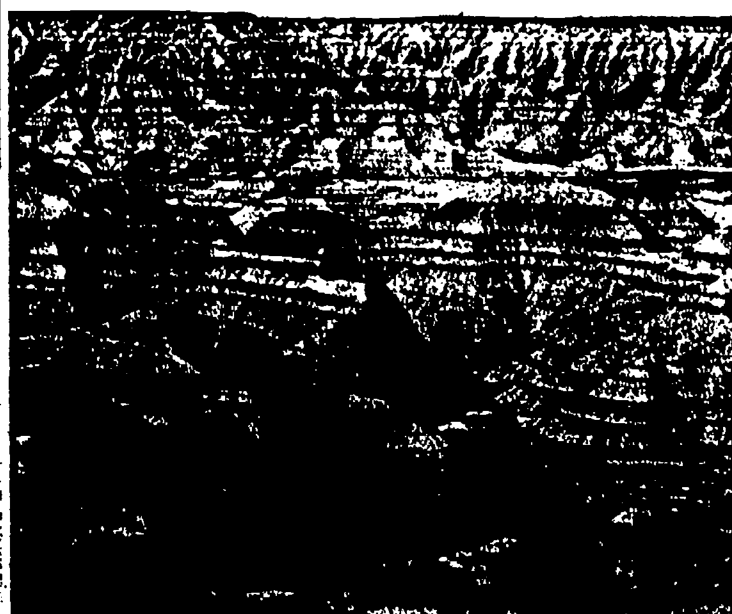
Each of the three chapters that follow focuses upon features shown in one of the three sections (A, B, or C) of the diagram. As you work through the chapters, you are to use your resources as a help in explaining how the various features got the way they are.

Chapter 2 centers upon some of the most spectacular scenery in the United States—the mountains (section C). In it you will try to figure out how landscapes like the one shown in Figure 1-5 got the way they are—and even try to guess what the area may look like in the future.

Figure 1-5

Chapter 3 deals with what might be called the "midlands" of the United States. This is the area shown in section B of the diagram. Among the features you will interpret are the ones shown in Figure 1-6.

Figure 1-6



Chapter 4 deals with the area that borders the sea—the shorelands. This is section A in the diagram. Examples of the kind of features you will study in Chapter 4 are shown in Figure 1-7.

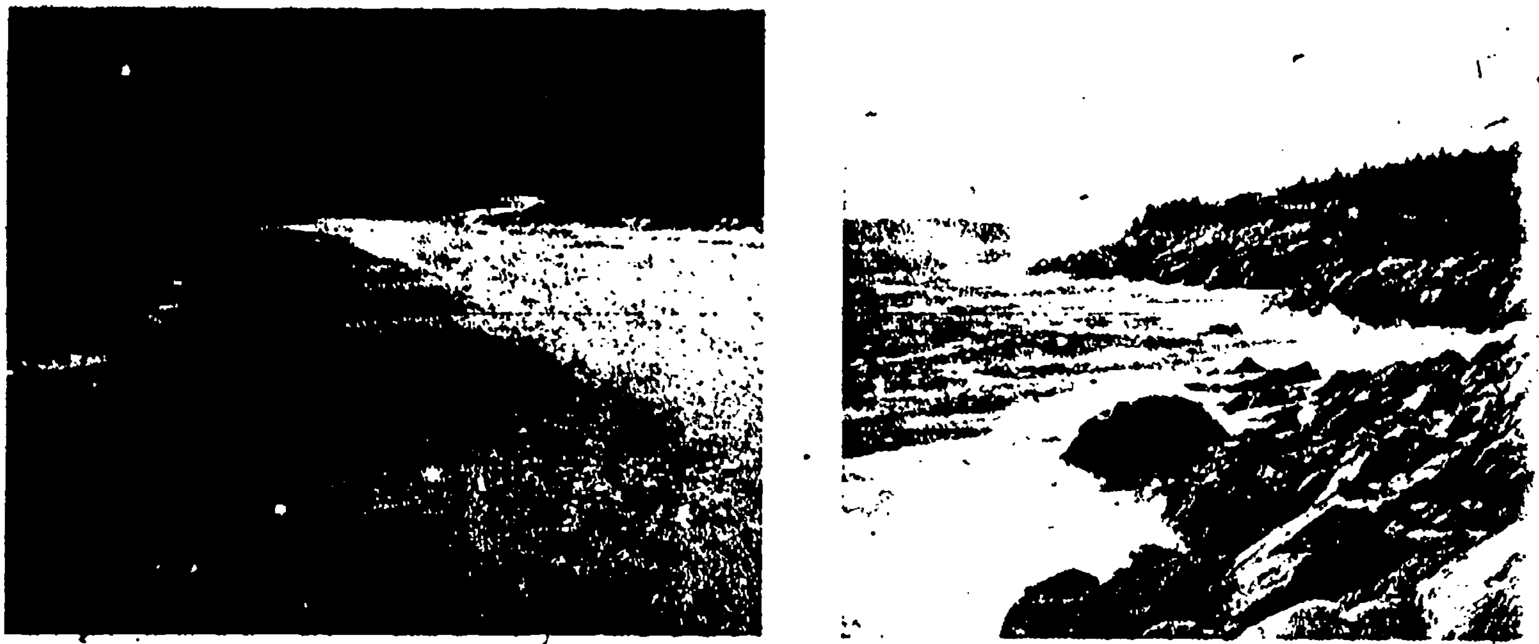
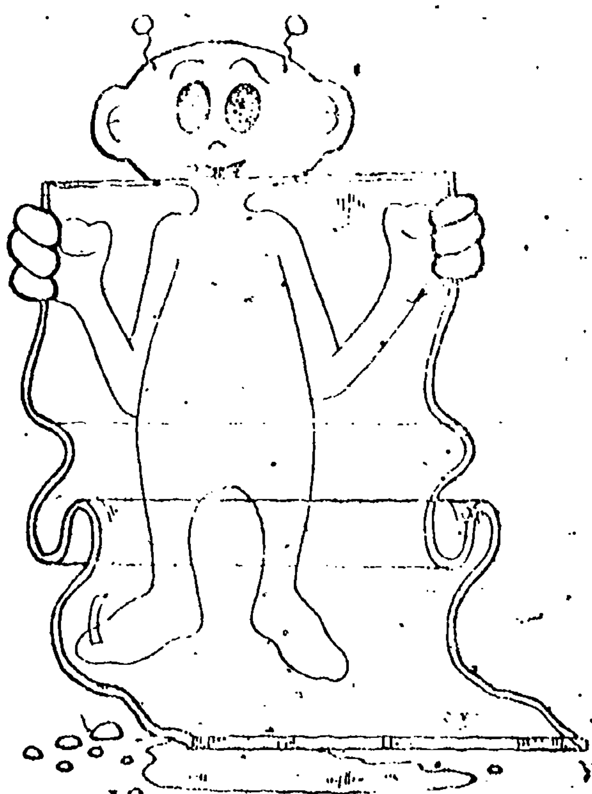


Figure 1-7

Begin your study of "crusty problems" with Chapter 2, "The Mountains." When you have finished all the chapters and the appropriate resources, you should be better able to interpret the country you live in. Good luck!

**Before going on, do Self-Evaluation 1 in your Record Book.**



# 1 Ancient Ice Sheets and Continental Drift

During the late nineteenth century, geologists discovered evidence that an ice age existed about 200 million years ago in three continents of the Southern Hemisphere—South America, Australia, and Africa. What was the evidence, and more important, what does an ancient ice sheet have to do with continental drift?

First let's look at the evidence. Figure 1 shows a rock outcrop that is rather smooth in appearance and has a series of parallel grooves. If you know anything about the hardness of rocks, you'll probably agree that whatever scratched the rocks in Figure 1 must have been a very powerful force. We know now that such grooves can be made by a huge mass of ice, several thousand feet thick, moving very slowly over solid rock.

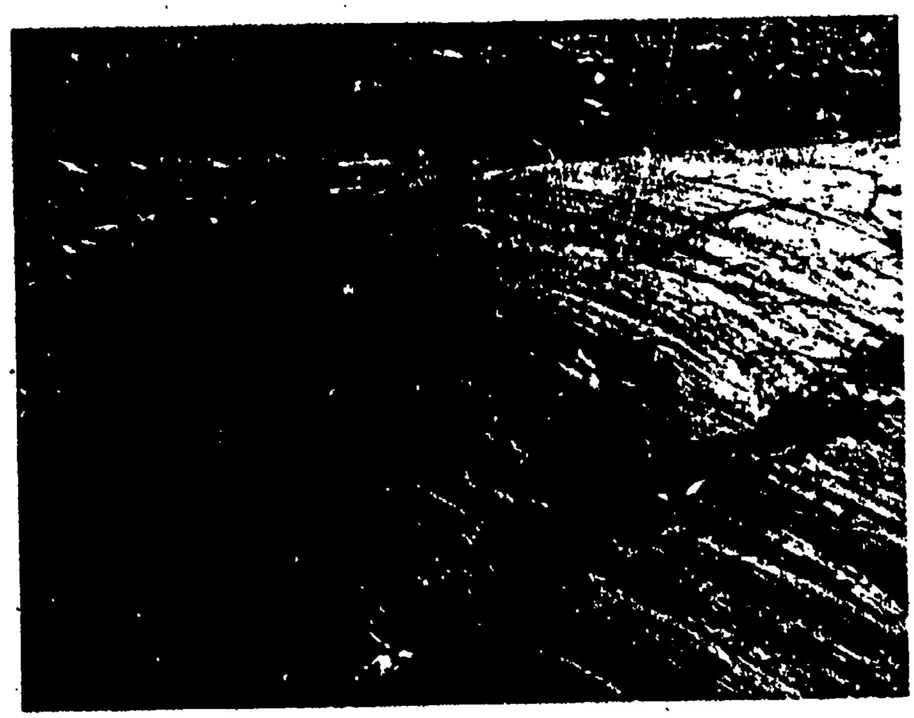


Figure 1

A glacier carries, at its base, rock fragments of various sizes that act as an abrasive, like sandpaper. Thus, as the glacier moves along, it is capable of scratching and cutting deep grooves in the rock.

Another piece of evidence is the location of deposits similar to that shown in Figure 2. Notice that the material contains rocks of various sizes, from large boulders to small fragments. Also, note that there is an abundant supply of finer material, such as sand, mixed in with the mass of rock. This is a typical feature of glacial deposits. Such a deposit is called *glacial drift*. River or stream deposits are more uniform in size because of the sorting effects of moving water.

Glacial grooves and drift of about the same age have been found on South America, South Africa, Australia, Antarctica, and India! Figure 3 shows the distribution of ancient glacial

Figure 2

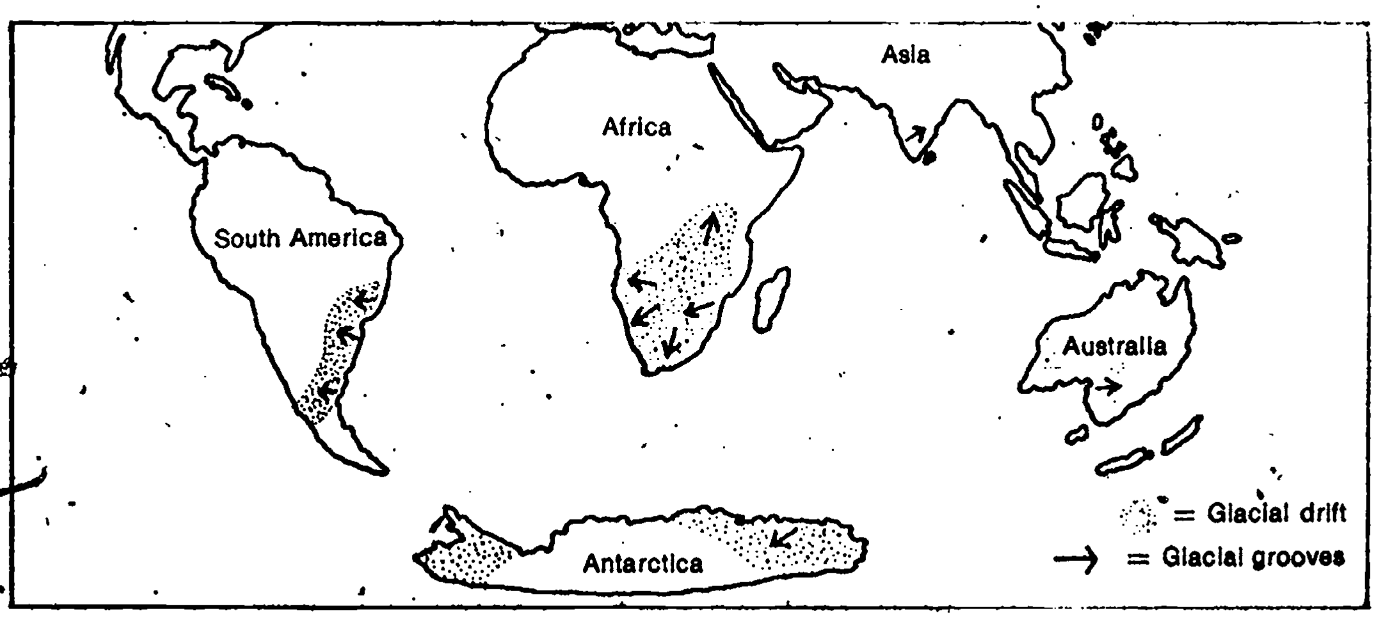



Figure 3

drift and the direction in which glaciers moved. (The direction of glacial grooves tells geologists the direction in which the glaciers moved.) Look at South America closely. In order to explain the glacial grooves there, it would be necessary for the glacier to have moved from areas now covered by an ocean. Also, note that glacial drift is found very near the equator.

One explanation of these facts is that the landmasses were connected at the time of glaciation and then the continents moved apart at a later time.

**ACTIVITY 1. Using the cutouts of the continents from Activity 1-2, draw the arrows showing the direction of glacial motion on each of your cutout continents, as shown on Figure 3. Use a colored pencil to show the distribution of drift. Fit the continents together, using as guides the direction of the arrows (assume the glacier moved out in all directions from a central area) and the distribution of drift.**

☐**1.** Do you think the distribution of glacial drift and the location of glacial grooves provide evidence to support, or reject, the idea of continental drift? Explain your answer.

☐**2.** If not, what other explanation can you make?

# 2 Rock Layers, Fossils, and Continental Drift

Do you think the rock layers on the left side of the highway in Figure 1 match the rock layers on the right side? Compare the areas at the ends of the two lines AA′ and BB′. They should help you conclude that they do match.

Figure 1

You shouldn't be surprised, because engineers blasted the rock away to build the highway. However, the photograph illustrates one of the things that geologists do; namely, try to match rock layers that are separated from each other.

Let's look further at the idea of matching rock layers.

☐1. Can you match one rock layer with any other rock layer shown in Figure 2?

**Figure 2**

The problem of matching is a little more difficult in this photograph, but if you use a rule you should be able to find several layers that match (based on the color of each layer). Notice the thin dark layer near the top on the ridge at the left. Perhaps you used this layer to help you match with other layers. To understand this examine the diagram in Figure 3. Notice how the layers are matched on the basis of the color of the rock.

**Figure 3**

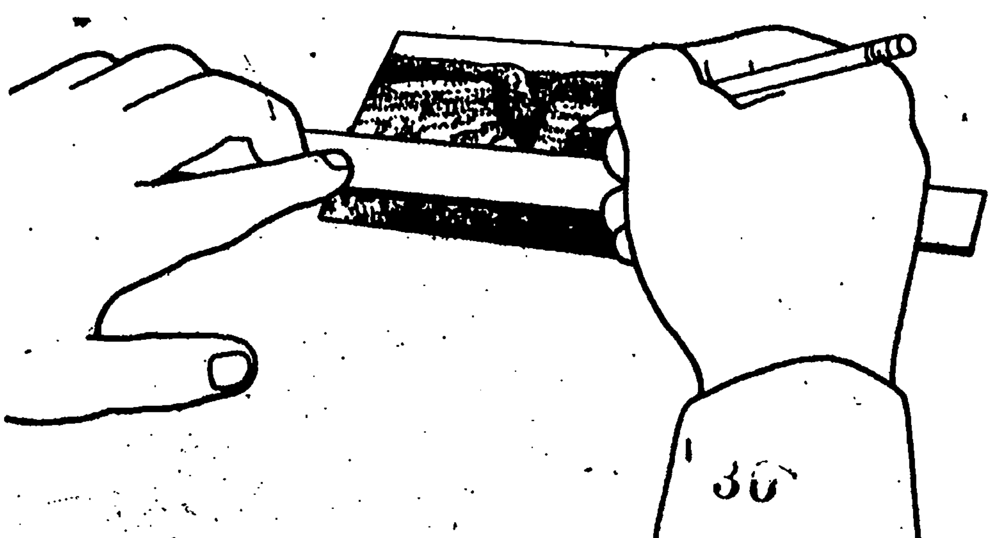


Figure 4 shows diagrams of two sequences of rock layers. All the rocks are layered. A key is provided to help you identify the rocks.

☐2. Do the layers in rock sequence 1 match the layers in rock sequence 2?

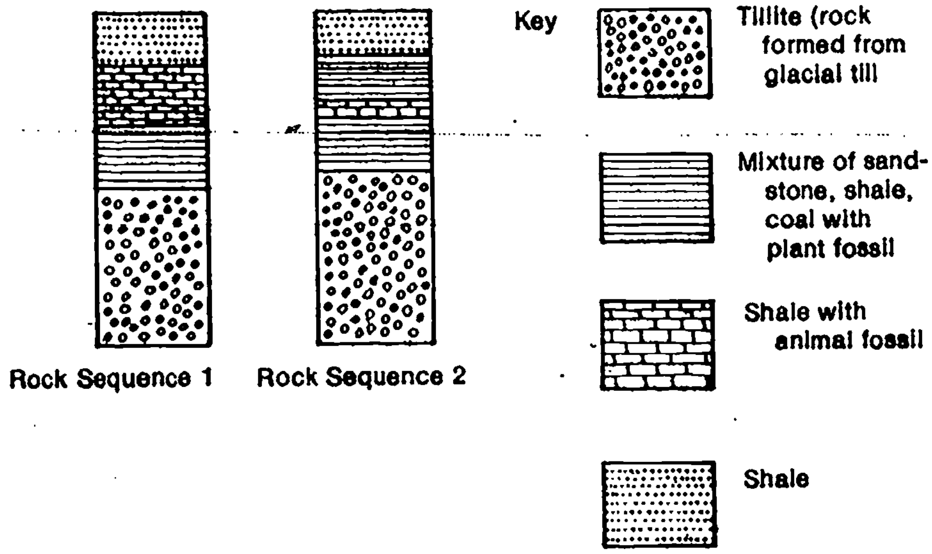


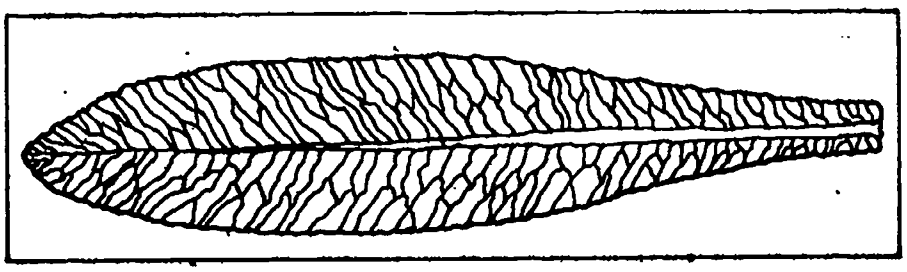

Figure 4

You probably found that the bottom three layers in each sequence matched. The first layer, or lowest layer, is tillite. Above that, is a layer that is a mixture of sandstone, shale, and coal with a plant fossil. The third layer is shale with animal fossils. The fourth layer in sequence 2 is a mixture of sandstone, shale, and coal, which appears to be missing in sequence 1. However, the fifth layer in sequence 2 matches the top layer in sequence 1. The two layers are very similar.

How is this going to help you decide whether the continents drifted apart? Let's examine these sequences again. Figure 5 shows a drawing of the plant fossil found with the layer of sandstone, shale, and coal.

You might have used the fossil to help you answer question 2. Geologists use fossils to help them match rock layers.

Figure 5



In fact, the presence of a certain type of fossil is a better clue that the layers match than is the type of rock. Notice that the layer containing this plant fossil, which is called *Glossopteris*, lies just above the tillite.

Here's one more fact that might be helpful. Rock sequence 1 in Figure 4 is found in southern Brazil and rock sequence 2 is found in South Africa!


☐**3.** How can you explain the occurrence of similar rock layers and identical fossil plants on two different continents?

Probably the strongest kind of evidence to support continental drift is the presence of identical fossil plants, such as *Glossopteris*, on different continents separated by hundreds of miles of ocean. Identical plants could hardly have developed in areas separated by such distances. It is possible that the seeds of these plants could have floated across the ocean, but most biologists rule this out. You may suggest that birds carried the seeds. However, the first flying animals did not occur until millions of years after this time. Thus, the idea of continental drift was supported on the basis of similar rock layers and fossils occurring on different continents.

You might be wondering whether similar sequences and the fossil plant *Glossopteris* have been found elsewhere. Well, they have! They were found in Australia, India, and Antarctica!

## 3 Contraction Theory

Tilting of rocks, movements of the earth's crust, and earthquakes are examples of the kinds of forces that affect the earth. What produces these forces that dimple, wrinkle, bulge, crack, and tilt the earth's surface? (See Figure 1.) Geologists disagree upon this, but several useful models have been developed.

One model is described below. Read the description carefully and think about how the process being described might have affected the earth. Later you will be asked to use the model to explain how certain mountains were formed.

Figure 1

Have you ever seen what happens to the skin of an apple when it is baked? As shown in Figure 2, the skin buckles and cracks as loss of water causes the fruit inside to shrink. If you have never seen a baked apple, bake one at home.

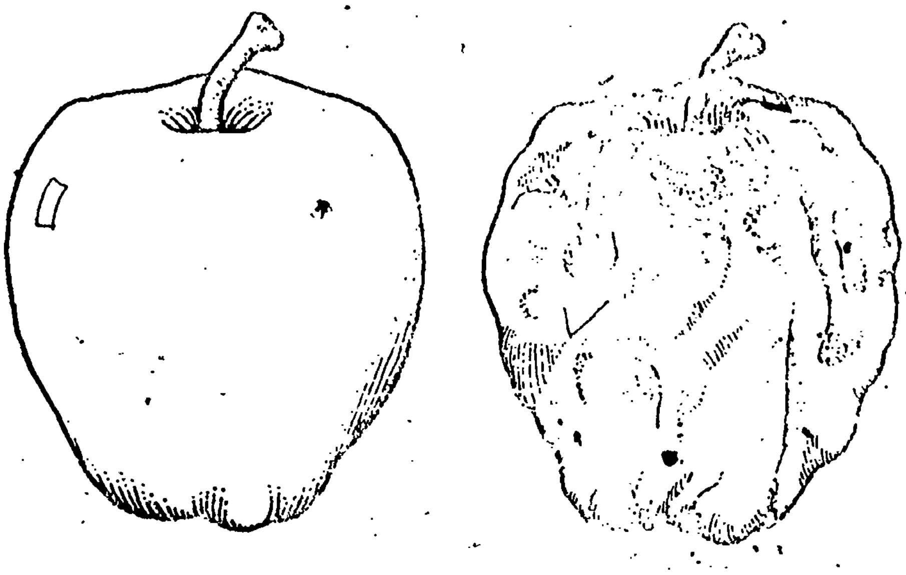




Figure 2

One model for mountain-building and earthquakes views the earth as being somewhat like a baked apple that is, as having a tough "skin" around a core that was once very hot and is now shrinking as it cools. According to this model, the core shrank, causing some parts of the earth's crust to be uplifted, forming mountains. Other parts of the crust were pushed downward into valleys (see Figure 3). Cracks formed in the crust and these led to still other changes.

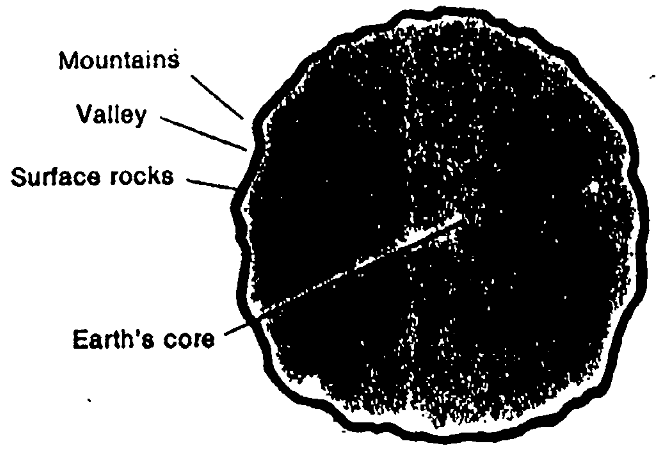



Figure 3

# 4 Sea-Floor Spreading and Earthquakes

You have completed an exercise in which you plotted the location of many earthquakes. Geologists have been collecting similar data for years and have compiled the data as you did when you plotted the earthquakes. Figure 1 on the next page is a world map showing the distribution of earthquakes.

Note that the earthquakes are restricted to zones or belts and are not evenly distributed on the earth.

☐**1.** In the region between South America and Africa, are the earthquakes shallow, intermediate, or deep?

☐**2.** How deep are the earthquakes that occur along the western coast of South America?

☐**3.** Identify two other areas where intermediate and deep earthquakes occur.



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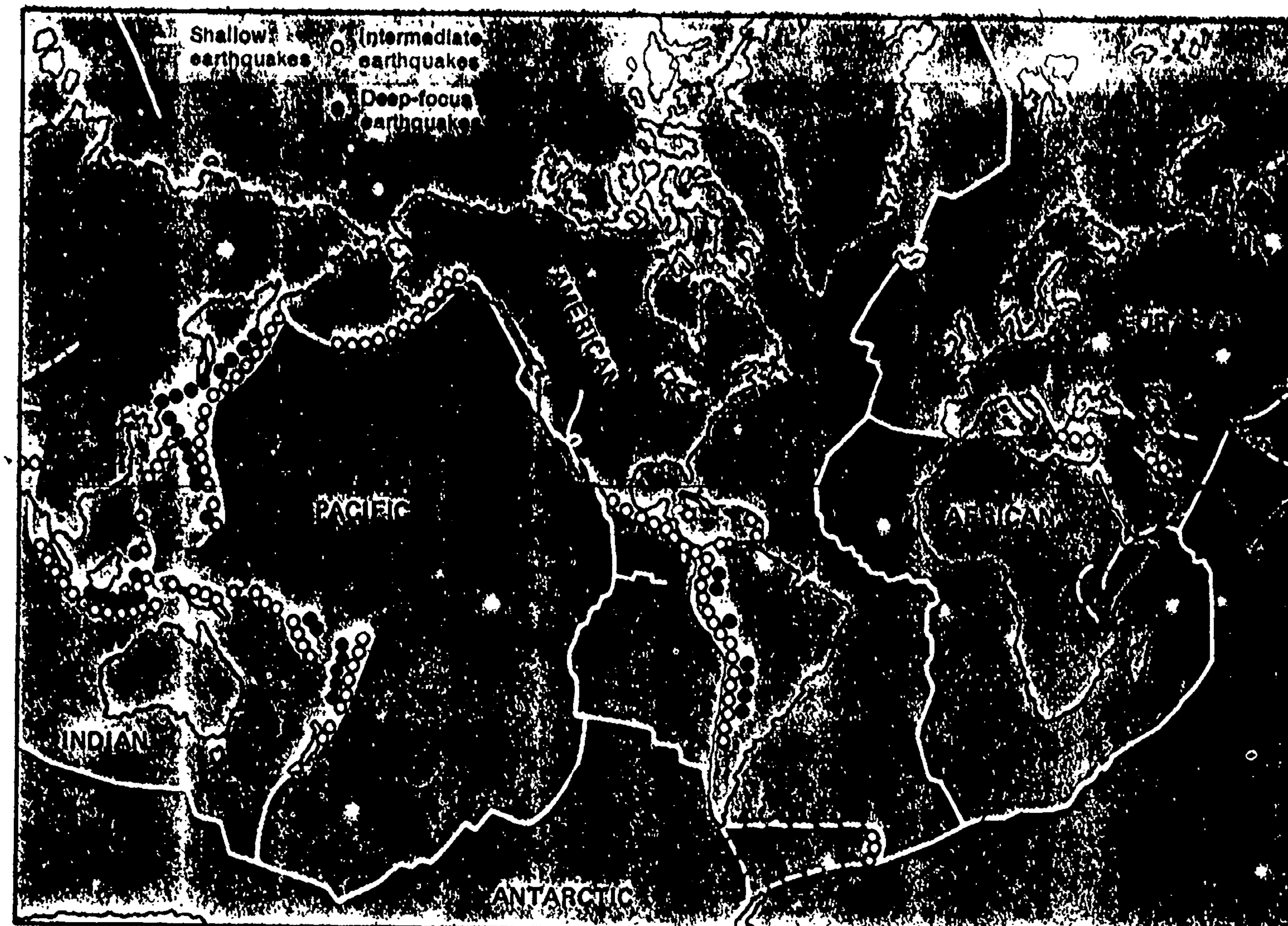



Figure 1

You should have noted that there is a zone of shallow earthquakes splitting the Atlantic Ocean. In fact, if you glance back to the map you can trace the shallow earthquakes around the earth. This system of shallow earthquakes is known as the mid-ocean ridge system and consists of a chain of volcanic mountains. Shallow and deep earthquakes occur along the boundaries of oceans and continents (such as South America and the Pacific Ocean) or between two continents (Africa and Europe).

How can this pattern of earthquakes be explained? One theory that has been proposed states that the earth's crust is separated into plates that in some places are spreading apart and in other places are colliding. The earthquakes occur when these plates of crust are separating or colliding.

According to the theory, new crust is being formed at the mid-ocean ridges and is spreading away in two opposite directions; at other places older crust is sinking back into the earth. It's like a great big conveyor belt. Figure 2 shows a continent rifting and then the two segments drifting away in opposite directions. New crust forms and spreads away from a central ridge.

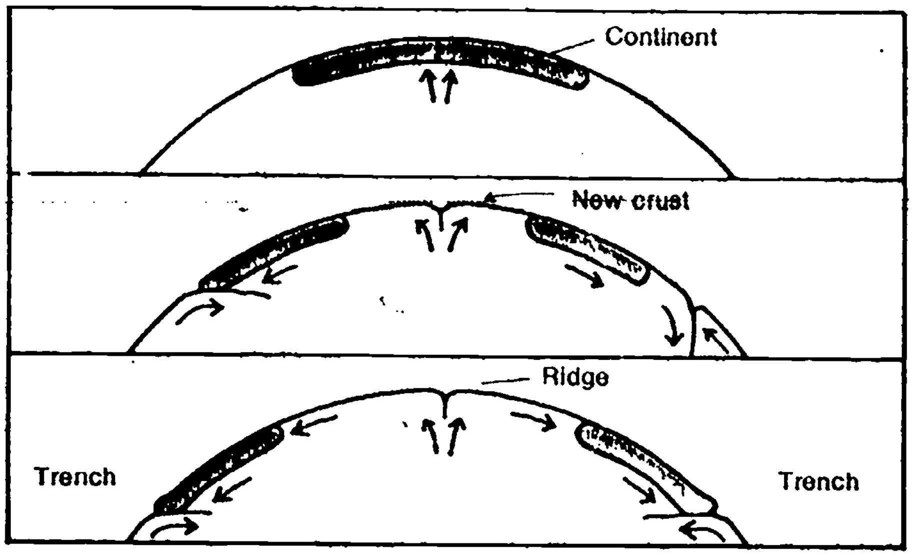
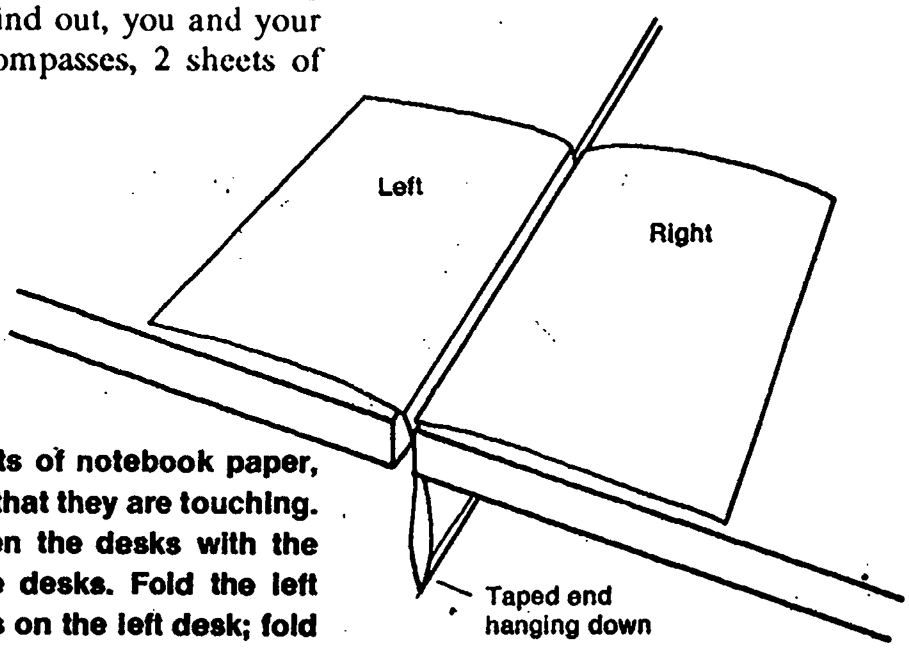
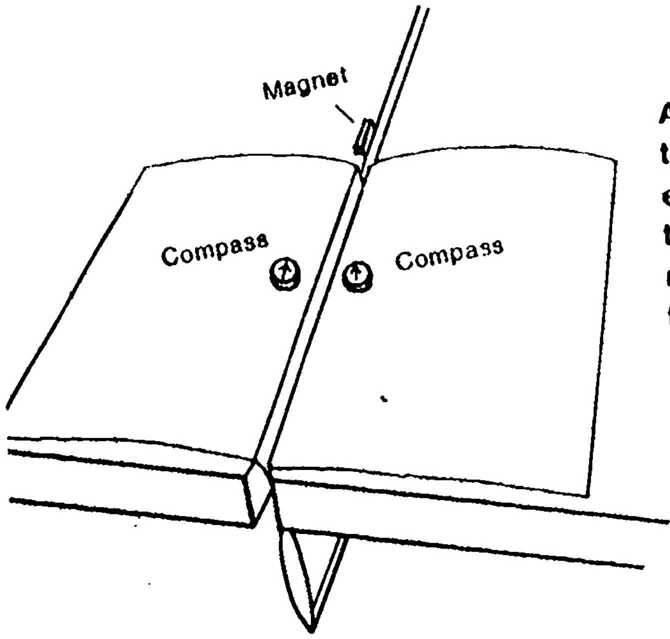



Figure 2

What evidence is there that the ocean floor is spreading away from the mid-ocean ridges? To find out, you and your partner will need a bar magnet, 2 compasses, 2 sheets of notebook paper, and a ruler.

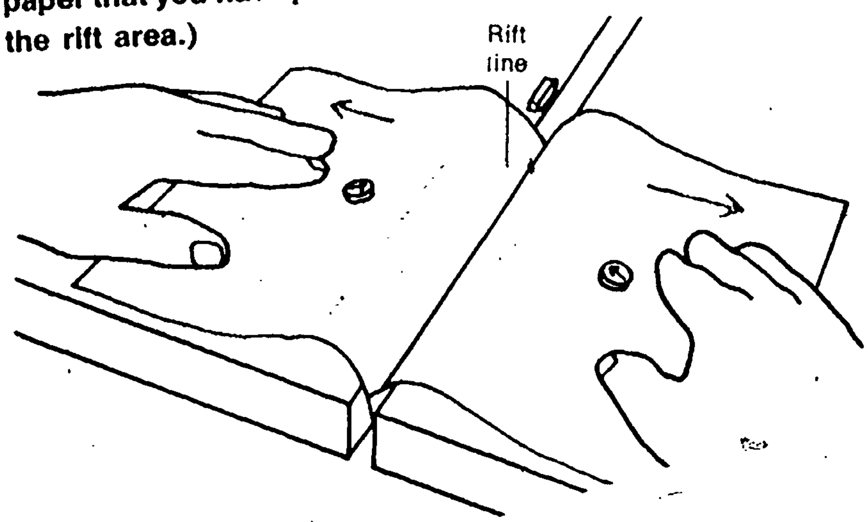



**ACTIVITY 1. Tape together the 2 sheets of notebook paper, as shown. Move two desks together so that they are touching. Insert the two sheets of paper between the desks with the taped end hanging down between the desks. Fold the left sheet of paper so that the top half rests on the left desk; fold the right sheet in the same manner over the right desk. Assume that the joined sheets of paper represent a continent before break up.**

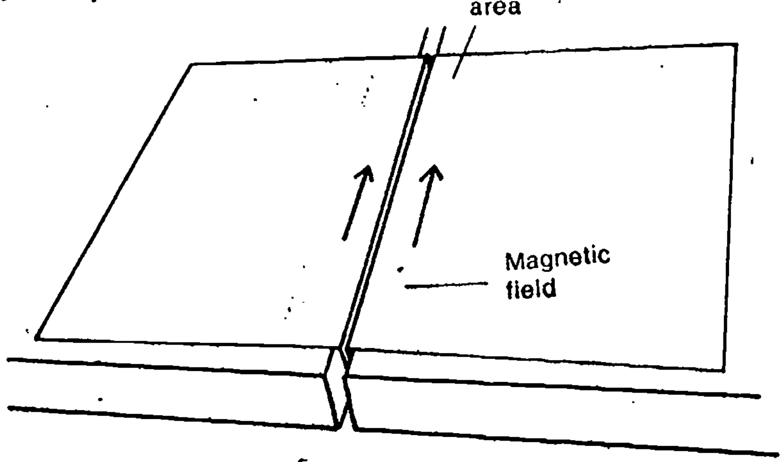



ACTIVITY 2. Place a small bar magnet next to the papers in the groove between the two desks. Place two compasses on each sheet of paper, as shown. Turn the magnet around if the needle on each compass is not pointing toward the magnet. The magnet represents the earth's magnetic field, and the compasses will be used to detect the field. Draw a line on each sheet of paper along the groove. This line represents the edge of the two continents.

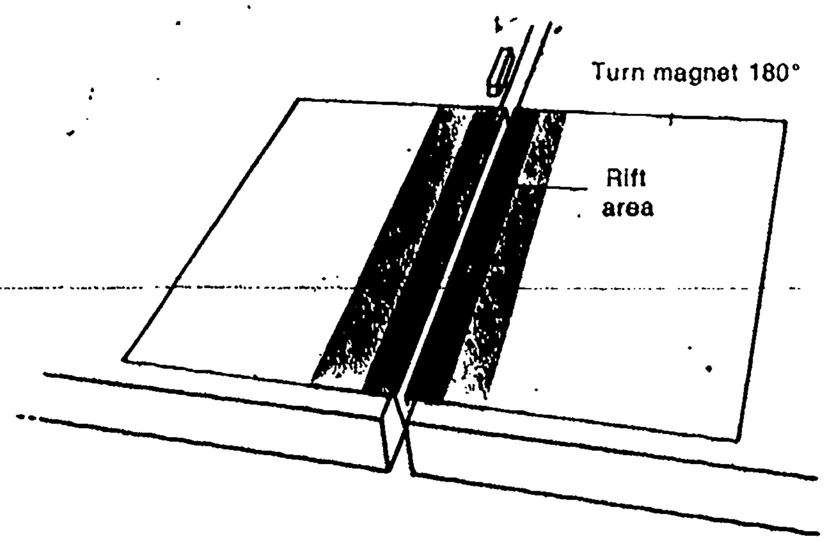
ACTIVITY 3. Rift, or split, the supercontinent by placing one hand on each sheet of paper and slowly spreading the papers away from the center. Spread each sheet of paper about 3 cm from the rift line you drew. Shade lightly in red the area of paper that you have pulled out from beneath the table. (This is the rift area.)




ACTIVITY 4. Record the magnetic field on each side of the rift by drawing an arrow in the direction that the compass needle is pointing.



**ACTIVITY 5.** **Turn the magnet around 180°, so that the end that was away from the paper is now pointing toward the paper. Spread the continents as you did in Activity 3, but this time spread them 1.5 cm. Shade lightly in blue the area that was pulled out. Again, measure and record the direction of the compass needle, as you did in Activity 4.**




Repeat Activity 5 two more times, spreading the continents 2 cm the first time and 4 cm the second. Be sure to alternate the colors, and also be sure to reverse the magnet each time.

It has been discovered that the earth's magnetic field has reversed several times during geologic time. Each time you turned the magnet around, you were reversing the earth's magnetic field. No doubt you have worked with a magnet and you know that metal, such as iron, will be attracted to a magnet. According to the sea-floor spreading theory, if molten rock spreads away from the central rift and if the rock contains metallic material that would act like little compass needles, then the record of the magnetic field should be recorded in the rock. The little metallic "compasses" would line up with the earth's magnetic field just as the compasses you are using line up with the magnet.

Figure 3 on page 24 shows a diagram of the magnetic field recorded in the North Atlantic.

The ridge axis is in the center and the shaded areas represent rock on the sea floor that records the earth's magnetic field as normal (same as it is now), and the white indicates rocks with a reversed magnetic field.

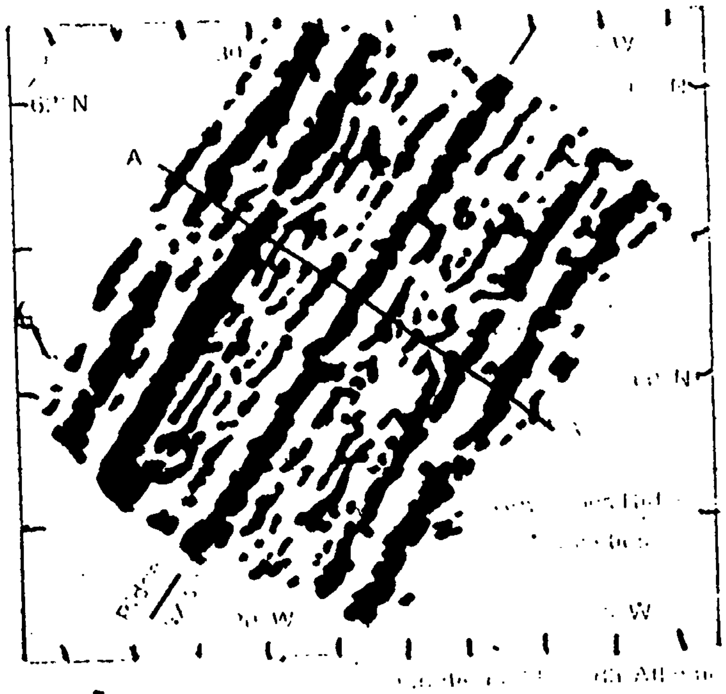


Figure 3

□4. Does the diagram in Figure 3 resemble the model you made with the two sheets of paper?

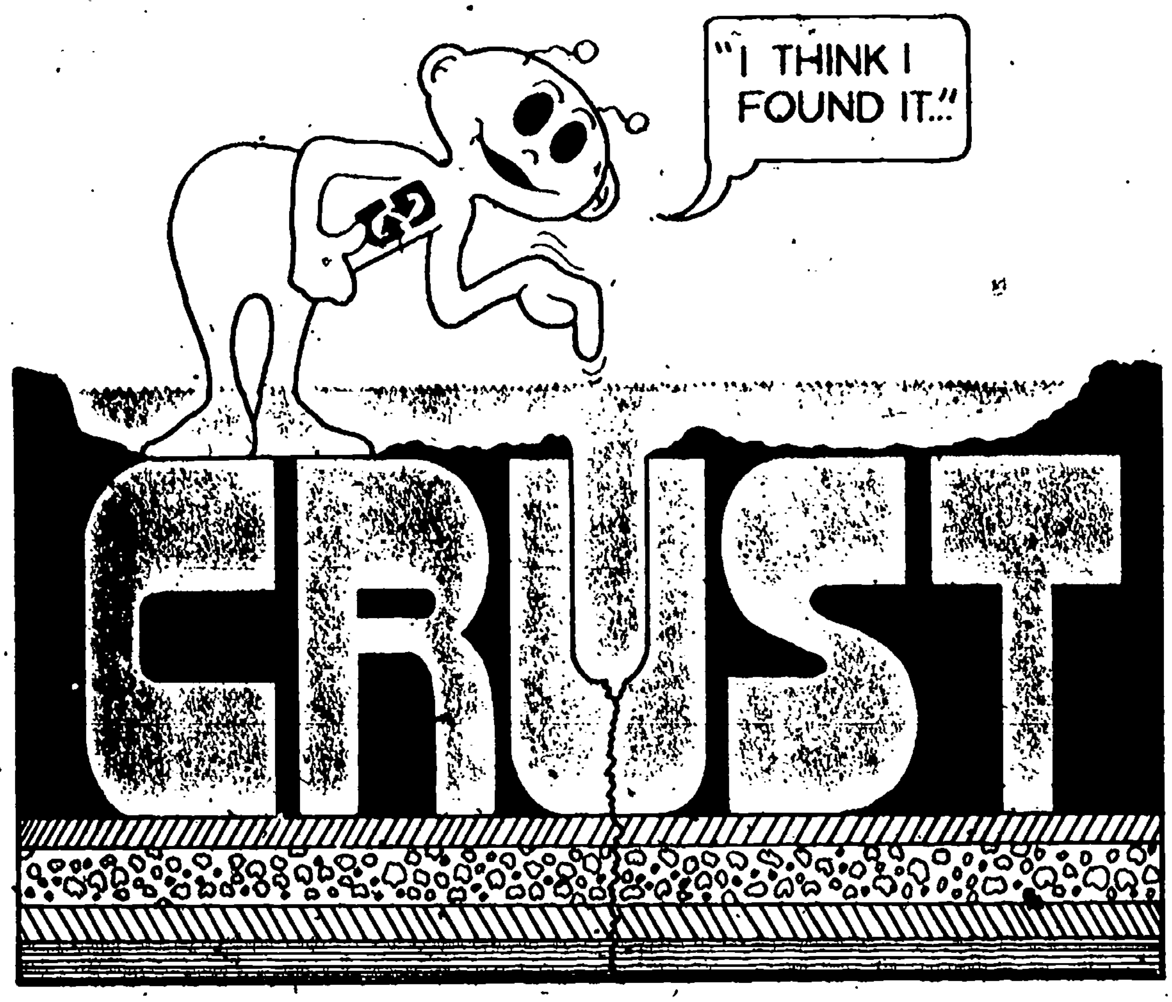
□5. Measure the distance along line AA′, from the ridge axis to the last shaded area on each side of the axis. Are the two distances about the same?

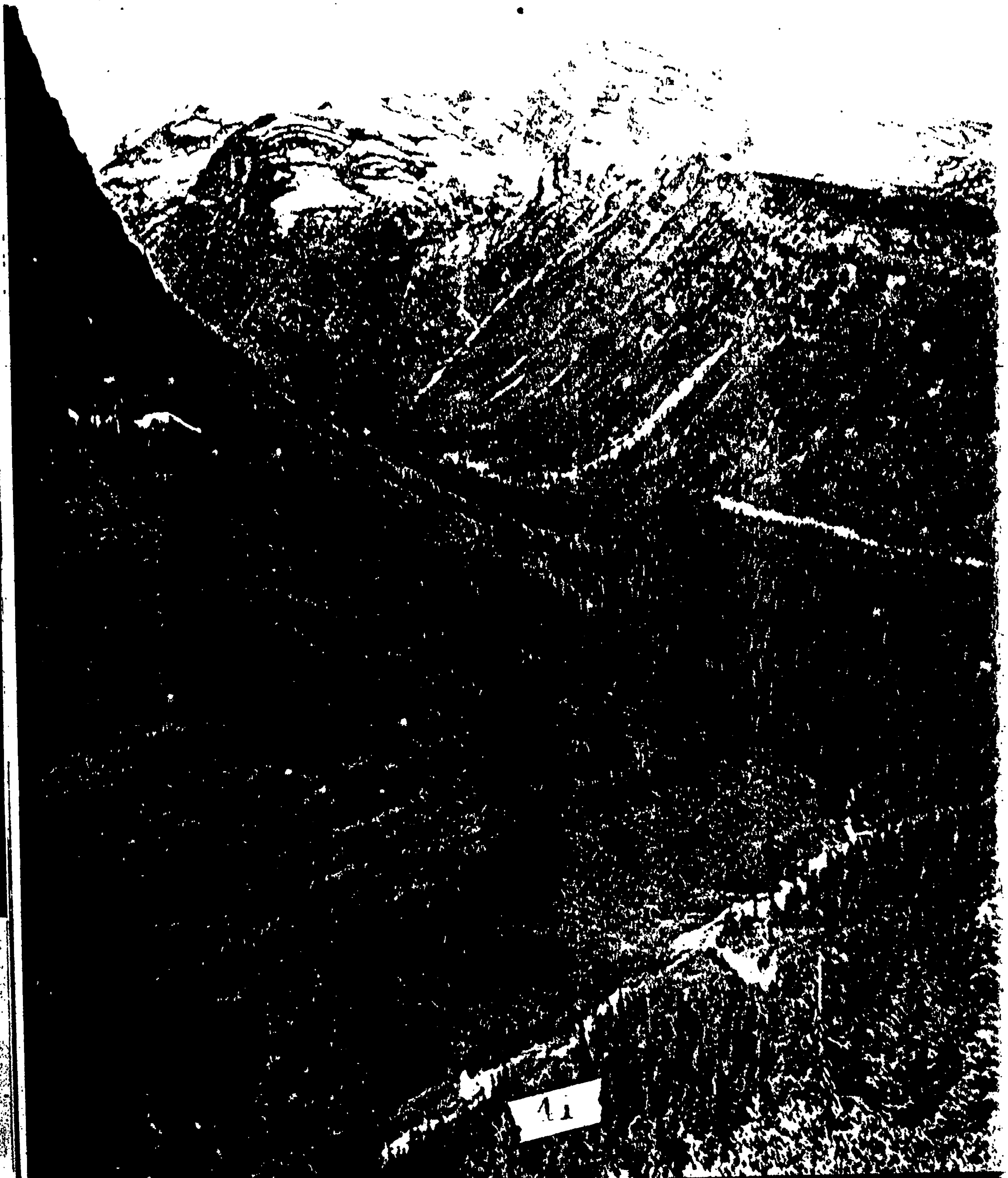
□6. What does this tell you about the amount of spreading on each side of the ridge?

Examine the drawing on the two sheets of paper that you worked with in Activities 1 through 5. According to the sea-floor spreading theory, the Atlantic Ocean now occupies the area between the two continents that you split apart. Assume South America is the continent on the left and Africa the one on the right.

□7. If you were to collect samples of rock at the ridge and at several other areas between the ridge and South America, what would you predict about the age of the rocks?

Since the activity at the ridge is near the surface of the crust, the earthquakes are shallow. As new crust forms, it spreads away from the crust, with spreading on either side about the same. Further, it has been discovered that the farther from the mid-ocean ridge the sediments are, the older they are. Thus, scientists now believe the ocean floor in the Atlantic is spreading slowly away from the mid-ocean ridge. The pattern of earthquakes along the mid-ocean ridge outlines a huge crack in the earth's crust.




11

# The Mountains

Chapter 2

Suppose you were asked to guess where the photograph in Figure 2-1 was taken. We're not so interested in the place, but rather in the general geologic setting of the picture. As a clue, we'll tell you that the features you see are called *ripple marks.*

Figure 2-1

Did you guess a seacoast, a stream, or a lakeshore? All of these are obviously sources of water. You may be surprised to discover that the ripple marks you see are in the Rocky Mountains in Colorado!

Not only are they in the Rocky Mountains, but they also are not lying flat. Look at the complete scene in Figure 2-2. The ripple mark surface is tilted!

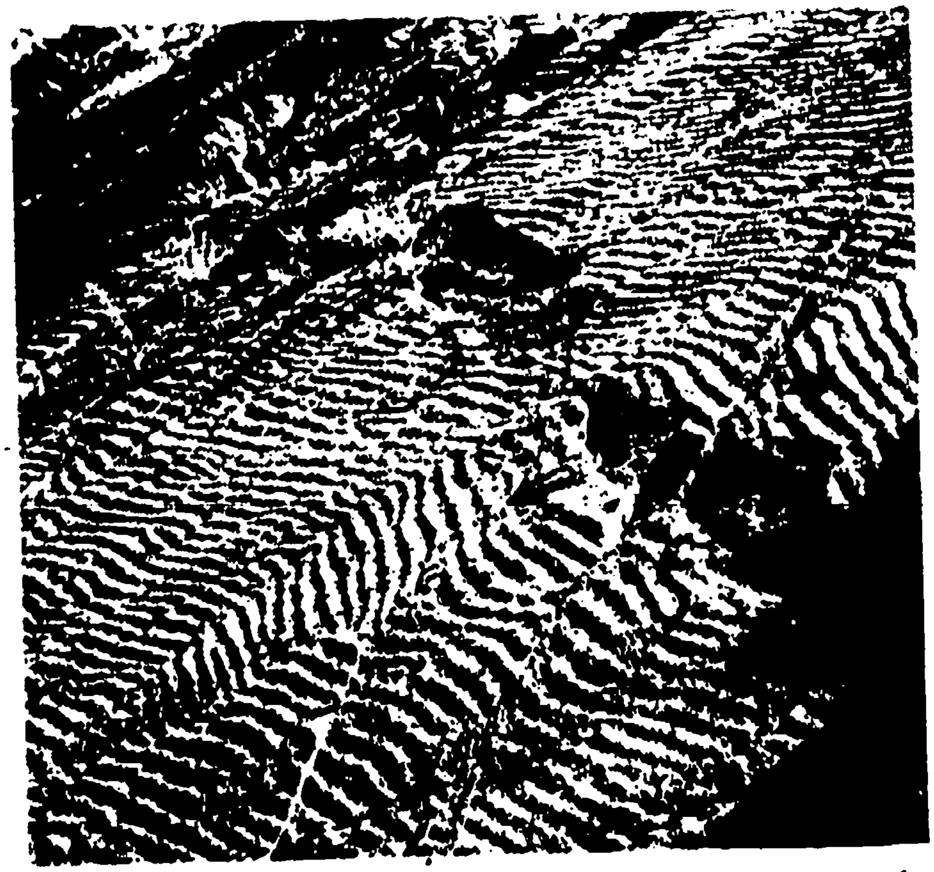
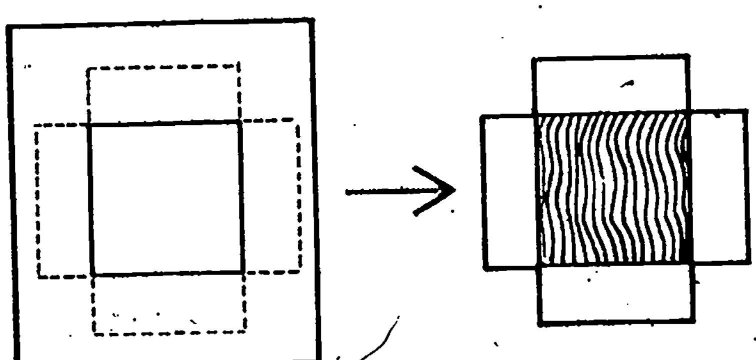


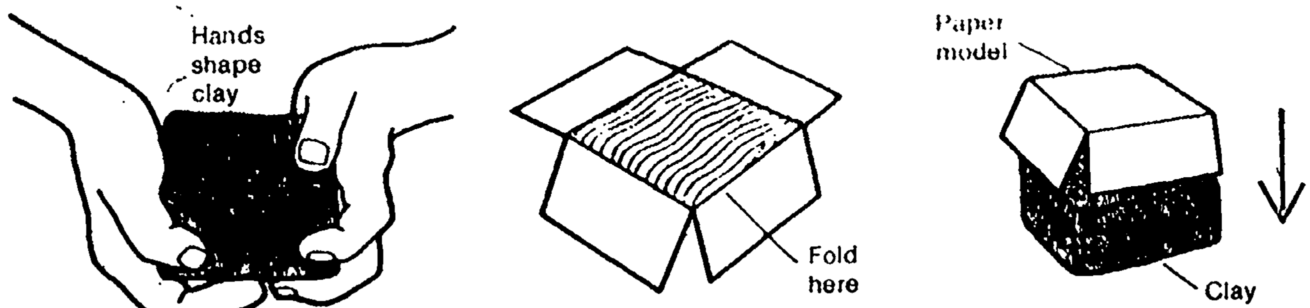
Figure 2-2

We have two observations here, don't we? First, we observe a feature that was probably formed underwater, perhaps in the sea but here it is high in the Rocky Mountains. Second, the surface upon which the ripples are seen is tilted. What does this tell us about these rocks and this area? To find out, let's trace the history of this area very briefly, using the observations we have. For this activity you will need a geology cutout block, a pair of scissors, a clinometer, and 2 colored pencils.



**ACTIVITY 2-1. Cut out the figure along the dotted lines; then within the area marked by the solid lines, sketch in a series of parallel lines to represent ripple marks.**

**ACTIVITY 2-2. Mold a square of clay the same size as the area within the solid lines and then fold the paper mold along the solid lines and place the model on top of the clay—you now have a geology-block model.**




Examine Figure 2-3, shown below. This is a cross-section diagram of the area shown in Figure 2-2.

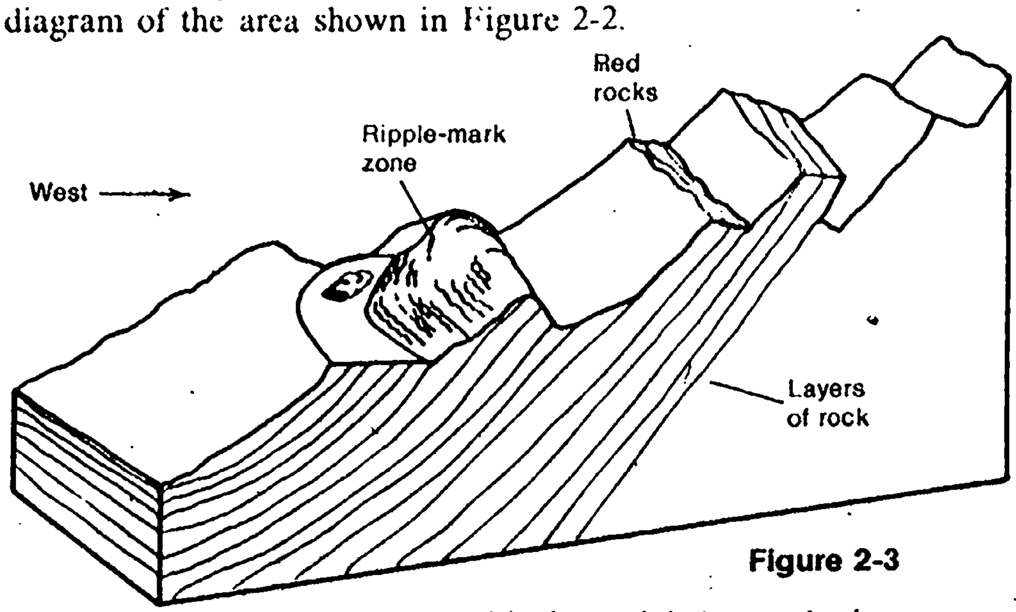
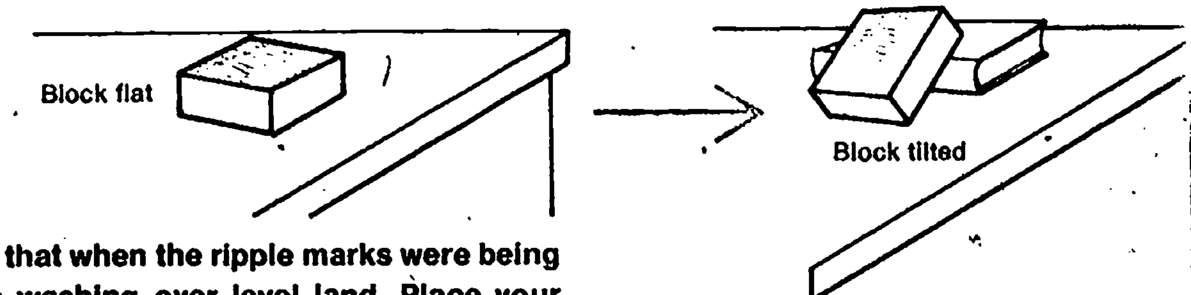



**Figure 2-3**

Now return to your geology-block model, remembering that you are looking at one section of the area shown in Figure 2-3.

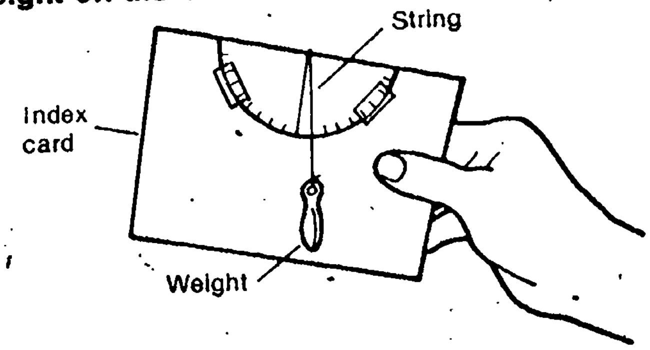


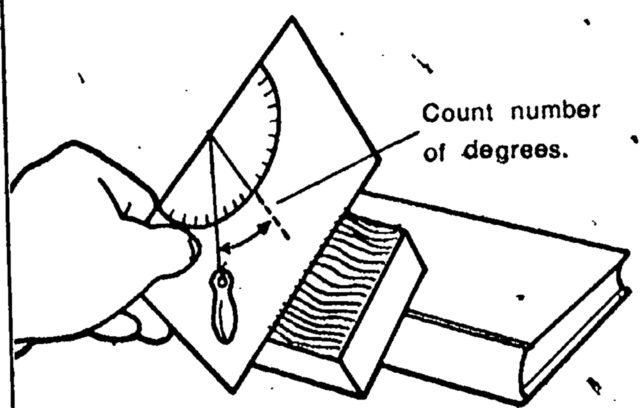

**ACTIVITY 2-3. Assume that when the ripple marks were being formed, the water was washing over level land. Place your block flat on the table with the ripples up. Look at the ripple mark zone of Figure 2-3 and then orient your block the same as in the figure. You may have to support your geology block with a book.**

☐2-1. Write in your Record Book a very brief account, based on what you have just done, of what you think might have happened in the past in the area of the ripple mark zone.

You've probably concluded that the rocks in this area were once lying flat but now are tilted. Some force must have pushed the rocks up from right to left on Figure 2-3. If you return to your geology block you can estimate how much it was tilted up. (If you took down the geology block, tilt it again as the rocks are tilted in Figure 2-3 in the ripple mark zone.)

**ACTIVITY 2-4. The tilt of the rocks (geologists call it dip) can be measured with an instrument called a clinometer. To make one, tape a protractor to a 5" × 7" index card, as shown, and then, from the reference point of the protractor, hang a string with a weight on the end.**




**ACTIVITY 2-5. Place the clinometer on your geology block and read the angle directly off the clinometer.**

☐2-2. How many degrees did you estimate the rocks have been tilted?

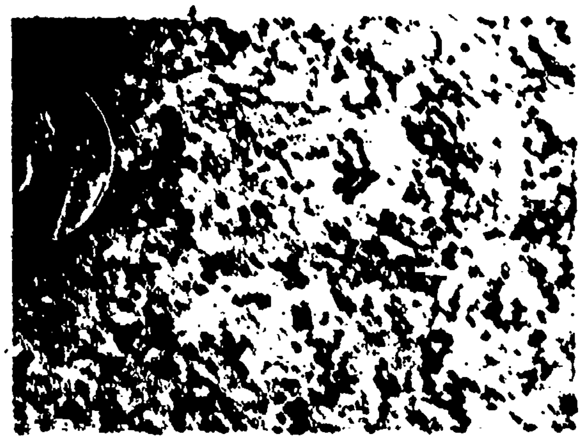
This angle is known as the dip angle and, as you have found out, is a measure of how much the rocks have been tilted. To move many thousands of tons of rock takes quite a bit of energy. In this chapter you'll examine rocks in a variety of mountains and attempt to determine how mountains were formed, what they are made from, and what is likely to happen to them in the future.

To find out more about mountains, let's start by examining materials from the mountains. Select the following rocks from the rock kit in the supply area: numbers 05, 06, 08, 12, 13, and 17.

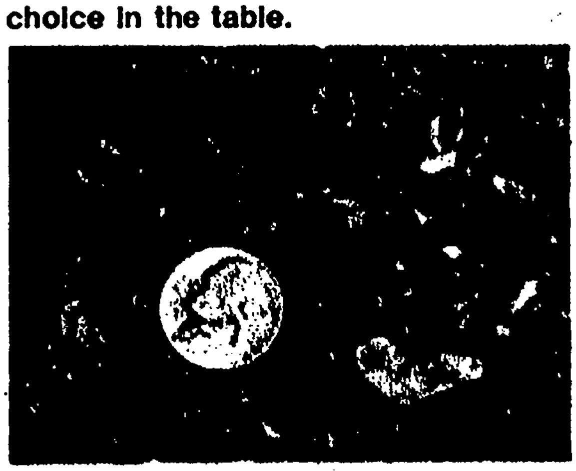
To begin your study, you will need a hand lens and a teasing needle (a sharp nail will do). Your goal is to be able to describe your samples and make a decision about the texture of each rock. You're going to discover that you can tell a lot about a rock from its texture. Enter all your decisions in Table 2-1 of your Record Book.

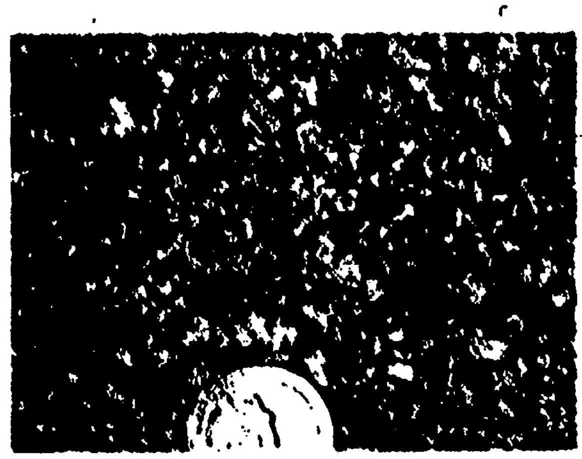
**ACTIVITY 2-6. Pick up a rock sample and look at it, using a hand lens. Hold the rock a few centimeters from your eye, with the hand lens up to your eye. Rotate the sample in your hand (in good light), examining the surfaces of the rock.**

**ACTIVITY 2-7. First decide whether the rock is made of only a single kind of material or component, or more than one. Enter your decision in Table 2-1.**

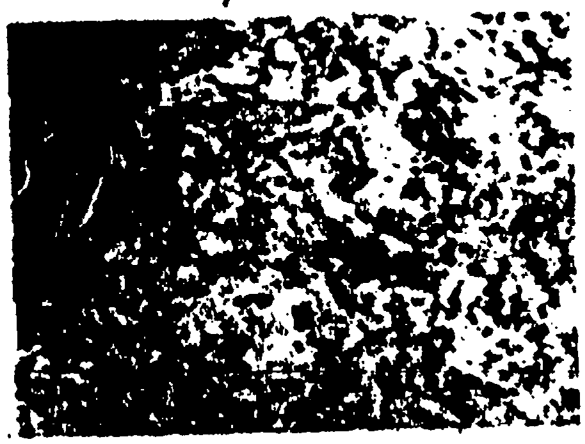


**ACTIVITY 2-8. Focus on the way the components in the rock are held together. Decide whether the components are non-interlocking, or if the components are interlocking. Enter your choice in the table.**





ACTIVITY 2-9. **For those rocks you decided were interlocking, decide if the components are oriented in a given direction or randomly distributed in the rock.**



| Sample Number or Color | Number of Components | Texture | | Arrangement | |
|---|---|---|---|---|---|
| | | Interlocking | Noninterlocking | Random | Oriented |
| | | | | | |

Table 2-1

Repeat Activities 2-6 through 2-9 for each rock sample, entering each of your decisions in the table. When you have studied each rock sample, use the data to sort your rocks into two groups, one with interlocking texture and the other with noninterlocking texture. Take careful note of which rocks are in each group. Later, after you find out more about how the rocks are formed, you will return to explain why they have different textures. You have now described a few samples of mountain rocks and have noted differences in the way they look.



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Here are some of the questions that you'll be tackling next.

☐2-3. a. How do you distinguish among igneous, sedimentary, and metamorphic rocks?
b. How do these rocks form?
c. What kind of materials are these rocks made of?

After having studied the resources in Cluster A, return to the six rocks you studied and answer the following questions.

TO CLUSTER A

☐2-4. How do you think rocks with interlocking texture differ from rocks with noninterlocking texture in terms of the way they are formed? Identify at least one mineral in each of the six rocks and indicate, in Table 2-2 in your Record Book, whether the rock is igneous, metamorphic, or sedimentary.

| Rock Number | Mineral | Type |
|---|---|---|
| 05 | | |
| 06 | | |
| 08 | | |
| 12 | | |
| 13 | | |
| 17 | | |

Table 2-2

## WHERE ARE THE MOUNTAINS

Before taking a tour of the mountains in the United States, let's get a general picture of the distribution of rocks in the country and how they are associated with the mountains. Examine the map in Figure 2-4 showing the distribution of flat-lying sedimentary, steeply-tilted sedimentary, and igneous and metamorphic rocks. Compare the rock distribution map with the map showing the location of the mountains in the United States (Figure 2-5). Using these two maps, answer the following questions.

[ ]2-5. What kind of rocks would you find if you visited the Appalachian Mountains?

[ ]2-6. Are there any mountains in your state? If not, go on to question 2-7. What is the name of these mountains? What kind of rocks are found in them?

[ ]2-7. If your response to 2-6 was No, where are the closest mountains?

[ ]2-8. What kinds of rocks would you find there?

Figure 2-4

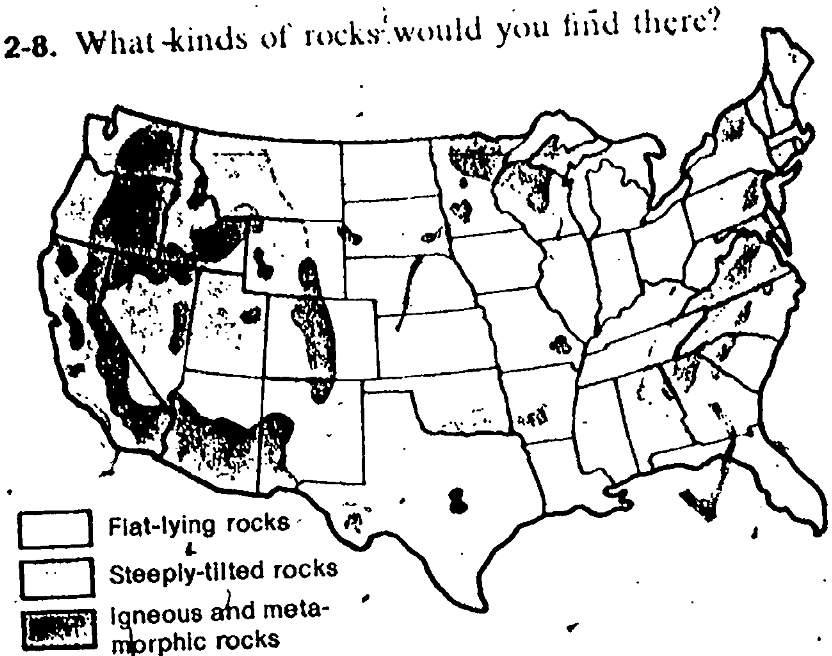
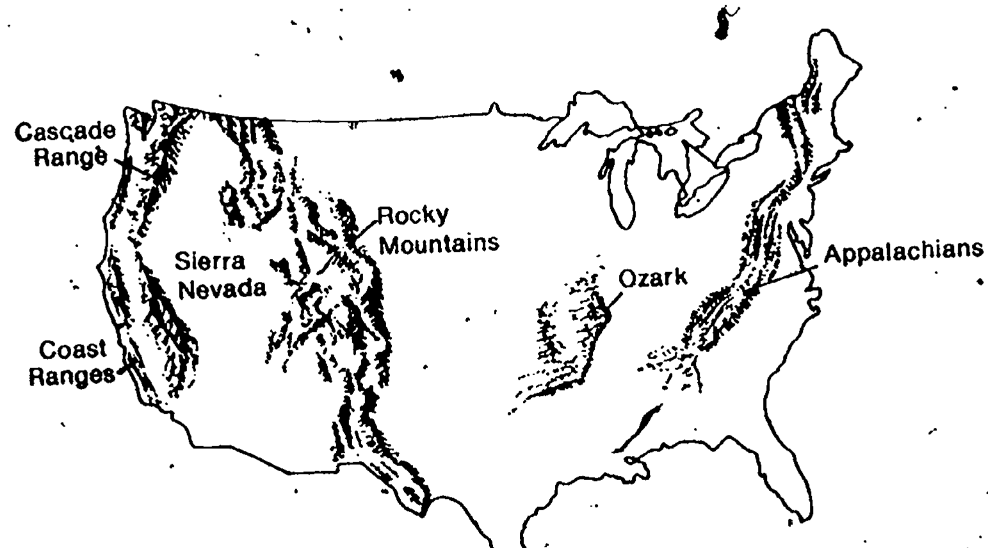



Figure 2-5




Mountains of the United States

**Death Valley, California**

Your first stop on an imaginary tour of the mountainous regions of the United States takes you to the lowest point in the country—Death Valley. An area 85 meters (280 feet) below sea level may seem like a strange place to begin a tour of the mountains. But if you take a look at Figure 2-6, you will see that some fairly high mountains surround the valley.

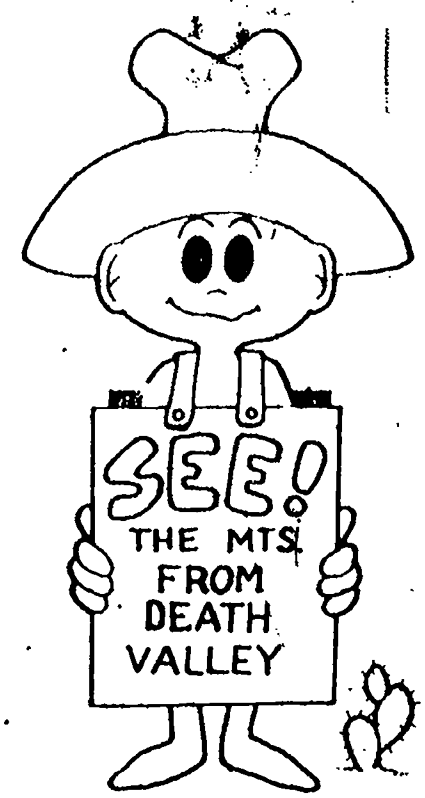



Figure 2-6

Notice how steep and rugged the west wall of Death Valley looks. Piles of sediment, apparent in Figure 2-6, fan out at the base of the wall, and you can see patches of light gravel on the steep fan-shaped formation in the center of the picture. If we examine the fan more closely, we can observe some features that may indicate that active processes are occurring in the area. Figure 2-7 is a view of an alluvial fan (sand washed down from the mountain) on the west side of Death Valley. Look closely at point A. There appears to be a line running left and right from this point.

☐2-9. What appears to have happened above the line on the fan?

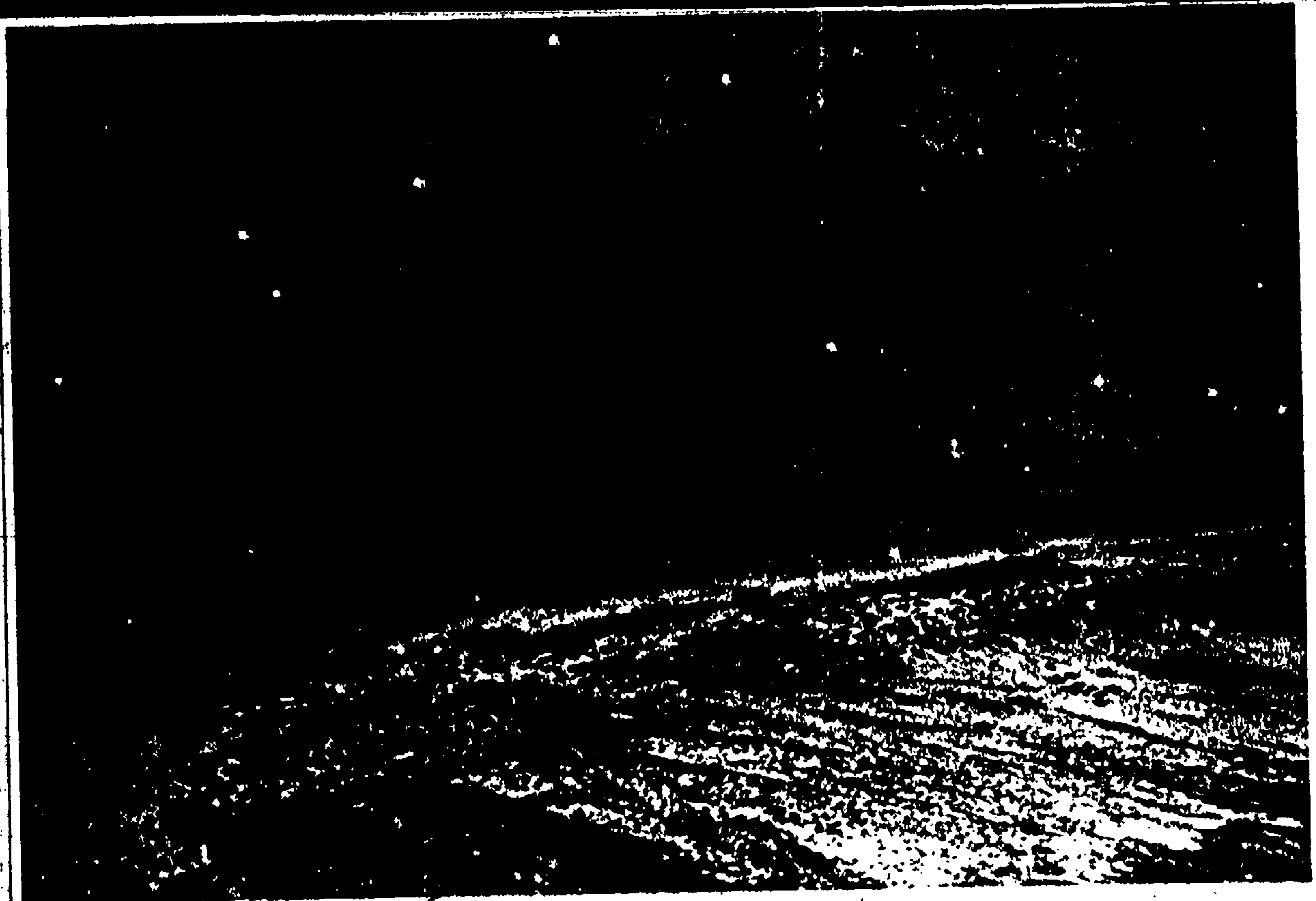


Figure 2-7

Now look back at Figure 2-6, the west wall of the valley. Locate a zone of layered rocks.

☐2-10. Based on what you know about the formation of layered rocks, what does the position of these rocks tell you about the probable movement on the west wall of the valley?

Figure 2-8 shows a general view of the Death Valley area. Once again, notice how steep and rugged the west wall of the valley is. Then check the steepness of the back side of the same mountain. Notice how many other mountains in the Death Valley area have the same wedge shape (see point A in Figure 2-8). Use Cluster C for help.

TO CLUSTER C

☐2-11. By what process did these wedge-shaped mountains form?

☐2-12. Explain your answer to question 2-11, using one model for uplift of the earth's crust.

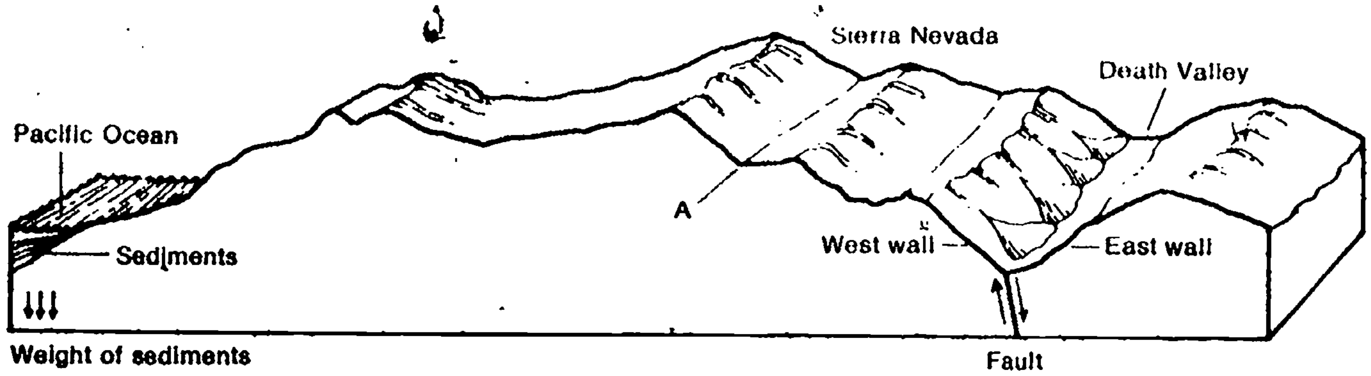
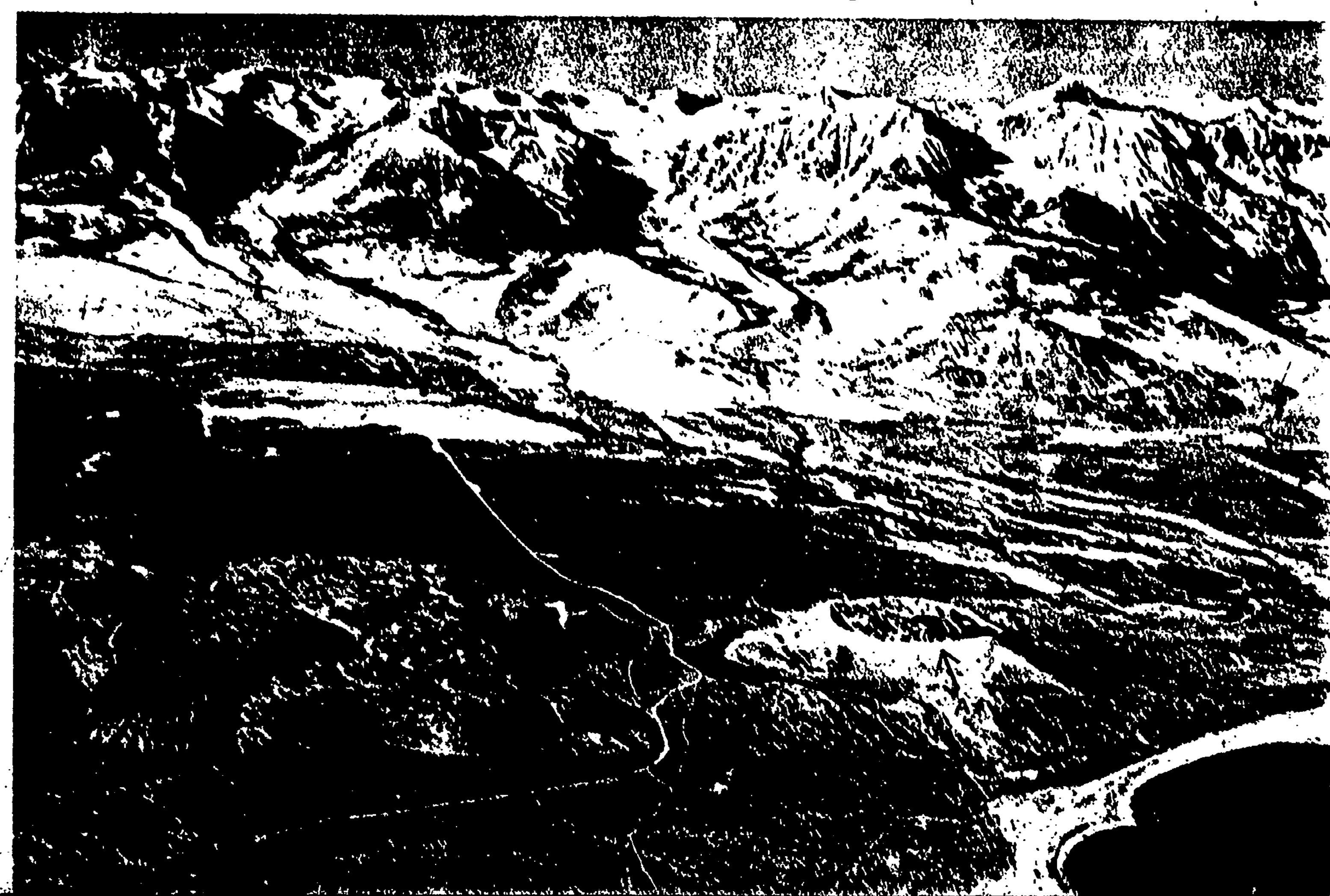



Figure 2-8

### Mono craters in California

About 320 kilometers (200 miles) north of Death Valley is a set of mountains that looks quite different from the ones you've looked at so far. The Mono craters are a group of about 20 domes, several of which appear in Figure 2-9. A single Mono crater is shown at A in Figure 2-9, while a trio are shown near B.

Figure 2-9



If you were to look at the trio of craters more closely, they would appear to be like the drawing in Figure 2-10. There you will notice that the dome contains a shallow hole at the top.

Figure 2-10

In the supply area are some specimens (number 10) of rock like the ones in the Mono crater area. Examine one or more of these carefully, and refer to Cluster B.

TO CLUSTER B

☐ **2-13.** Based on your knowledge of rocks, what clue does the texture of the rock give you as to the origin of the rock?

☐ **2-14.** Based on the shape of the features in Figure 2-10 and the kind of rock samples you have seen, how do you think the Mono craters were formed?

Figure 2-11

Examine Figure 2-11, a photograph of Mount St. Helens in the state of Washington. Notice that this almost 3,000 meter(10,000 foot) high giant stands well away from any other mountain and is rather cone-shaped.

[ ]2-15. Do you think Mount St. Helens was formed in a way similar to the Mono craters? Explain your answer

### Stone Mountain, Georgia

One of the most interesting mountains in the country lies just outside of Atlanta, Georgia, and is called Stone Mountain (see Figure 2-12). This 200-meter(650-foot)-high hunk of once molten rock is surrounded for miles in all directions by rocks that geologists believe were originally formed in water but are now metamorphic.

Figure 2-12

The rocks that make up Stone Mountain are quite different in appearance from the rocks you examined from the Mono craters. In the supply area you will find samples (number 07) of rocks like those from Stone Mountain. Compare these samples with the Mono crater rocks.

□2-16. What do the differences in these rocks tell you about how and where the Stone Mountain samples were formed?

[ ]2-17. If the rocks from Stone Mountain were formed within the crust, how can you explain the fact that they are exposed at the surface, and are higher than the surrounding rocks? Cluster B will help with the explanation.

TO CLUSTER B

## CHECKUP

*Here is a sketch of the roadcut shown in the photograph in Figure 2-13. The light-colored rock is sedimentary, and the dark-colored rock is igneous. Based on the resources in Cluster C, answer the following.*

1. How did the dark-colored rock get where it is now?
2. Which do you think is older: the sedimentary rock or the igneous rock?

Figure 2-13

### Ridges and valleys of the Appalachians

As the map in Figure 2-14 shows, the Appalachian Mountains extend over much of the eastern United States. Looking closer at the mountains (see Figure 2-15), three zones can be identified as follows: zone A, the Appalachian plateau consisting of flat, gently tilted sedimentary rock; zone B, a series of ridges and valleys trending toward the northeast; and zone C, metamorphic and igneous rocks, forming the Great Smoky Mountains. Farther to the east, the Piedmont and coastal plains are encountered.

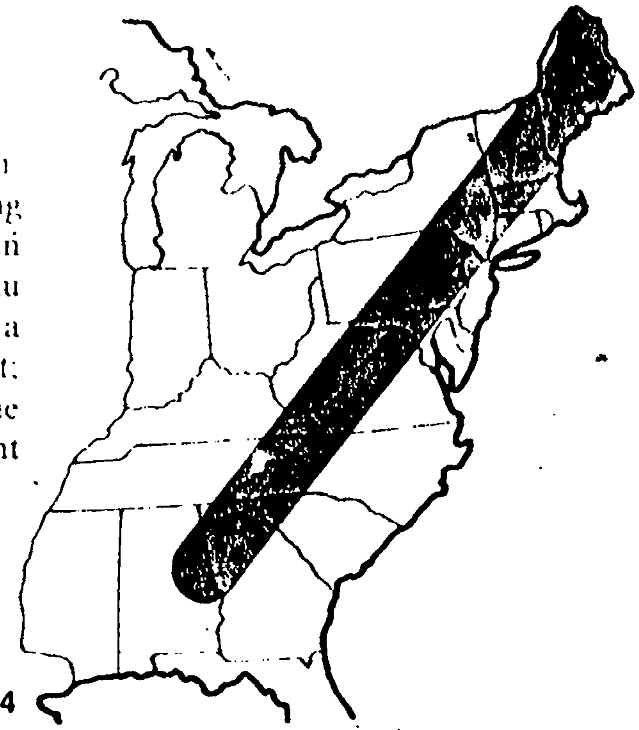


Figure 2-14

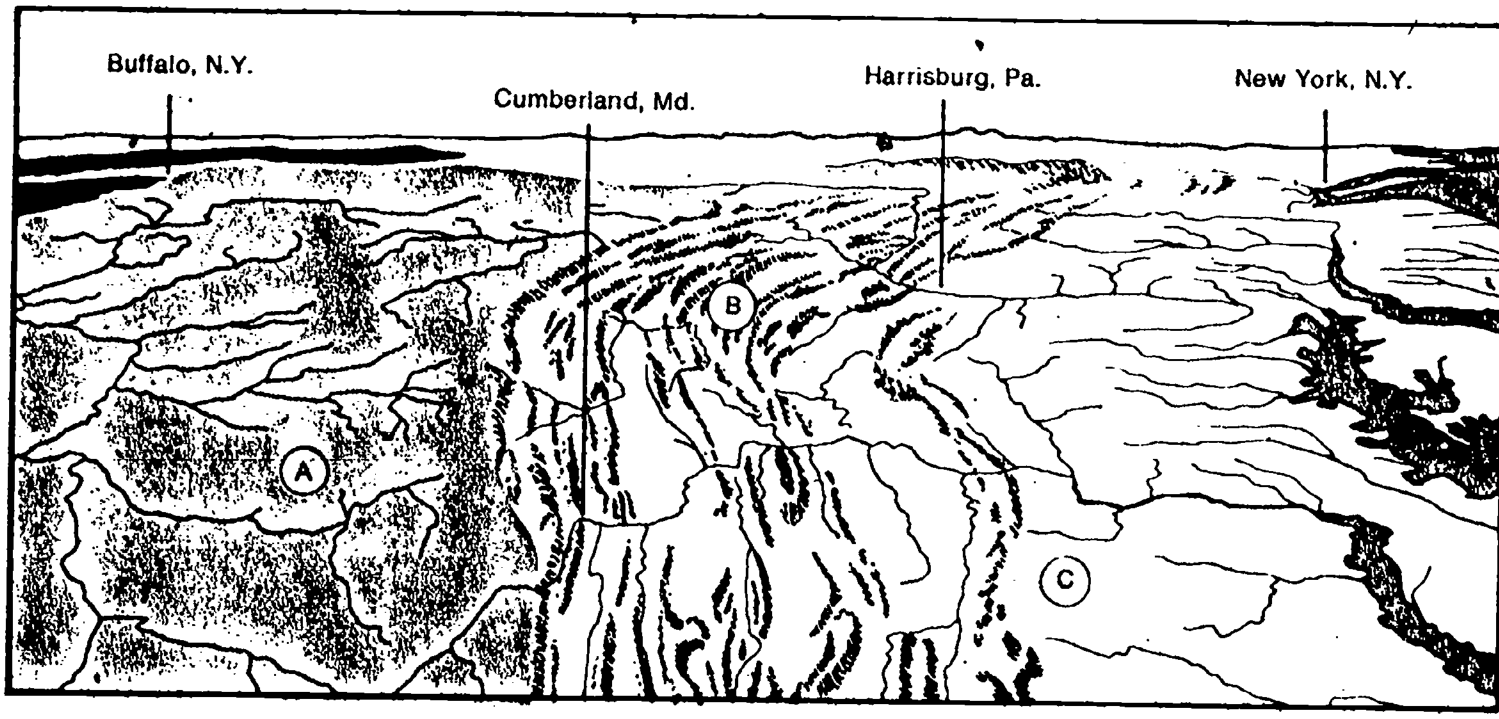
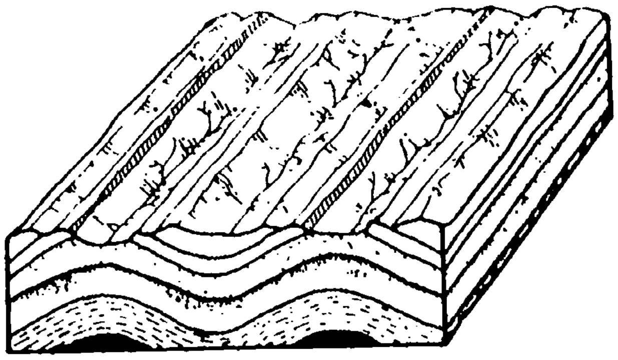



Figure 2-15

Let's focus on zone B, the ridges and valleys of the Appalachians. If you were a geologist trying to judge how ridges and valleys were formed, you would have to travel over a wide area. Figure 2-16 has been drawn to save you time. This diagram shows some of the ridges and valleys, as well as the rocks, in cross section.

Figure 2-16



[ ]2-18. Explain and describe a process that will account for the series of ridges and valleys shown in Figure 2-16.

TO CLUSTER C

**SEARCHING FOR A MODEL**

In Chapter 1, you studied several models that dealt with uplift of the earth's surface. In this chapter, you studied several types of mountains. Table 2-3 summarizes for you information about each mountain that you investigated.

| | Types of Rocks | Origin of Rocks | Shape of Mountains |
|---|---|---|---|
| Block-Fault (Death Valley) | sedimentary and metamorphic | marine deposits | linear; wedge-shaped |
| Mono craters | igneous | cooling of molten material at the surface of crust | round |
| Stone Mountain | igneous | cooling of molten material beneath the crust | round |
| Valley and Ridge of Appalachians | sedimentary | marine deposits | linear; folds |

Table 2-3

□2-19. Do any of the models you have studied help you explain how any one or several of the mountains listed in Table 2-3 might have been formed?

### Removing the mountains

Mountains don't last forever! Up to this point, you have been concentrating on how the land is uplifted to form mountains. Let's make a slight departure and see how they are cut down and sculptured. Much of the variety that causes mountains to be so awe-inspiring was caused by the sculpturing of already uplifted materials. One way that mountains are sculptured is by glacial action. Take a look at Figure 2-17.

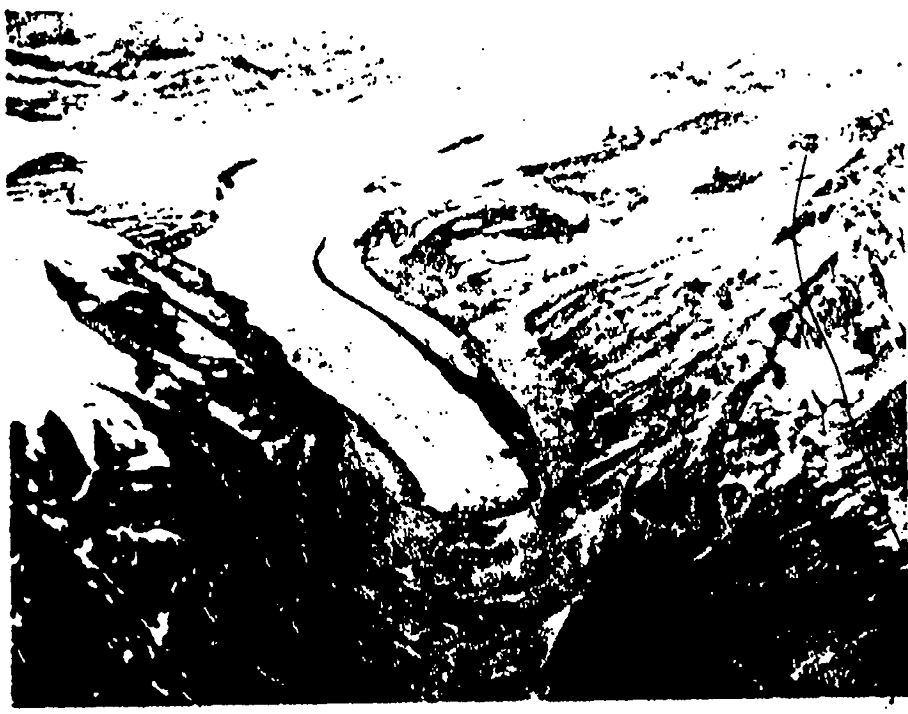


Figure 2-17

Notice how many sharp ridges are in this portion of the Canadian Rocky Mountains. Notice also the U-shaped valleys, the many bowl-shaped basins, and the almost complete absence of flat surfaces. This kind of landscape is fairly typical of areas that have been carved by glaciers—moving rivers of ice. In fact, the remains of what was probably once a much larger glacier are shown in the center of the photograph.

□2-20. How does a glacier sculpture mountains? To help solve this problem, you might use Cluster D and consider the following questions.

□2-21. How are glaciers made, and how do they move?

[ ] 2-22. How are glacial features, such as U-shaped valleys, bowl-shaped basins, glacial lakes, and hanging valleys, created?

**SUMMARY**

Well, if you've done good work, you've learned a great deal about the way mountains took on their characteristics. You've also had a chance to think about forces that are acting upon mountains today.

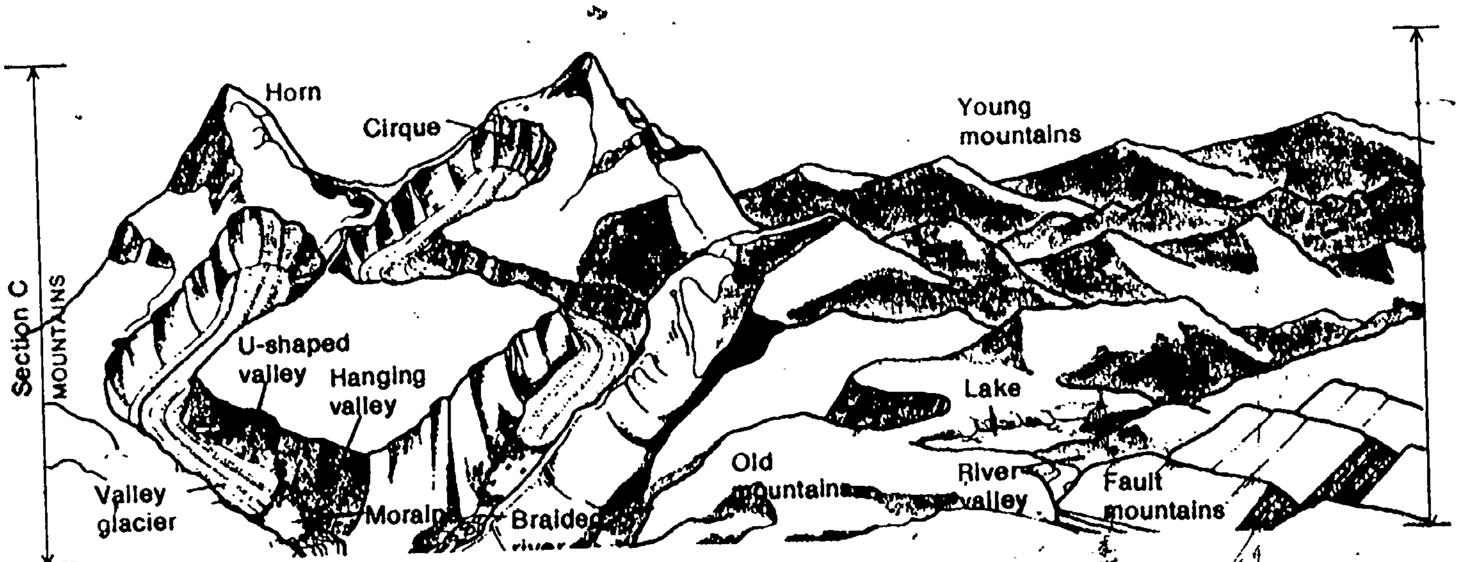


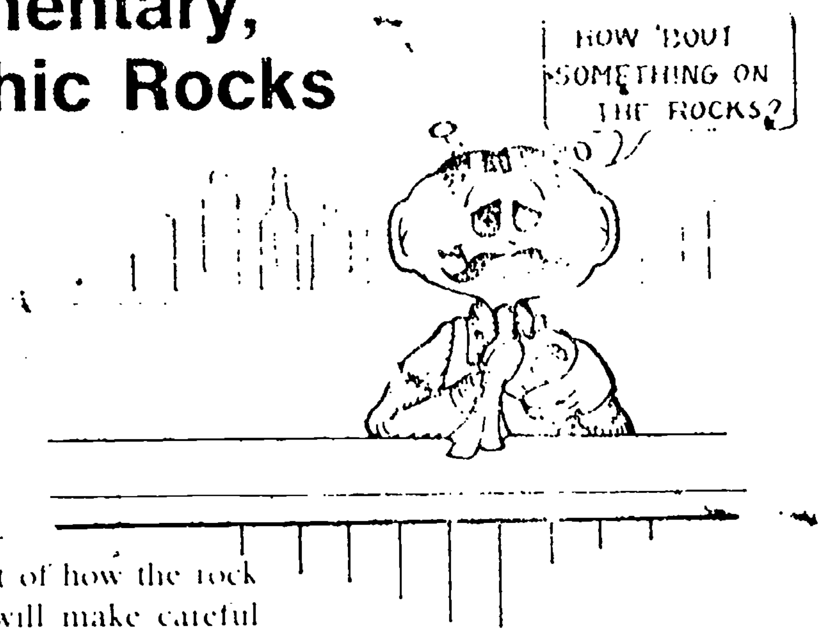

**Figure 2-18**


To find out how well you've done your work, look over Figure 2-18. You will recognize this drawing as part of the overview sketch you saw before in Figure 1-4. On the drawing, you will find examples of just about all the kinds of situations you've looked at in this chapter. If you've worked well, you should be able to give reasonable descriptions of the way each type of mountain in the picture was formed. You should also be able to identify the forces acting upon each kind of mountain and to predict what changes these will produce in the future.

**Before going on, do Self-Evaluation 2 in your Record Book.**

# 5 Distinguishing Among Igneous, Sedimentary, and Metamorphic Rocks

CLUSTER A
(Resources 5–12)




The properties that a rock has are a result of how the rock was formed. Thus, in this resource you will make careful observations of rocks in order to determine how they were formed. In doing this, you will then be able to tell if a given rock is sedimentary, igneous, or metamorphic.

Go to the supply area and pick up a kit of mixed rocks, a hand lens, 1 bottle of HCl, and a steel nail. Before working through the activities that follow, predict which rocks you believe were (1) once molten and then hardened as they cooled, or (2) once sediment but then cemented together. Make separate lists, using the number on the rocks, and then at the end of the resource you can check to see how good your predictions were.

Listed below are a few simple tests that will help you sort the rocks. Read the tests first so that you understand them. Then sort the rocks into three groups according to these tests and the sequence of numbered questions that follow.

### Rock Tests

*Texture test:* Determine whether the specimen (1) has visible components (minerals) that are held together in an interlocking fashion, (2) has visible components (minerals) that are held together by a cement (noninterlocking), (3) looks glassy and is very smooth, (4) looks frothy and has lots of holes, in it, or (5) has a very fine-grained appearance and seems to lack minerals.

*Composition test:* Look at the minerals in the specimen and try to identify as many minerals as you can. The most common minerals you will probably see are quartz, feldspar, mica, calcite, and hornblende. If you can not identify these, do Resource 11.

*Fossil test:* Look for fossils in the rock. They may be in the form of small shells or imprints of leaves.

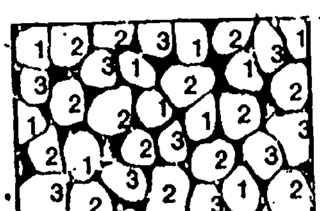
*Chemical test:* Put a couple of drops of HCl on the specimen and look for bubbling. Be sure to wash the specimen with water when you are done.

Pick up a specimen and write down its number. Ask yourself the following questions and write down the answers as you go. If your rock fits the description of any of the items that are preceded by asterisks, then you can make a decision on the specimen at that point. You won't need to go any further in checking that specimen. When that happens, pick up another specimen and start with question 1 again.

1. Is the rock made up of visible minerals that are interlocking? If the answer is Yes, it cannot be sedimentary—go on to item 2 in this list. If the answer is No, go to item 7.

2. Are the minerals of the same kind (same color, about the same shape, same hardness)? If the answer is Yes, it cannot be igneous—go to 3. If the answer is No, go to 4.

*3. A rock with crystals of all the same kind is probably metamorphic.



4. Are the minerals of the different types distributed in a uniformly mixed pattern like the one shown in the sketch (each number represents a different kind of mineral)?
If the answer is Yes, go to 5. If the answer is No, go to 6.

*5. A rock with different types of minerals in a uniformly mixed pattern is an igneous rock.

*6. A rock with different types of minerals arranged in stripes or bands is metamorphic rock.

7. Is the rock frothy (full of small holes)? If the answer is Yes, go to 8. If No, go to 9.

*8. A rock, with lots of small holes, that looks as though it has been full of gas at some time is an igneous rock formed by cooling a gassy lava.

9. Is the rock glassy (like a piece of colored broken glass)? If the answer is Yes, go to 10. If No, go to 11.

*10. A dark, hard rock that looks like glass is probably igneous rock formed by fast cooling of a lava flow from a volcano.

11. Is the rock made up of strong, flat sheets that look as though they will split off into slatelike pieces? If the answer is Yes, go to 12. If No, go to 13.

*12. A rock that splits easily into thin, flat sheets is probably metamorphic. The splitting has been caused by pressure. It used to be sedimentary. If fossils are present, they are probably squashed and flattened.

13. Does the rock contain easily recognized particles, like fine silt, sand, or pebbles, cemented together? If the answer is Yes, go to 14. If No, go to 15.

**Table 1**

| Test | Sedimentary | Igneous | Metamorphic |
|---|---|---|---|
| Texture | Noninterlocking; size of minerals ranges from very large grains to invisible. | Interlocking; random distribution; size of minerals ranges from glassy to large grains. | Interlocking; random and oriented distribution in bands or flakes; size ranges from invisible grains to very large grains. |
| Composition | Minerals may include quartz, feldspar, calcite. | Usually contains quartz, feldspar, mica; sometimes hornblende, olivine. | Minerals may be quartz, feldspar, mica; some contain garnet or calcite. |
| Fossil | May have fossils. | No fossils | If fossils are present, they are usually squashed or twisted. |
| Chemical | May bubble with HCl. | Does not react with HCl. | May bubble with HCl. |

14. A rock made of silt, sand, or pebbles cemented together is sedimentary. It may have fossils. You can probably see the layering in good specimens.

15. If you have come this far, you have a specimen that is difficult to identify. It is not igneous. It may be sedimentary or metamorphic. An expert is needed to sort this one out.

Check your answers against Table 1.

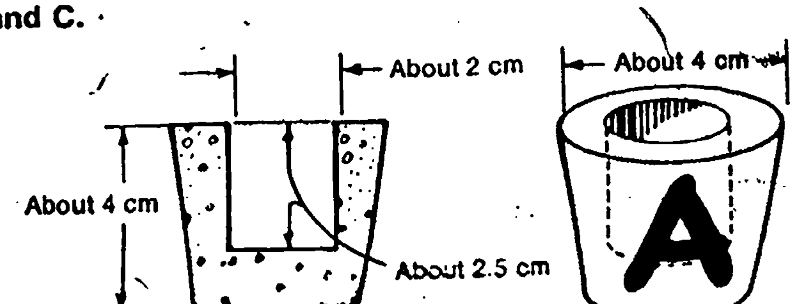
# 6 How Igneous Rocks Are Formed

Igneous rock is rock that was once molten and that crystallized as it cooled. Some igneous rocks are made of very small crystals, and others are made of large crystals, but most are made of crystals of different sizes, colors, and compositions.

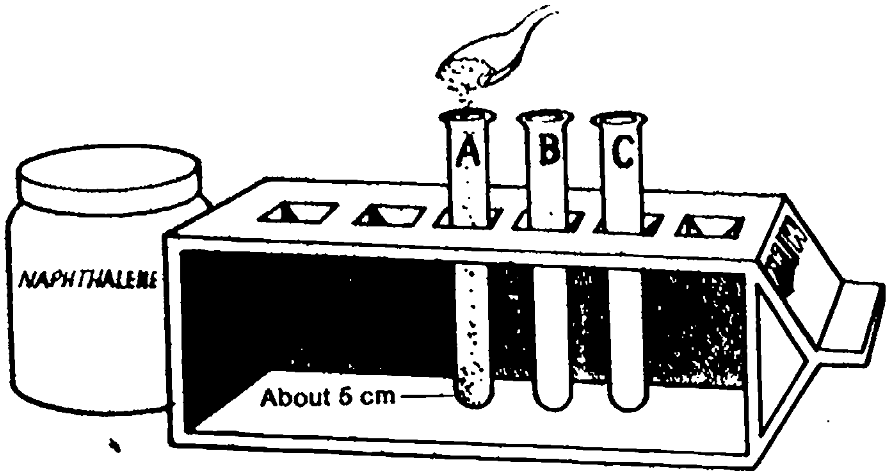
To be able to understand how igneous rock forms from molten rock, you can simulate (imitate) the process on a small scale. You will need the following items:

- 1 test-tube rack
- 3 test tubes
- 1 alcohol burner
- 1 test-tube holder
- 3 large corks
- 1 flat metal or glass surface (aluminum foil, window glass)
- 1 baby-food jar
- 1 knife, cork borer, or scissors
- Naphthalene flakes
- Sodium thiosulfate
- Sulfur

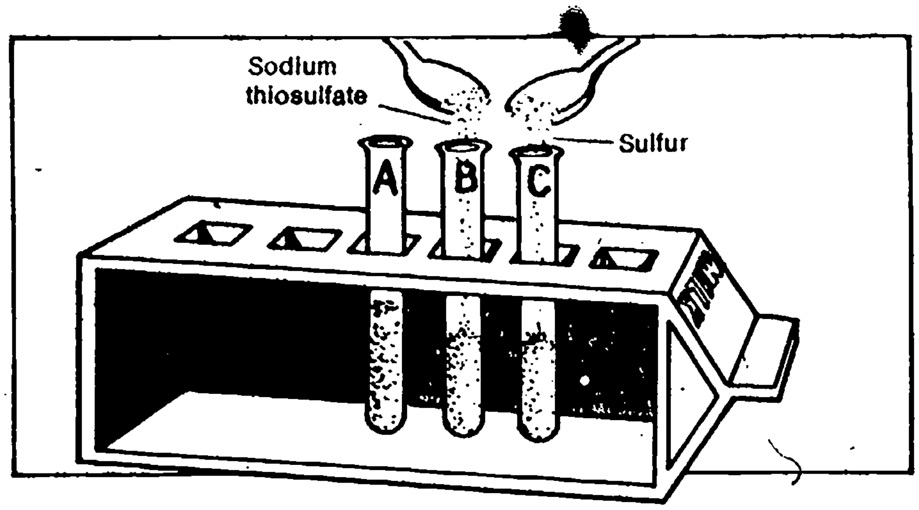
**ACTIVITY 1. Using a knife, cork borer, or scissors, carefully dig out the middle of a cork to make a well, as shown in the diagram. Prepare three corks like this and label them A, B, and C.**



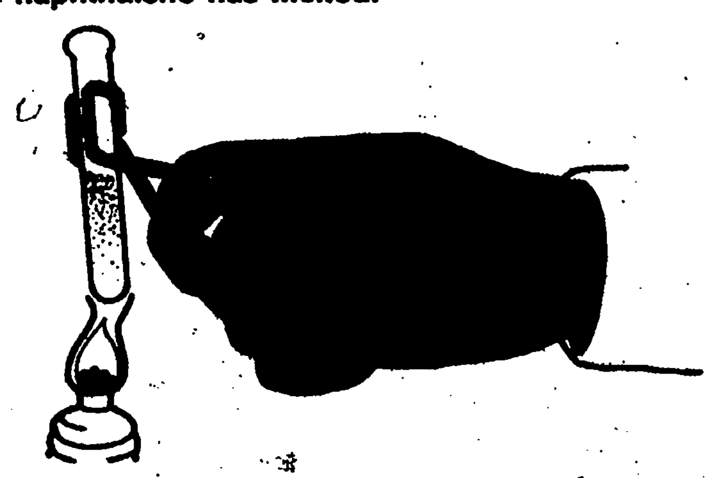
**ACTIVITY 2.** Get 3 test tubes and label them A, B, and C. Put about 5 cm of naphthalene flakes into test tube A.



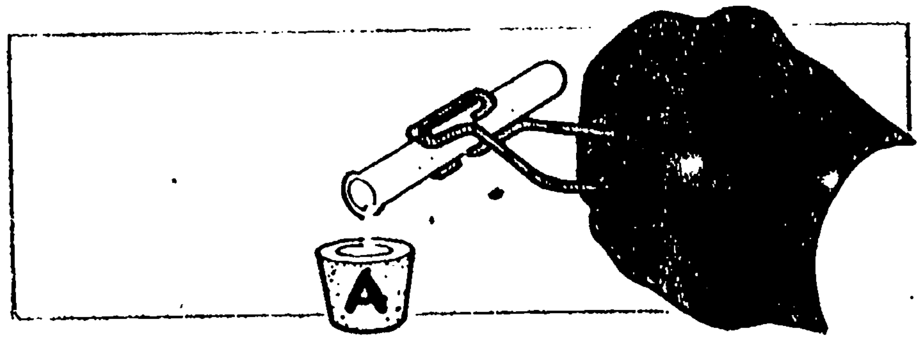

**ACTIVITY 3.** Put about the same amount (5 cm) of sodium thiosulfate into tube B and of sulfur into tube C.



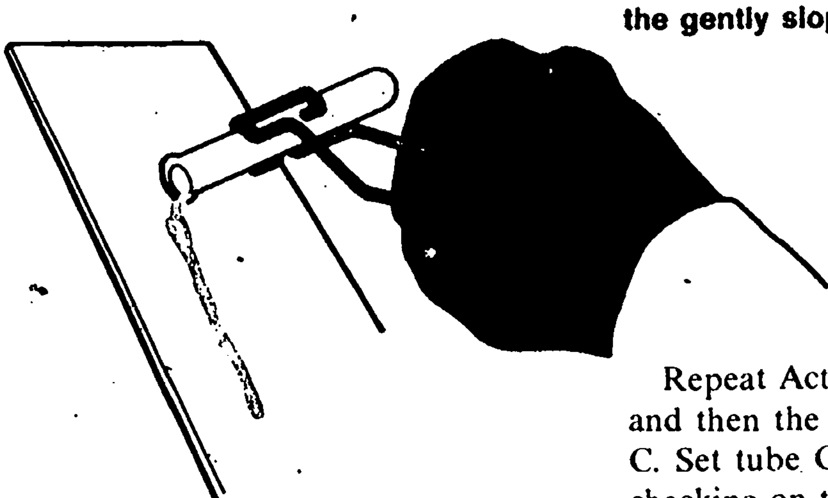

**ACTIVITY 4.** Very gently heat tube A until the naphthalene starts to melt. Then take the tube away and shake it gently. Heat a little more and then shake again. Keep doing this until all the naphthalene has melted.



**ACTIVITY 5. Pour part of the melted naphthalene quickly into the well in the cork labeled A, just filling the well. Put the cork aside in a safe place where it won't get knocked over. Look at the top of the liquid every few minutes or so, but don't move the cork.**

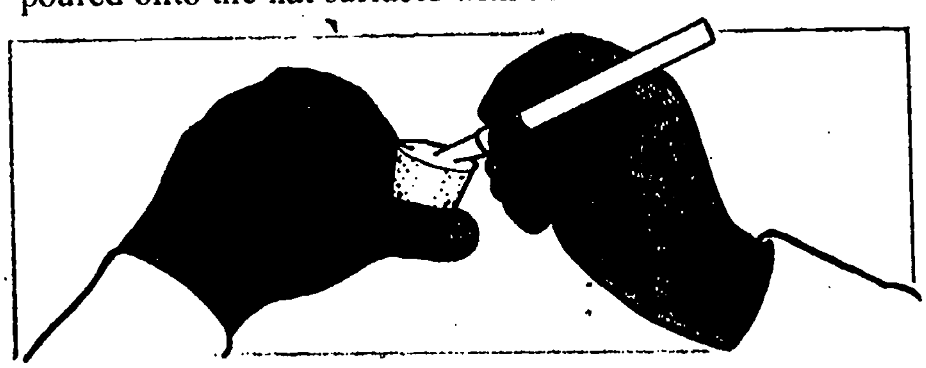



**ACTIVITY 6. Support the piece of glass or aluminum foil on a paper towel. Now pour the rest of the naphthalene down the gently sloping glass or foil.**



Repeat Activities 4, 5 and 6, using the sodium thiosulfate and then the sulfur. Try not to use all the sulfur from tube C. Set tube C aside after these activities. Meanwhile, keep checking on the melted materials you poured into the wells in the corks.

Now carefully compare the structure of the materials you poured onto the flat surfaces with the materials in the corks.



**ACTIVITY 7. When the substance in each cork is completely solid, cut the cork in half with a sharp knife.**

What differences do you observe between the substances cooled by pouring down the glass and the substances cooled by pouring them into a well in a cork?

You have just carried out a simulation experiment. Pouring the molten material down a cold slope is somewhat similar to what happens when lava pours out onto the land surface. Lava, however, contains several different chemical substances, and its temperature is about 900–1100° C, depending on the mineral composition.

The liquid in the cork simulates molten rock that has forced its way into cracks deep in the crust. The surrounding rock acts as an insulator just as the cork does and prevents rapid loss of heat. A body of igneous rock formed in this way is called an *intrusion*.

Sometimes the lava in contact with the cold rock at the margin of an intrusion is chilled more quickly than in the center.

Look at the substances in the corks you have cut (Figure 1). What differences can you see in the structure of the material next to the cork (at A) and in the middle (at B)?

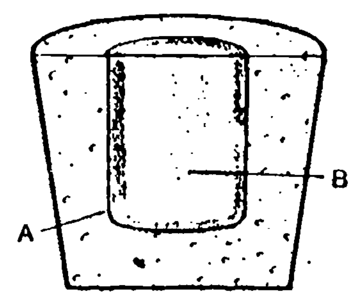
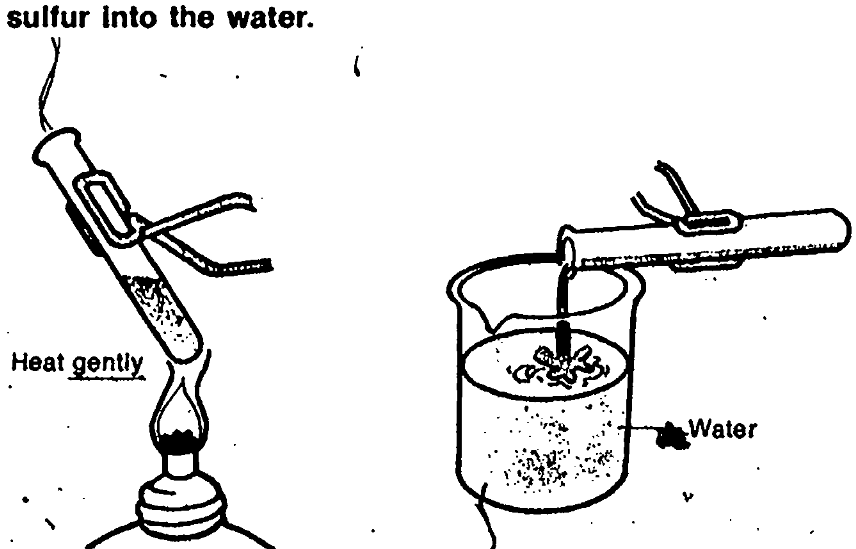


Figure 1

**ACTIVITY 8. Now get test tube C with the leftover sulfur in it. (If you used all the sulfur, add about half an inch more.) Heat very gently as you did before to produce a pale golden liquid. Have a beaker of cold water ready. Pour the liquid sulfur into the water.**



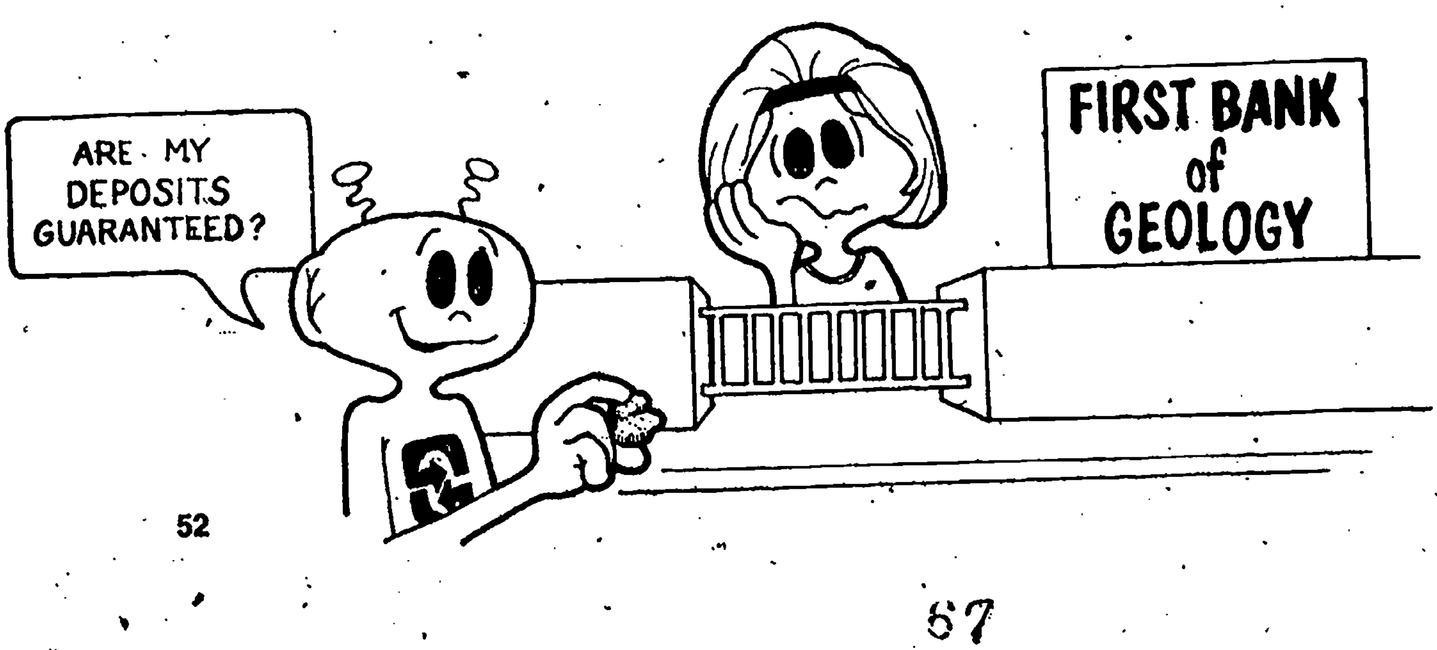

Pick the lumps of solid sulfur out of the water and look at them closely. Compare the structure with the sulfur from the "intrusion" and from the "flow." These differences are very similar to what happens to lava. If lava pours out under the sea, it rolls into lumps with a glassy looking surface. If it pours out onto the land in thin flows that cool very rapidly, it may form a glassy substance.

Sulfur does not really form a glass, but the very rapid cooling does not allow crystals to form properly. When this sort of thing happens to the silicate minerals in lava, crystals cannot form; therefore, a glass is formed instead.

Get the rock kit and select the igneous rocks from it. (You should already have done the resource on distinguishing rock types. If you have not, stop here and do the previous resource.) Compare the different types of igneous rock. What differences can you see in the colors, shapes, and sizes of crystals? Can you predict whether each rock is from an intrusion or from a flow?

A simulation experiment is often a useful device for helping to develop models of processes that are difficult to observe. Geologists in the field can add other evidence to that from simulation experiments because there are active volcanoes in existence. Freshly cooled lava flows from a new eruption can be examined and compared with much older rocks.

# 7 The Formation of Layered Sediments



Whether you are at the seashore, in the mountains, or on the plains, you are likely to find rock outcrops like those shown in Figure 1. The outcrops all have one striking feature in common. Take a careful look at Figures 2 and 3, too, and see if you can identify the feature that all three photographs have in common. It is a feature that probably came about in roughly the same way each time.

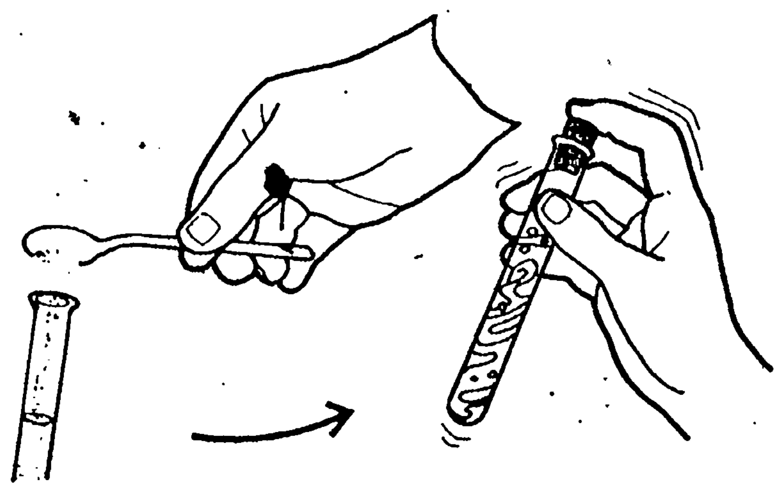
Figure 1

Figure 2

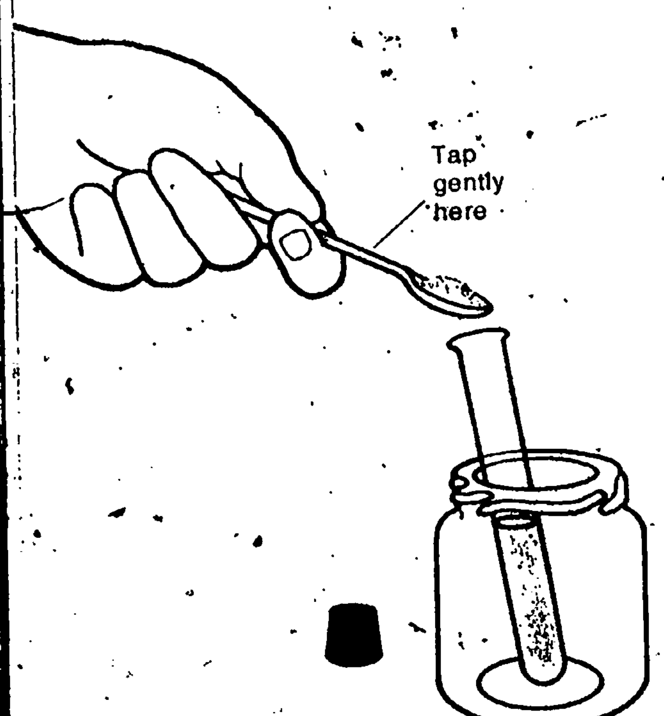
Figure 3

To try to get some clues about the formation of this feature, you can do some simple experiments. You and your partner will need the following materials:

- 4 test tubes, with stoppers
- 2 baby-food jars
- 50 ml water
- ½ tsp crushed chalk (white)
- ½ tsp crushed chalk (colored)
- ½ tsp sand
- ½ tsp silt
- 1 tsp sand-silt mixture
- 1 plastic teaspoon
- 1 bottle of calcium chloride powder
- 1 bottle sodium carbonate powder
- 2 droppers
- Dropping bottle of HCl
- 1 watch glass or other piece of glass
- 1 filter-paper disk

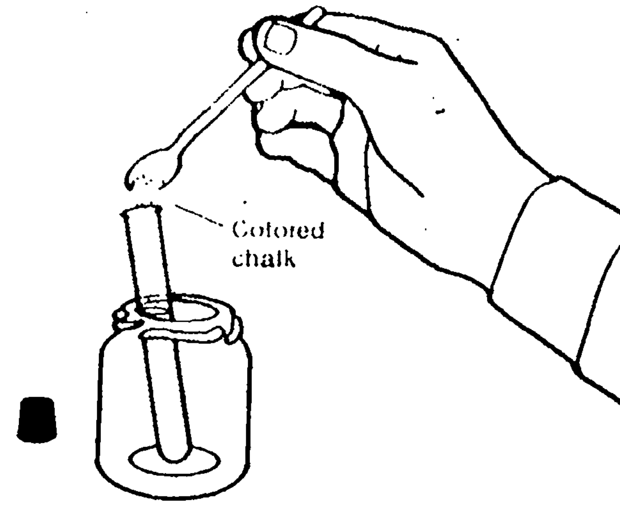


**ACTIVITY 1. Fill a test tube about half full of water and add about $\frac{1}{4}$ teaspoon calcium chloride. Cap the test tube and shake it to dissolve the calcium chloride.**



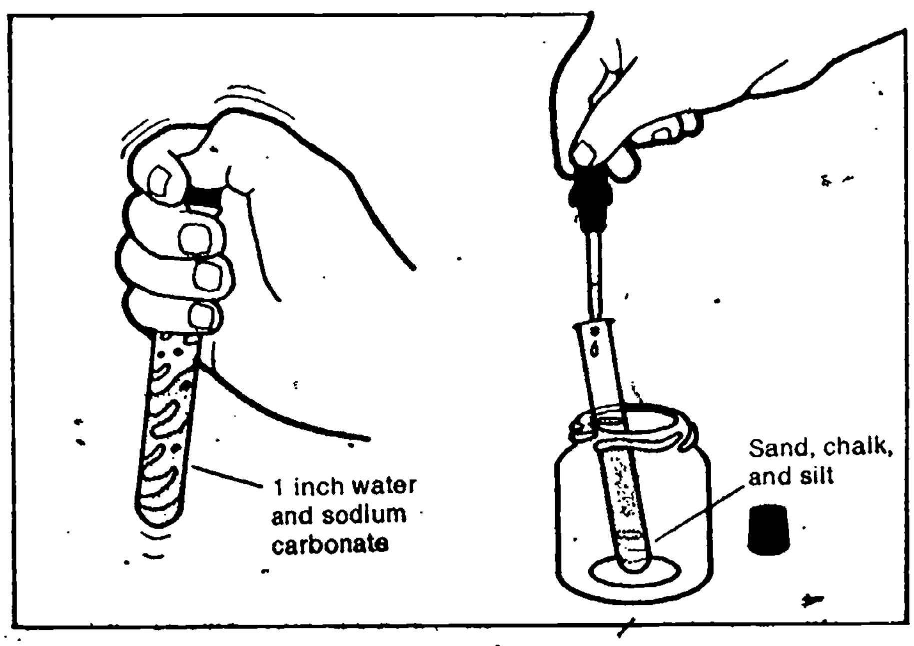

**ACTIVITY 2. Stand the test tube in a baby-food jar on the table. Remove the stopper and let the water settle. Now take $\frac{1}{2}$ teaspoon sand, hold it over the bottle, and tap gently so that the sand grains fall slowly into the water in the test tube. Keep tapping until all the sand has gone...**

**ACTIVITY 3. Using the same test tube, carefully add $\frac{1}{2}$ teaspoon crushed colored chalk in the same way. Do not disturb the test tube while you are doing it, and let it stand for a few minutes afterward.**



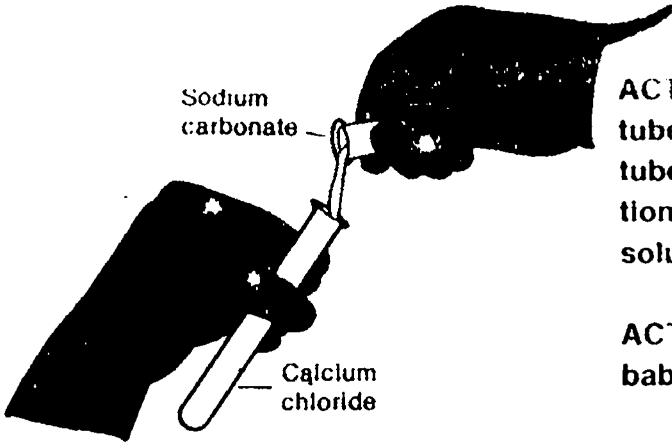

Repeat the process once more, using the white chalk. Allow it to settle for about two minutes and then add the silt in the same way. Now look into the test tube through the side, without disturbing it. What do you see?

**ACTIVITY 4. Put about an inch of water into a clean test tube, and add $\frac{1}{4}$ teaspoon sodium carbonate. Stopper and shake it until everything dissolves. Take up the solution into a dropper. Slowly add the solution, a couple of drops at a time, into the test tube to which you added sand, chalk, and silt. Observe what is happening. When you have used all the sodium carbonate solution, let the test tube stand for several minutes.**



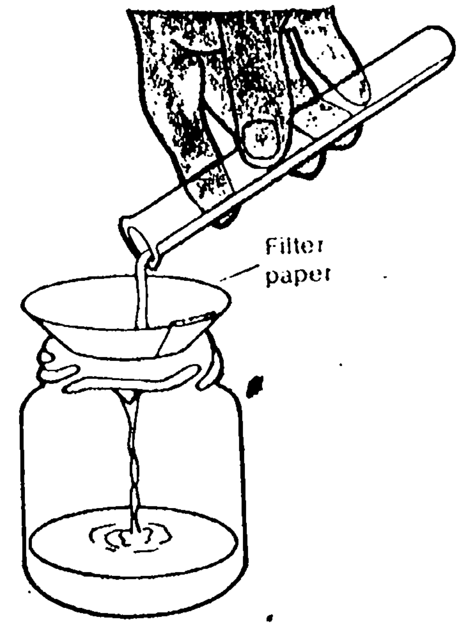

Could this process—particles settling in water—form layers like those in the photographs? What evidence would you need about the rocks in the photographs to confirm that this process caused the layers to form?

In the experiment just completed, you selected different kinds of particles, and you used a chemical reaction to produce another kind of particle. Let's take a closer look at the chemically formed particles.

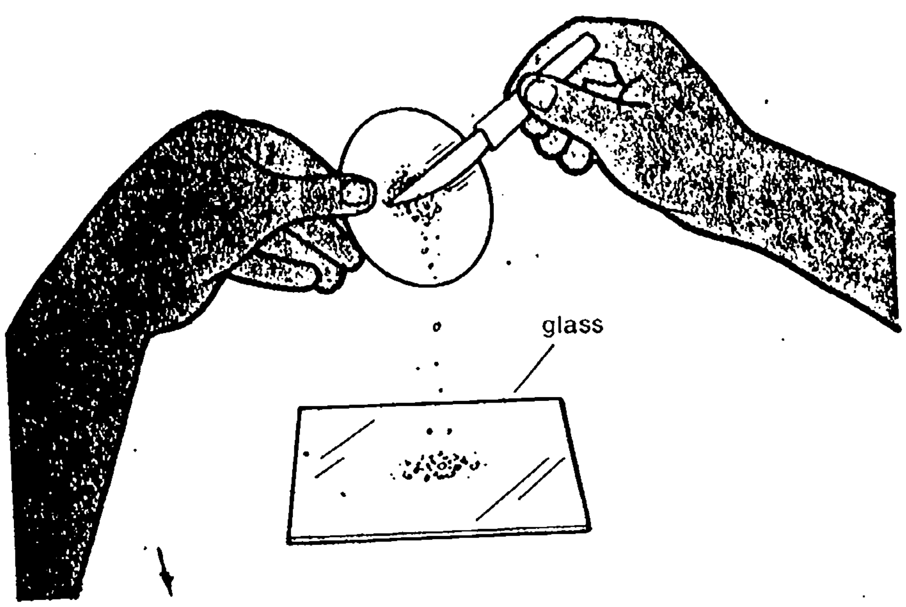



ACTIVITY 5. Put about an inch of water into a third clean test tube. Add about a $\frac{1}{4}$ teaspoon calcium chloride. Stopper the tube and shake it until everything dissolves. Make up a solution of sodium carbonate as you did for Activity 4. Add this solution to the calcium chloride solution.

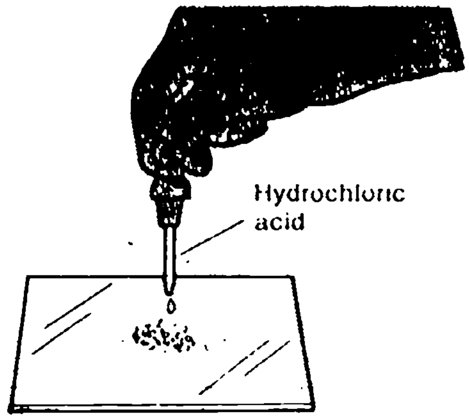
ACTIVITY 6. Now filter the mixture you have made into a baby-food jar.




ACTIVITY 7. Scrape the particles off the filter paper onto a small watch glass or other piece of glass. That which remains on the glass is the residue.



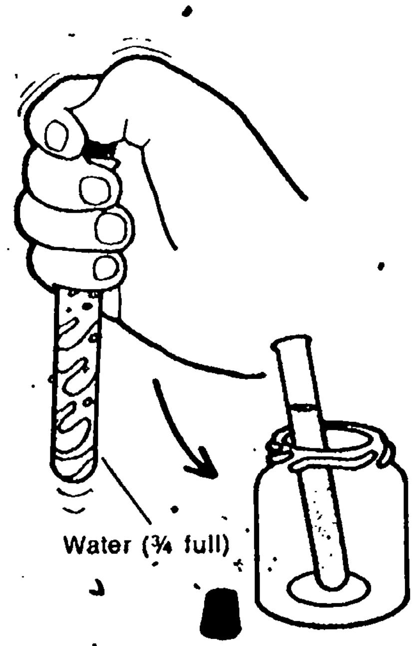
**ACTIVITY 8. Using a clean dropper, add one drop of hydrochloric acid to the residue.**




What happened when you added hydrochloric acid to the particles? You will find that some of the rock specimens in the rock kit will also react in a similar way with hydrochloric acid. These rocks are called *limestones* and contain calcium carbonate, the same chemical contained in the particles that settled out of the solution in Activity 4. Some limestones are thought to have been formed by the settling-out of calcium carbonate in layers.

Get the rock kit and find out which specimens react with hydrochloric acid.

**ACTIVITY 9. Take your fourth clean test tube and fill it about three-fourths full of water. Pour about 1 teaspoon of the sand-silt mixture into the test tube. Stopper the test tube and shake it vigorously for a few seconds. Put the test tube into the jar and let the contents settle. Carefully observe what is happening.**




What do you notice about the rate of settling of the different-sized particles?

These simple experiments and the evidence in the rock specimens give a few clues that layers might be formed from particles settling out from water, but how are these layers changed into rock?

You can get some more clues by doing the following resource, "How Sediments Harden into Rock."

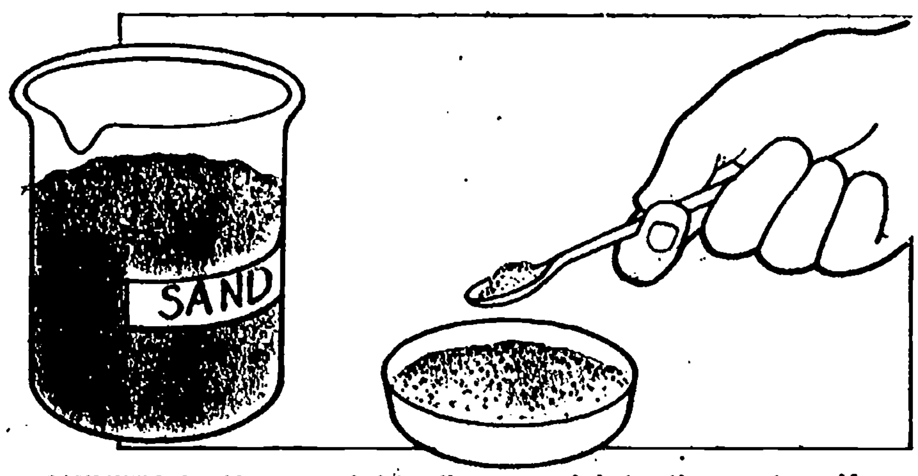
# 8 How Sediments Harden into Rock

Sediments are deposited in the form of layers of particles. The particles in most layered rock have properties that show they were once sediments deposited in water. But how do such sediments become hardened into rock?

Since the water in rivers and in the oceans contains many dissolved minerals, perhaps these minerals have an effect on deposited sediments. To study how dissolved minerals can affect sediments, you can try the following experiment. Go to the supply area and get the following items:

3 paper cups
1 teaspoon
Fine sand
Ferrous sulfate (a soluble compound of iron)
Ferrous ammonium sulfate (a soluble compound of iron)
Scissors


**ACTIVITY 1. Get a paper cup and cut it off to make a small flat dish about half an inch deep. Fill it about halfway with water and add about $\frac{1}{4}$ teaspoon ferrous sulfate. Shake the dish until the $FeSO_4$ dissolves completely.**




**ACTIVITY 2. Now sprinkle fine sand into the water. Keep adding until wet sand almost fills the dish. Shake the dish to level the sediment and then set it aside in a warm safe place until your next class.**

Repeat the experiment, but this time use ferrous ammonium sulfate as the substance to be dissolved.

Also set up a third experiment, using only water and sand, without any dissolved mineral.

[ ]1. What is the purpose of this third experiment?

Since it will take at least a day for the sand to dry out, you might go on to the next resource, "Sedimentary Rocks," if you still have class time left. When the sand has completely dried out, remove it from the paper cup, and compare the results of the three experiments.

[ ]2. What do you notice?

In this experiment, the presence of a dissolved iron compound in water causes a cementing and hardening action on the sand particles as the deposit dries out. You may even have found that your deposit changed to a yellowish color.

Iron compounds have been identified as the cementing agent in many sedimentary rocks, and the yellowish or reddish color of many sandstones is due to the presence of such compounds in the cementing material.

This experiment suggests at least one way that deposited particles might harden. Natural waters contain many dissolved materials that could act in a way similar to that of the materials you tried.

# 9 Sedimentary Rocks

Get the rock sample kit and pick out the sedimentary rocks. (If you have trouble doing this, see Resource 5.) Your task in this resource will be to identify each sedimentary rock as sandstone, shale, or limestone.

*Sandstone*, as its name implies, is composed of sand grains cemented together. *Shale* is hardened clay or mud. It often has a "muddy" odor when it is moistened. *Limestone* is composed of calcium carbonate, the same chemical contained in sea shells. Limestone fizzes vigorously when a drop of HCl is applied to it.

Here are some tests that you may find helpful in classifying the rocks.

1. Look closely at each rock with a hand lens.
   a. What is the average size of the grains?
   b. What is the shape of the grains rounded, angular, or elongated?
   c. What is the color of the grains?
2. Study the material that holds the grains together.
   a. Is it fine-grained or crystalline?
   b. If it is crystalline, what is the size of the individual crystals?
3. What happens when you put a drop of dilute HCl (hydrochloric acid) on each rock?
4. Breathe on each rock. Try to identify any odors that result.

The results of the above tests should give you enough information to identify the rocks.

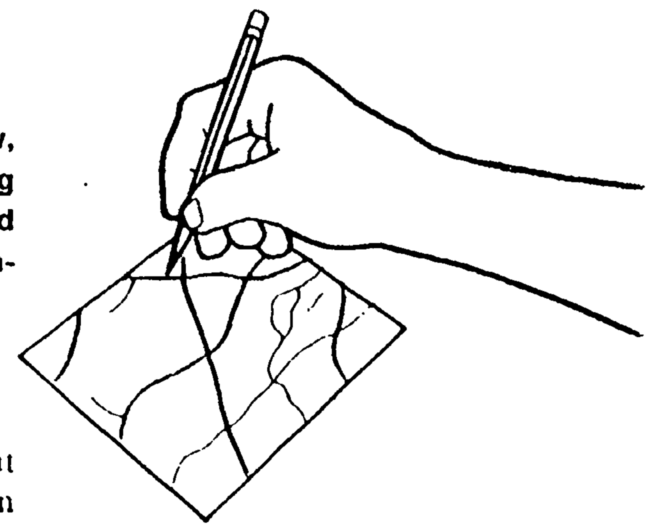
After careful thought and experimentation, geologists have concluded that rocks like sandstone, shale, and limestone were formed in lakes and seas. The theory is that the sand and clay that were deposited in seas and lakes became cemented into sandstone and shale. Limestone is thought to be fused calcium carbonate that was once dissolved in seawater (calcium carbonate is part of the "salt" of the seas).

Sedimentary rocks are generally found in layers. If you would like to know why, see Resource 7, in this cluster.

# 10 Metamorphic Rocks—A Field Trip in the Classroom

Metamorphic rocks are rocks that have been changed in form because of increases in temperature and pressure. Any rock may be subjected to metamorphism. In this resource you are going to imagine that you are going on a field trip in an area where metamorphic rocks are found. After collecting the rocks you will return to the laboratory as would a geologist, to study and examine the rocks you collected. To do this resource, you will need the following:

| | |
|---|---|
| 1 geologic map of a metamorphic area | 1 hand lens |
| 1 piece of cellulose acetate film | 1 metal file |
| 1 bottle of acetone or nail polish remover | 1 rock kit containing samples 05, 16, 18, 20 |
| | Piece of fine sandpaper |
| | Pan of clean sand |



**ACTIVITY 1. For each of the geology stops listed below, imagine you are in the field collecting samples of rocks. Using the directions at each stop, locate that spot on the map and record on the map the identification number of the rock sample. Use the map in your Record Book.**

Stop #1 At the north end of unimproved dirt road about 1 mile from west end of Iggy Road. Specimen fragment 16 collected here.

Stop #2 Intersection of Iggy Road and ISCS Highway 21. Sample 18 collected here.

Stop #3 Intersection of ISCS Highway 21 and East Street. Sample very similar to 18 collected here.

Stop #4 Intersection of East Street and an unimproved dirt road. Sample similar to 16 collected here.

Stop #5 Intersection East Street and Iggy Road. Sample 20 located here.

Stop #6 Edge of map and East Street. Sample 05 collected here.

Stop #7 Intersection of Lake Street and Lake Creek. Sample similar to 20 found here.

Stop #8 Intersection of Lake Street and the light-duty road. Sample similar to specimen 05 collected here.

When you have finished the field trip, make sure you have recorded the sample numbers on the map at each of the eight stops. Although you made eight stops, you should only have four rock samples, since you collected a similar rock for each of these four at another station.

ACTIVITY 2. Draw a line from the upper left corner of the map to the lower right corner of the map and then place each rock sample at any one of the stations from which it was collected.

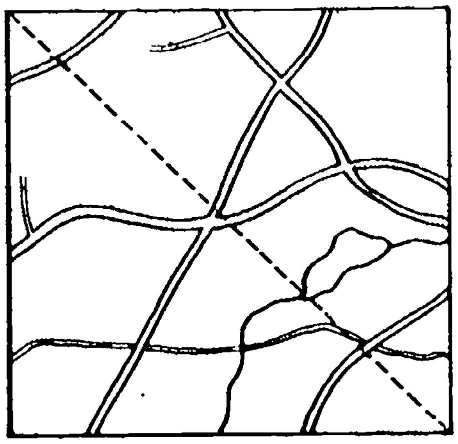
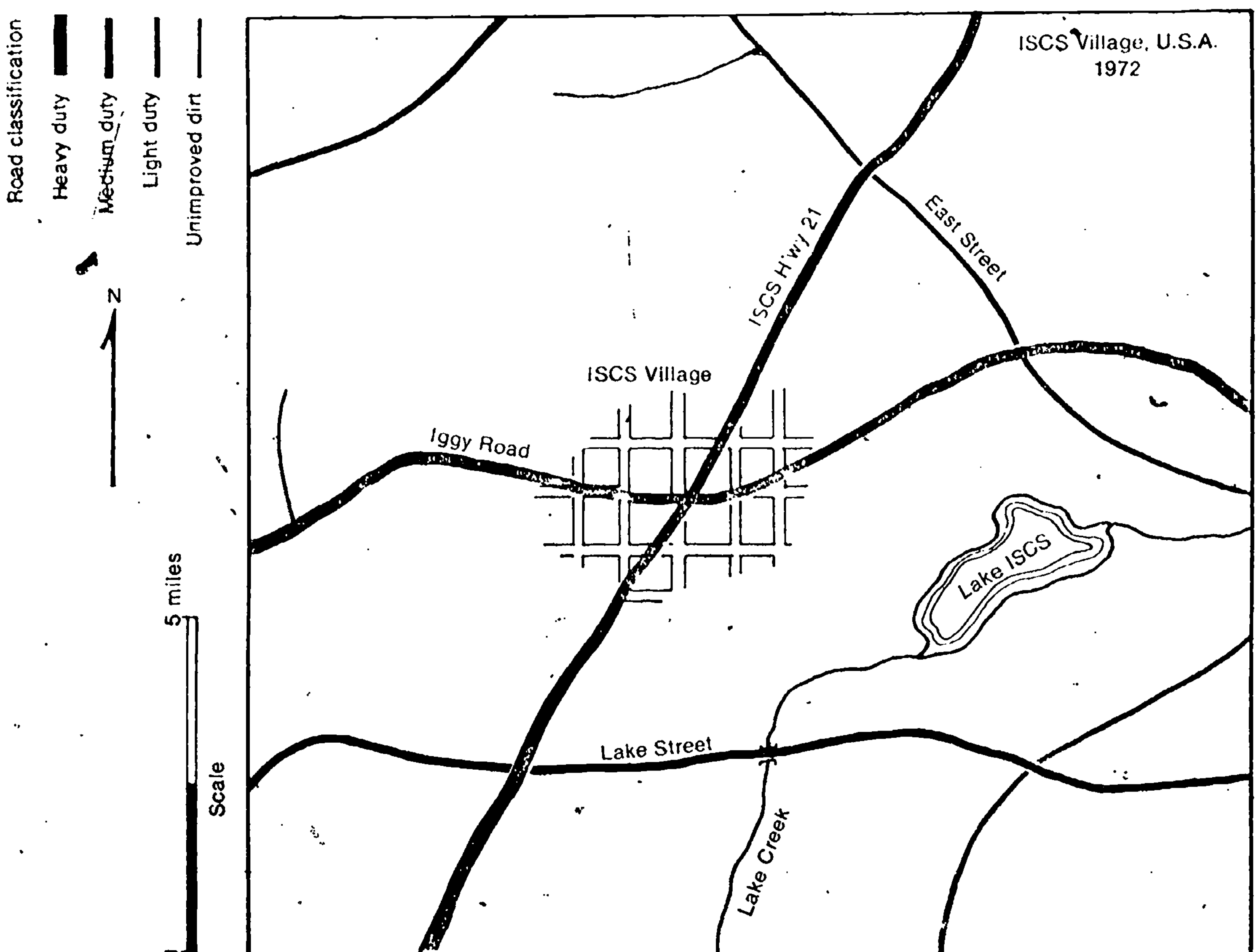


Figure 1

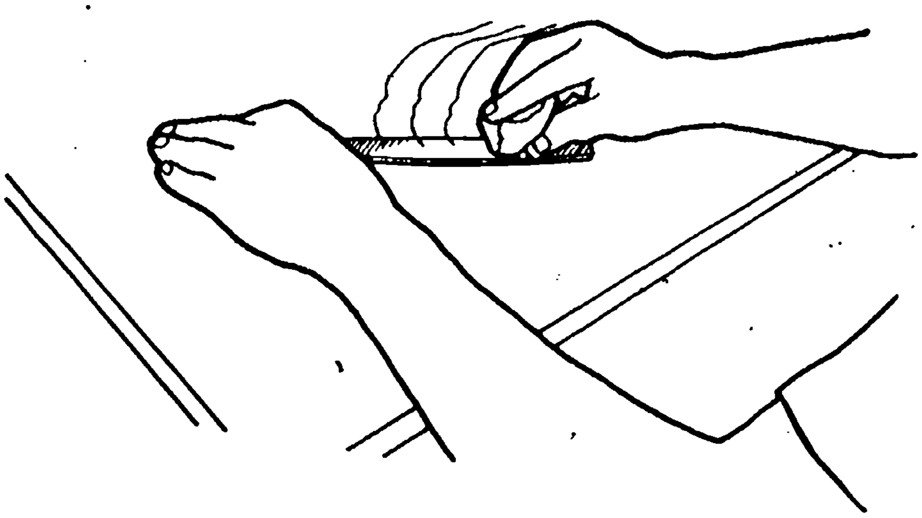
[ ] 1. If you start from the upper left hand corner and move along the line to the lower right, what major differences among the rocks do you note?

If you examine the rocks in the upper left part of the map you will note that they are sedimentary, and as you move toward the lower right they grade into metamorphic rocks. You should have noted that as you move toward the lower right the rocks become more layered or banded, and the minerals in the rocks become larger.

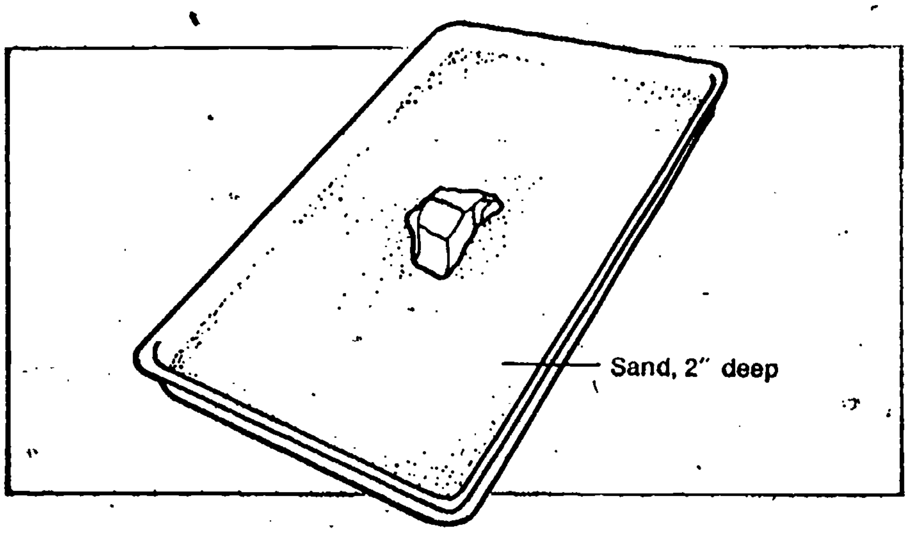


Let's examine each of these rocks more closely. Geologists sometimes study rocks by making an acetate peel of the rock. Pick up rock 05 and examine it carefully, looking for a flat, polished surface. If your rock does not have a polished surface, then you will have to polish it by following the instructions in Activity 3. If it is polished, start with Activity 4.

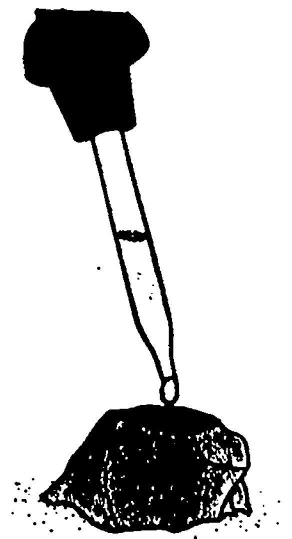
**ACTIVITY 3. Hold the rock in your hand so that the surface to be polished faces outward. Lay a steel file flat on the desk and grind the surface of the rock on the file for a few minutes. The area you grind should be at least 1.5 cm square. Use fine sandpaper when you think the surface is smooth. Wash the rock in water and let it dry.**

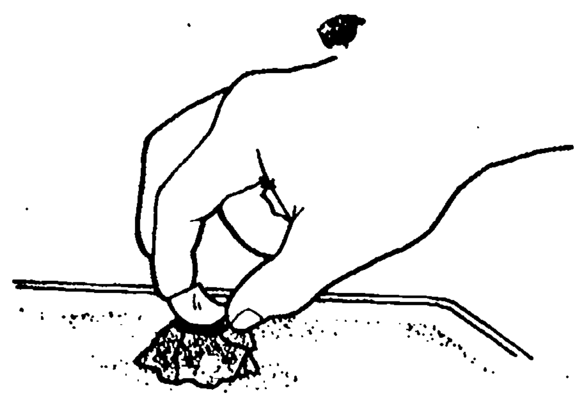


**ACTIVITY 4. Support the rock sample by gently pushing downward and slightly rotating the rock into a pan containing clean sand. The polished surface should be face-up and horizontal.**

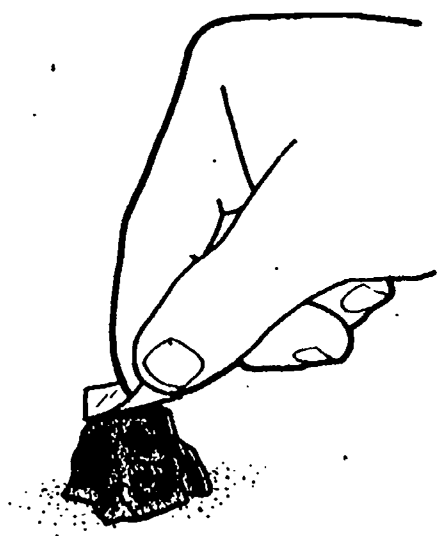


**ACTIVITY 5.** Carefully wet the polished surface with a few drops of acetone or nail polish remover. Hold the acetate film between thumb and forefinger of each hand and bend downward into a U shape. Apply to the rock so that the base of the U is first to touch the wet surface. Progressively roll the film out so that it is flat on the rock. Do not press with your fingers. Let this dry for about 15 minutes.





While the first rock is drying, repeat Activities 3 through 5 for the other rocks.



**ACTIVITY 6.** After 15 minutes, carefully lift the peel off by grasping one corner with your finger and gently lifting. The acetate should peel off.

When you have made four peels, examine them carefully with a hand lens. Using the peels, answer the following questions.

☐ **2.** What differences do you note in the size of the minerals in each rock?

☐ **3.** What differences do you note in the arrangement of the minerals in each rock?

You have already learned that metamorphic rocks originate when rocks are changed by conditions of high temperature and pressure. Let's assume that the original rock for the three metamorphic rocks in this activity was the sedimentary rock you collected in the upper left regions of the map. This rock is called shale, which is made of very fine particles of silt and clay. You should have noted from the peels that the grain size of the minerals of the rock increased as you moved toward the southeast regions of your map. Also the appearance of a layer or bands became more pronounced as you moved toward the southeast.

[ ]4. What part of the map do you think was subjected to highest temperatures and pressures?

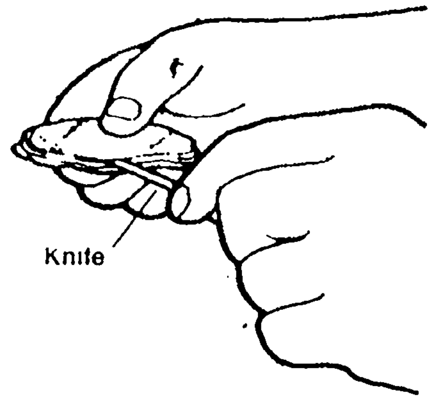
The type of metamorphism you are studying here is called regional metamorphism. The reason for this is that metamorphic rocks generally occupy large areas on the earth. These rocks form deep in the crust, and the fact that you collected them on the surface indicates they were uplifted and the rocks above them were eroded away. It is generally agreed that the rocks with pronounced layering or banding have undergone more change than other rocks. Perhaps the higher temperatures and pressures occurred in the southeast region of the map.

As you will learn later in this unit, greater masses of hot rocks buried deep in the crust, known as igneous intrusions, might provide the high temperatures necessary to metamorphose rocks.

# 11 Identifying Rock-forming Minerals

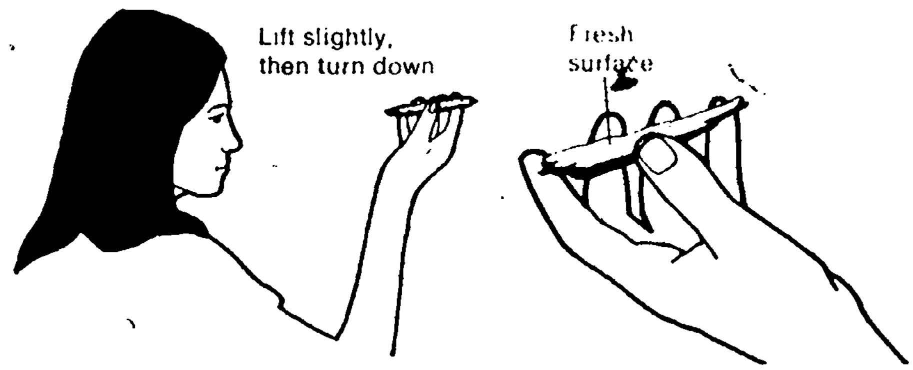
There are more than 2,000 different minerals on the earth, yet the ones that are useful in the study of rocks can be reduced to about a dozen. In this resource you will use a simplified classification system to help you identify mineral specimens.

Obtain from the supply area a kit of minerals, a glass plate, a knife, and a hand lens.




**ACTIVITY 1.** Pick up mineral sample 29 (biotite mica) and carefully try to peel a layer off the top. Place a knife between the layers and lift. This peeling or separation along a smooth surface is called cleavage.

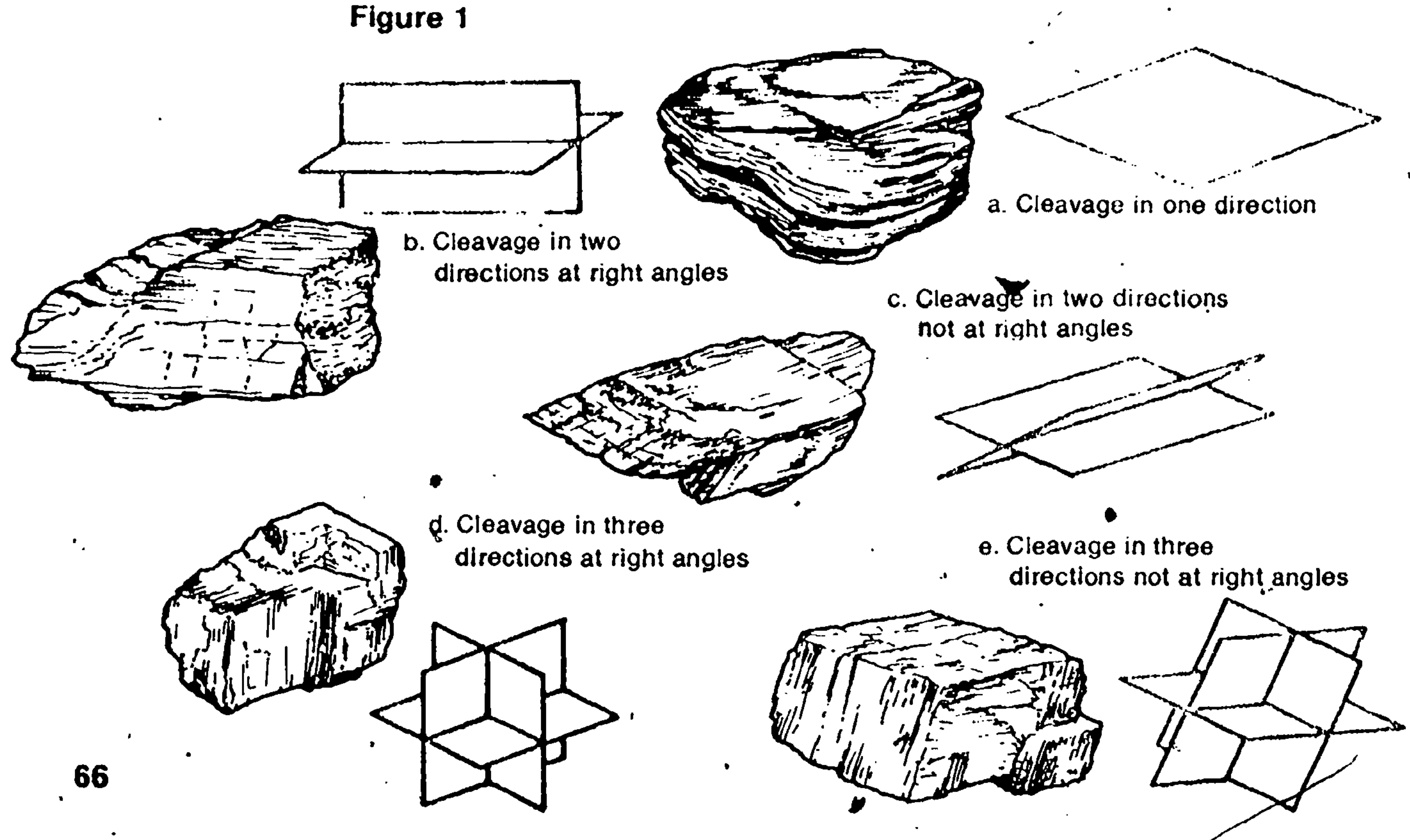
**ACTIVITY 2.** Hold the sample in your hand with the fresh surface up at about eye level. Now rotate the sample until you see a flash of light. Cleavage surfaces will flash in light as a mirror will if you hold it at the right angle to the sun.




Minerals can have several cleavage surfaces. The mineral you are now holding has one cleavage surface.

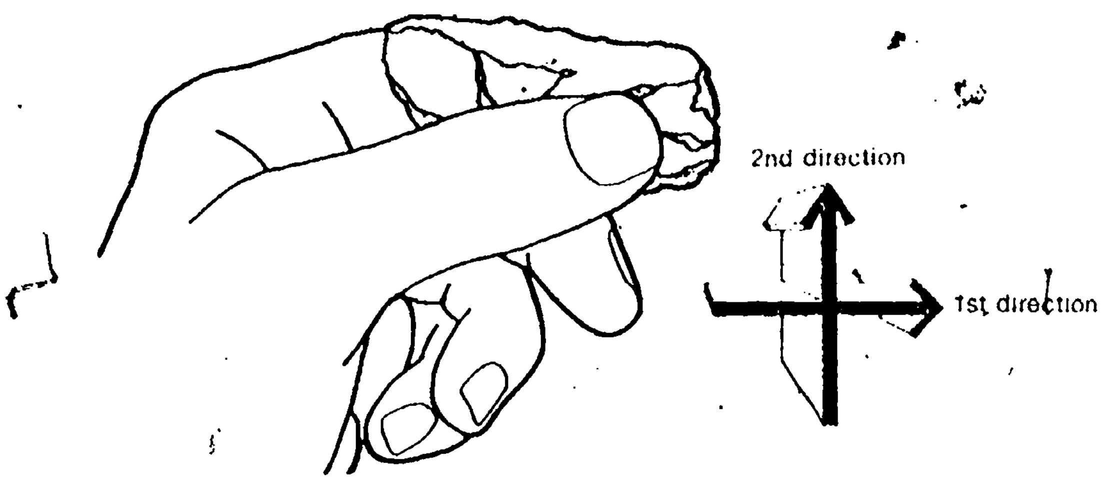
Examine the drawings in Figure 1. Cleavage surfaces are shown for samples having one, two, and three directions.

**Figure 1**

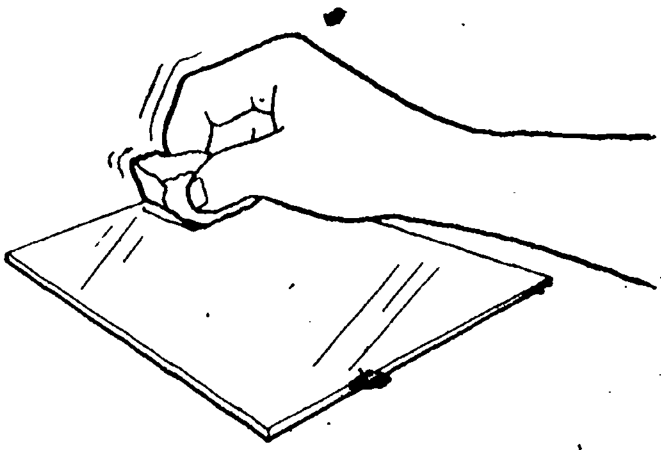


Remember that cleavage faces will flash when you rotate them in good light; other surfaces will not.

**ACTIVITY 3. Pick up mineral sample 23 (microcline feldspar). Hold the sample in good light and rotate, looking for flashes. You should be able to identify two cleavage directions, at about 90° to each other.**




**ACTIVITY 4. Lay the glass plate on the table. Holding mineral sample 23 (feldspar) in your hand, try to scratch the glass with the sample. To determine if you have scratched the glass, rub your moistened finger across the mark. If the mark comes off, then you have not scratched the glass. If the mark remains, look closely at it with a hand lens.**



If you can scratch the glass with the mineral, then we conclude that the mineral is harder than glass. If you cannot scratch the glass, then the mineral is softer than glass.

☐1. Is the mineral sample 23 harder, or softer, than glass?

You should have determined that mineral sample 23 is harder than glass.

Using the same mineral you tested in Activity 4, determine its luster. To do this, examine Figure 2, which shows two photos of minerals having either a metallic luster (look like a metal) or a nonmetallic luster (look glassy, greasy, waxy, pearly).

☐2. What kind of luster does mineral sample 23 have?

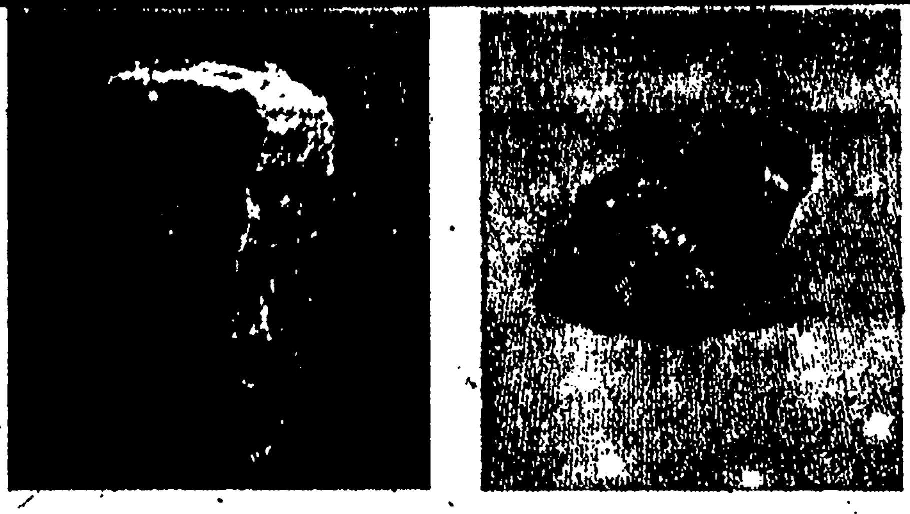


Figure 2

To identify a mineral, you will need to determine its luster (metallic or nonmetallic), its hardness (harder or softer than glass), and if it has cleavage surfaces. When you determine these three properties, you should then refer to the mineral classification chart on this page and the next page.

Identify each of the samples in the mineral identification key by following the procedure above.

Mineral Classification Chart

| | | | Special Properties | Name |
|---|---|---|---|---|
| Nonmetallic luster | Harder than glass | Cleavage | 2 directions of cleavage; pink, white | Microcline feldspar |
| | | | 2 directions of cleavage; white, blue-gray, striations (lines) on some cleavage planes | Plagioclase feldspar |
| | | No cleavage | Red, brown, or yellow | Garnet |
| | | | Olivine green; commonly in small glassy grains | Olivine |
| | | | Transparent, milky-white | Quartz |
| | Softer than glass | Cleavage | Brown to black; perfect cleavage producing thin elastic sheets | Biotite mica |
| | | | 3 cleavage directions—surfaces look like this ▱; colorless, white; effervesces in HCl | Calcite |
| | | | Perfect cleavage, producing thin elastic sheets | Muscovite mica |
| | | | Dark-green to black; 2 cleavage directions | Hornblende and Augite |

| | | | | |
|---|---|---|---|---|
| Metallic luster | Harder than glass | | | |
| | Softer than glass | Cleavage | Heavy; silver-gray color; little cubes | Galena |
| | | No cleavage | Black | Hematite |

# 12 How Rocks Change from One Kind to Another

The earth's crust is in constant change. Whether you examine rock in the mountains, the midlands, or the shorelands, you see the same cycle of change. Figure 1, on the following page, is a simplified diagram of the rock cycle. With it, you should be able to predict how one kind of rock can change into another kind.

As a starting point for making predictions from the diagram, consider the molten rock coming from a volcano. This lava was pushed upward and exposed to weathering. Any rocks exposed to wind, water, and changing temperature will be broken down and carried away as sediments, which may then be deposited in a lower region. Constant wearing away and deposition of more sediments will bury the first sediments to arrive.

In time, the buried sediments become hardened to form

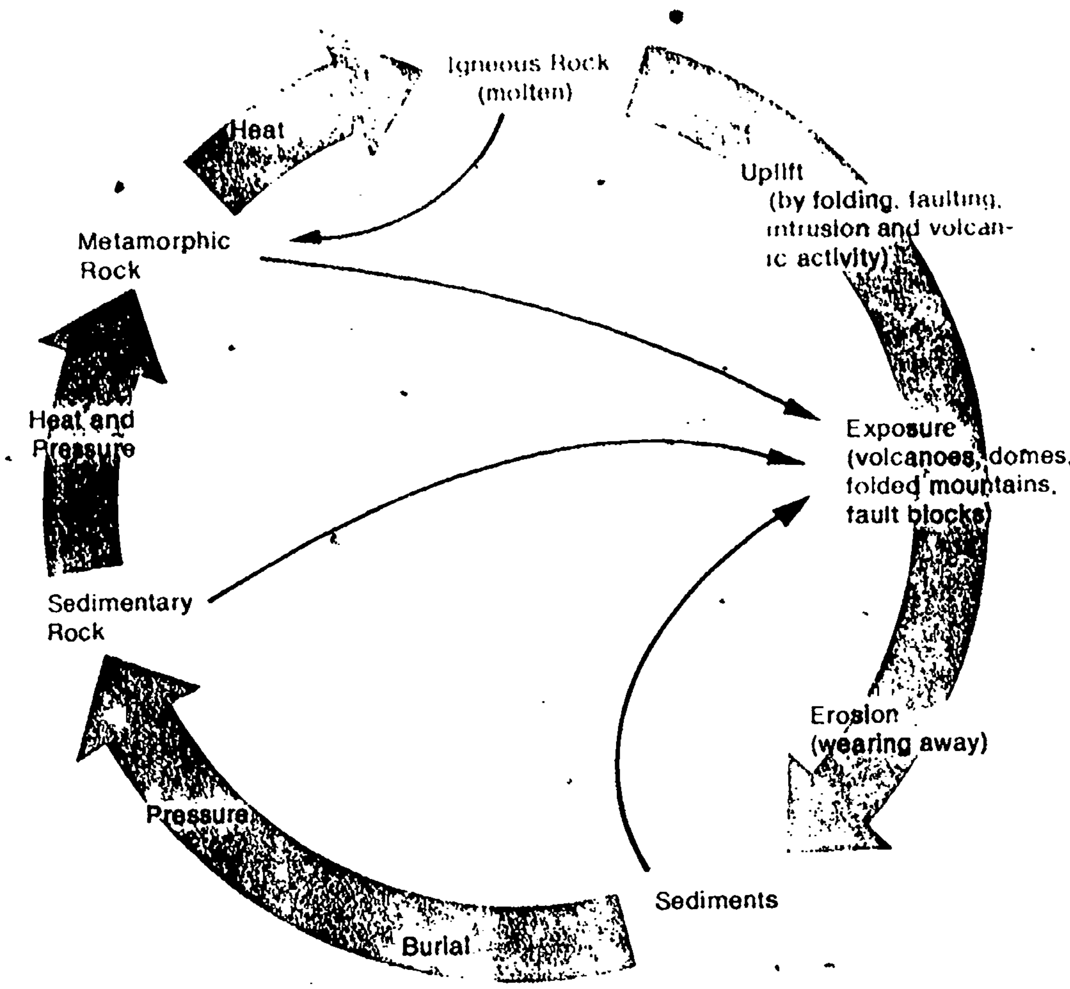



Figure 1

sedimentary rock. With added pressure and heat, the sedimentary rock may change to metamorphic rock. The metamorphic rock can melt and be pushed into or onto overlying sediments as igneous rock. This completes the cycle for this case, since this rock has gone through a whole cycle from igneous rock to igneous rock.

CLUSTER B
(Resources 13–16)

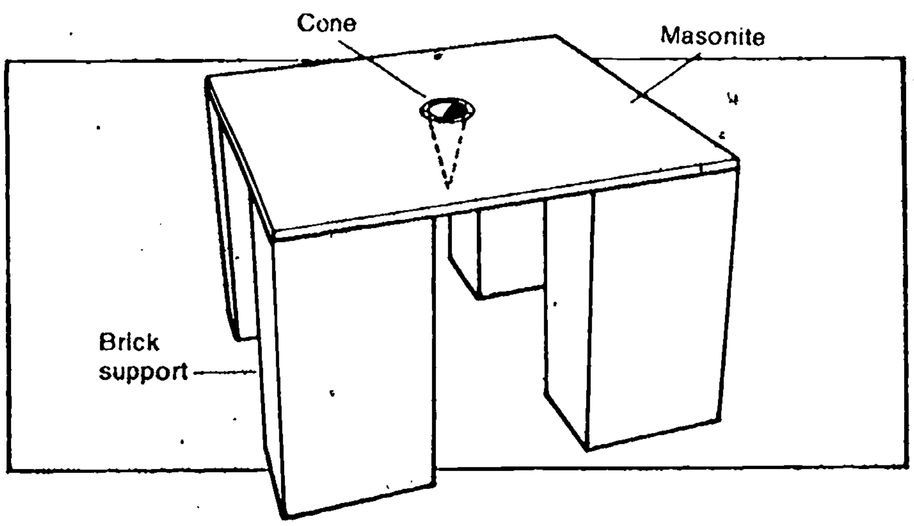
# 13 Making a Volcano

Caution *Do this resource only after obtaining your teacher's permission!*

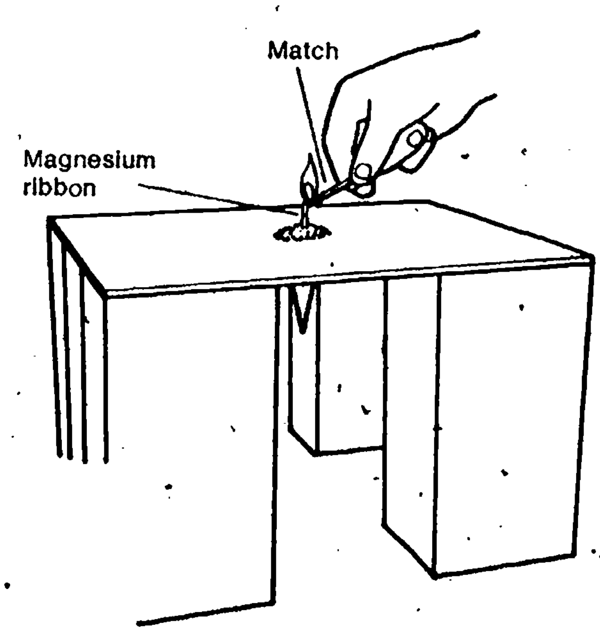
During a volcanic eruption, molten rock and gases come to the surface of the earth. In some cases the eruption is very violent, sending molten rock several hundred feet into the air, while in other volcanoes hot rock pours slowly out of the vent. In this resource we will use a simple model of a volcano to study its behavior when it erupts. Obtain the following materials from the supply area

1 copper cone
1 masonite board, 10" × 10"
2 strip magnesium ribbon, 2½" long
1 pair tweezers
30 cc ammonium dichromate, $(NH_4)_2Cr_2O_7$
4 bricks
Wooden matches

**ACTIVITY 1. With your partner, set up the apparatus as shown in the diagram and fill the cone to the top with the ammonium dichromate. Do not pack down. Using tweezers, insert unlighted 2½" piece of magnesium ribbon into cone, leaving 1" exposed above the dichromate.**



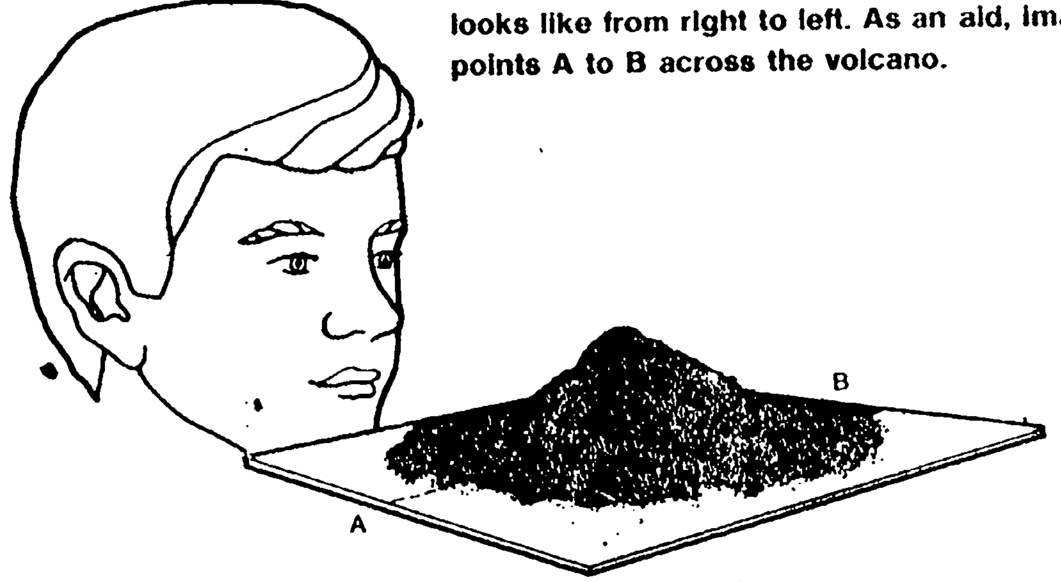

**Caution** *Keep your face and hair away from the cone. Avoid touching the powder.*




**ACTIVITY 2. In a dimly lighted room, ignite a match and carefully bring the match up to the ribbon and ignite it. Do not touch match to the dichromate. When ribbon ignites, stand back and observe what happens.**

Without disturbing the powder on the masonite board, refill the cone with ammonium dichromate, and insert a fresh piece of magnesium ribbon. Repeat Activity 2.

**ACTIVITY 3. At eye level with the masonite board, sketch a diagram in your Record Book, showing what the volcano looks like from right to left. As an aid, imagine walking from points A to B across the volcano.**




[ ]1. Does your sketch resemble any of the Mono craters you saw on page 38?

[ ]2. How do you believe Mono craters were formed?

# 14 Layered Igneous Rock

When molten rock flows out onto the earth's surface through cracks in the earth's crust, it forms a layer of lava that cools to a fine-grained crystalline rock. What happens to the molten rock trapped in the cracks?

Look at Figure 1, which shows a rock outcropping in a cliff in Glacier National Park, Montana. Notice the layers in this outcrop, also seen in many other rock outcrops illustrated in this book.

Figure 1

The dark layer near the top of the photograph is a different kind of rock from the rocks above and below it. It is a very hard, medium-grained crystalline rock containing several different minerals. The crystals in the middle of the layer are slightly larger in size than those near the top or the bottom of the layer.

If you have done the resource on identifying the main classes of rocks, you will recognize these properties as belonging to igneous rock—a rock layer formed by the cooling of molten rock. The rocks above and below the dark layer are sedimentary. Careful examination of the boundary with the dark rock shows a narrow band of baked, light-colored rock much harder than the rest of the sediment.

The dark layer of igneous rock is called a *sill*. It is thought to have been formed from the cooling of molten rock that forced its way through a crack formed at the zone of weakness much later than the sediments above and below it. (See Figure 2.)

When a series of layers of sedimentary rocks is divided by layers of igneous rocks, you sometimes can't tell what happened. You don't know whether the igneous layer is a lava flow with the sediments deposited above it later or

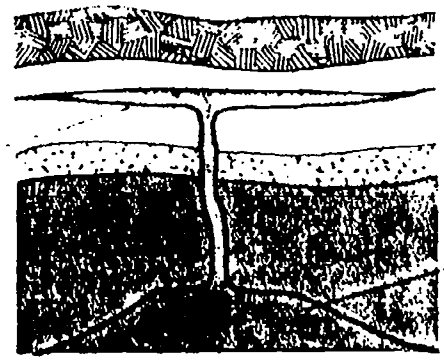



Figure 2

whether it is a sill that intruded between layers of sediment. If you look closely at the top and bottom of the igneous layer, however, usually you can decide fairly easily. Can you guess how? Remember that a sill is pushed into rocks and that a lava flow is poured out onto the surface.

The answer is fairly simple. A sill, being very hot when it was squeezed between layers, would change the rocks both above and below it. The heat would change (metamorphose) the sedimentary rocks on either side. However, when a lava flow forms, there is only rock beneath it as it pours out onto the surface. Therefore, only the lower boundary of the layer will be metamorphosed. By the time a rock layer is deposited on top of the igneous layer, it would be cold.

# 15 Molten Rock Beneath the Crust

What happens when molten rock cools within the earth's crust? That's what you will discover as you do this resource. You will make a clay model to represent several igneous rock features that form when molten rock cools while still within the crust of the earth.

Figure 1 shows a slab of igneous rock (a dike) that cuts across layers of sedimentary rock. Which was formed first, the igneous rock or the sedimentary rock?

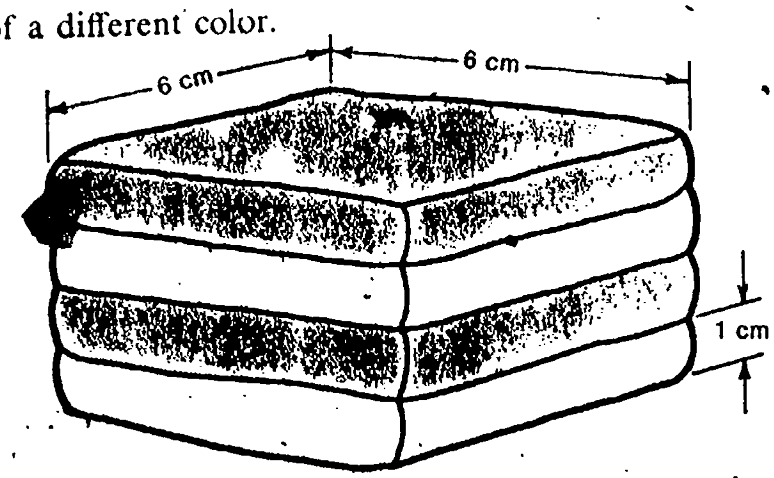
Figure 2 shows Moro Rock, a dome-shaped mound of solid granite. You might think this mountain of igneous rock was volcanic, but it has none of the features associated with volcanoes. The large crystals of which it is made are evidence

Figure 1

Figure 2

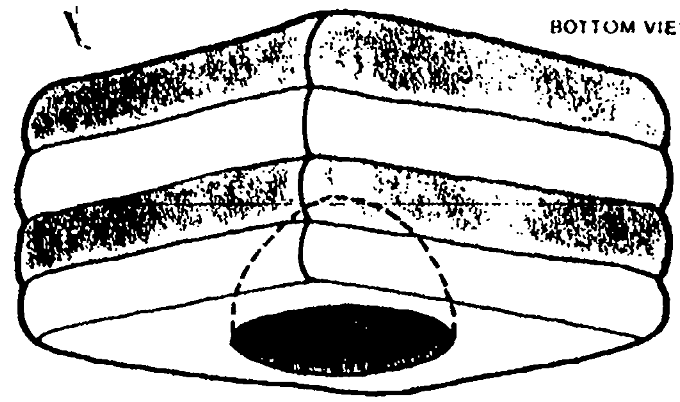
that it cooled very slowly—perhaps while buried in the crust. If so, how do dome mountains like this become surface features?

The following activities with modeling clay will help you understand the theories that have been developed to explain these features. You will need a knife and three lumps of clay, each of a different color.

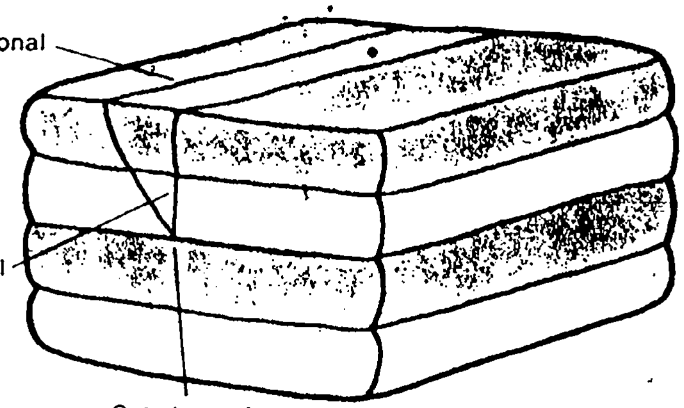


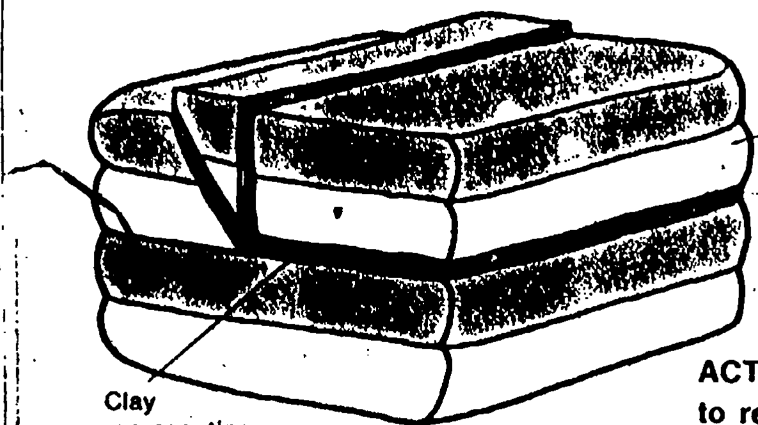

**ACTIVITY 1. Cut two strips of modeling clay of one color, 6 cm × 6 cm × 1 cm, and two strips the same size of another color. Make them into a block (alternating the colors as shown) to represent sedimentary beds in the earth's crust.**

ACTIVITY 2. Scoop out a dome-shaped hole in the bottom of the block so that you remove clay from the bottom two layers, but not the top two layers. Imagine that the rock has melted. Pack a different-colored clay (to represent molten rock) into the hole. Fill the hole completely.



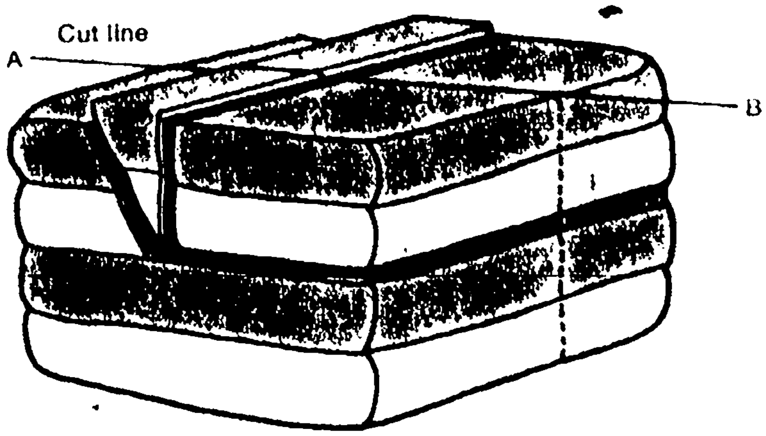

ACTIVITY 3. Use a knife to make two cuts into your block. Make one vertical cut across the middle, cutting down only as far as the second layer from the bottom. The other cut should be a diagonal cut, intersecting the first one as shown.




ACTIVITY 4. Take some more of the colored clay you used to represent the molten rock and flatten it into thin sheets about 2 mm thick. Open up the two top cuts you have made and push a thin piece into each one, joining them with the dome piece. Separate the second and third layers of the block, and slip in a sheet on top of the second layer. It will connect with both top cuts and the dome.

**ACTIVITY 5. Now cut your block in half along the line AB all the way to the bottom of the block.**




Look closely at the block's inner face. You have a model of molten rock intruding as a dome, as a sill (between the beds), and as dikes (across the beds). See Figure 3. Notice that intrusion of the sill has caused uplift.

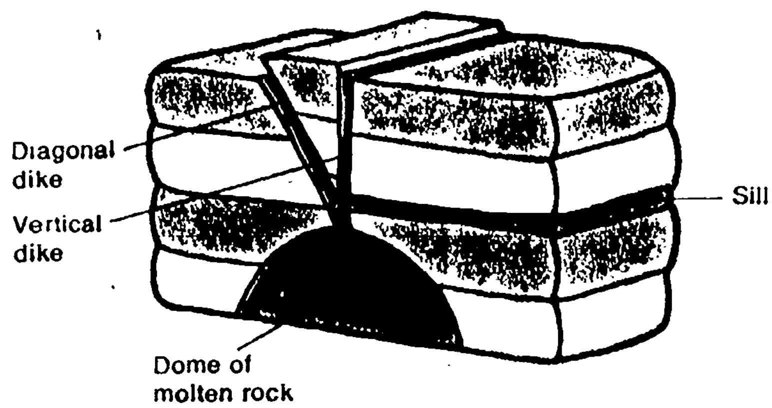



**Figure 3**

Now imagine that the molten rock has cooled and that steady erosion keeps removing the sediments, the dikes, and the sill.


**ACTIVITY 6. Take one half of the cut block and carefully remove all three top layers, the sills, and the dikes until you are left with the bottom layer and the dome.**

A big mass of molten rock like that in a dome would have cooled very slowly. It would have much larger crystals than the dikes or sill. Being such a big mass of hard igneous rock, it would be resistant to erosion.

# 16 Cone-shaped Mountains and Lava Flow

In the western part of the United States, you can find cone-shaped mountains, some of them with craters in the top. The cinder cone (Figure 1) at Lassen Volcanic National Park, California, is typical. The rock in these mountains is igneous, meaning that it has cooled from molten rock, which may be alternately layered with ash.

The shape and the rock type are evidence that these cone-shaped mountains were once volcanoes, but not all lava flows form cones. The Columbia plateau in the northwest United States is covered by layers of igneous rock over an area of 500,000 square kilometers, as shown in Figure 2.

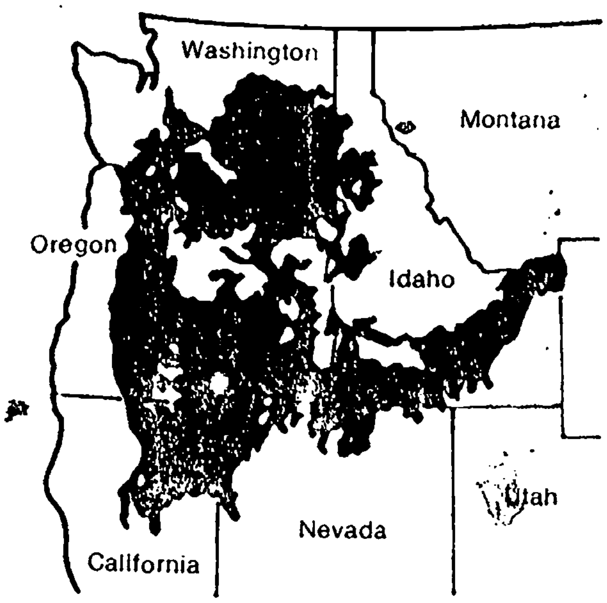



**Figure 2**

Although there are several cone-shaped mountains in this region, the lava coming from them could not have covered such a vast area. Instead, most of the lava is believed to have poured out of long cracks, called *fissures*, in the earth's crust. The cooled lava that poured out of these fissure volcanoes is a hard, fine-grained igneous rock. It has properties similar to those of the volcanic rock that is still being formed by the Kilauea and Mauna Loa volcanoes in Hawaii.

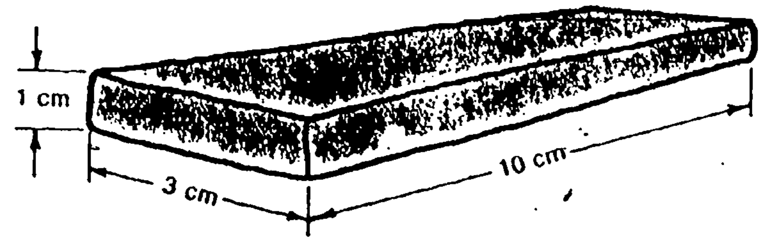
# 17 Wedge-shaped Mountains and Uplift by Faulting

CLUSTER C
(Resources 17–19)

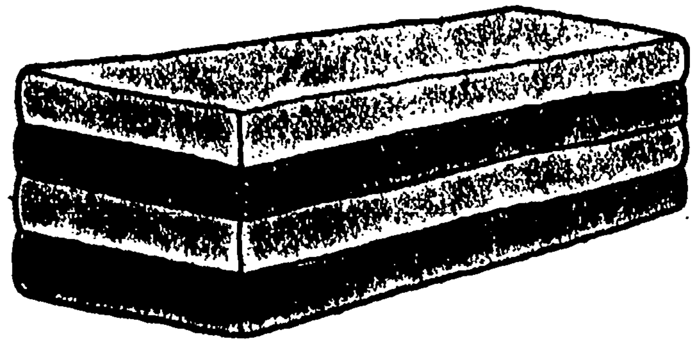
High in the Rocky Mountains, several thousand meters above sea level, are layered sedimentary rocks. What does evidence like this show? One explanation is that the crust of the earth must have been pushed upward over a vast period of geologic time.

In this resource, you will look at some models of how this uplift may have come about. Get two colors of modeling clay and a knife.

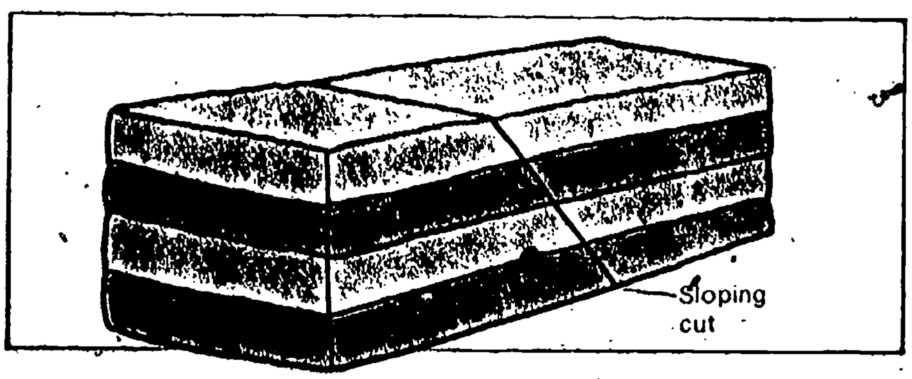
**ACTIVITY 1. From each colored piece of clay, cut two thin strips, each about 10 cm long, 3 cm wide, and 1 cm thick.**



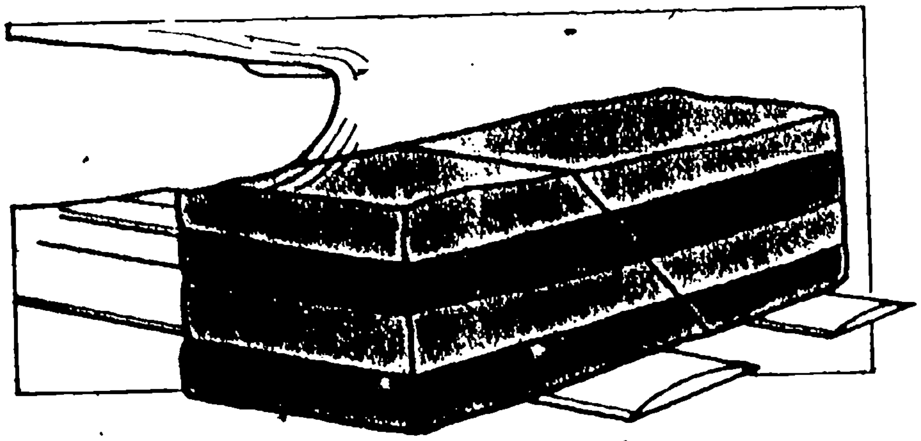

**ACTIVITY 2. Let each strip represent a layer of sediment deposited in water. Deposit one on top of the other, alternating the colors, to make a block.**



**ACTIVITY 3. Imagine that these layers represent a region where forces on the crust cause a crack or zone of weakness. Cut a sloping crack as shown.**



**ACTIVITY 4. After cutting, press the two pieces together again so that they just barely hold together. Support the block on two rulers. Press down on one end of the block and vibrate the block slightly as you push. Gently vibrate and push until the cut surfaces begin to slide apart.**



The line of slippage as shown in Figure 1 is called the *fault line.*

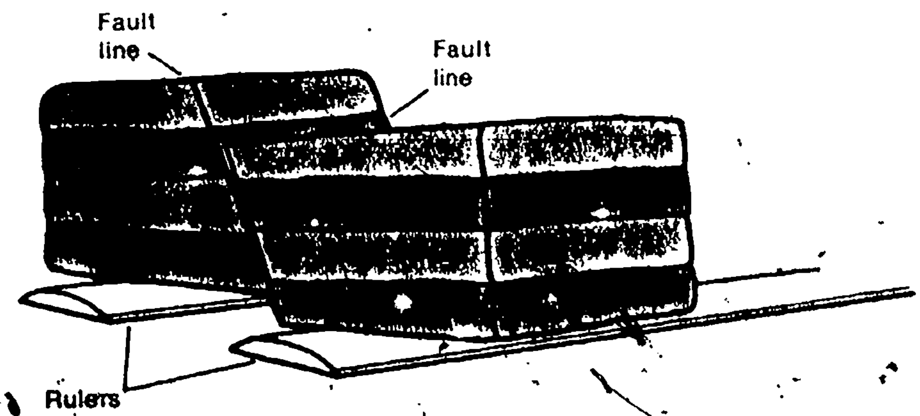



**Figure 1**

If you were careful in following directions, your block should now look like the sketch in Figure 1. Compare your clay model with Figure 2. Can you identify the fault line in this picture?

Two conditions are necessary for this theory to explain mountains like those in Figure 2. There must be a zone of weakness in the rocks, and there must be a strong downward force some distance away to cause a tilting of the block.

Figure 2

Figure 3 shows a profile of the Sierra Nevada in California to indicate how faults cause mountain uplift there.

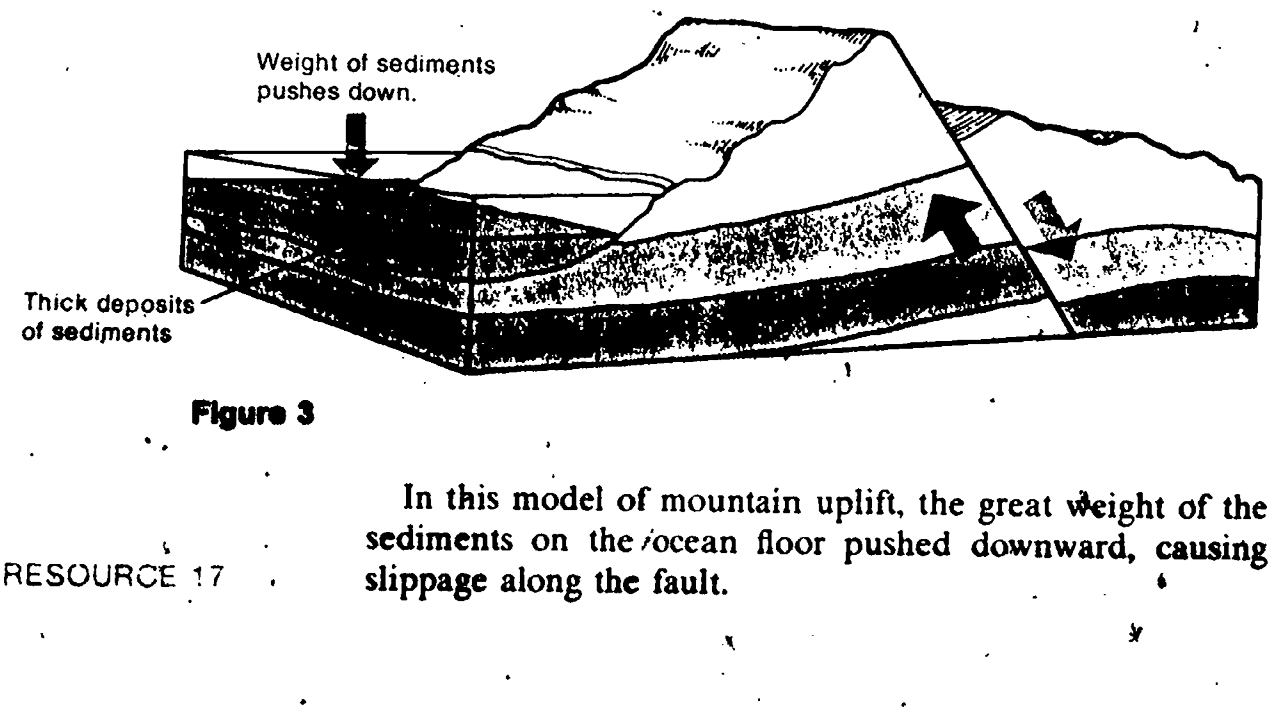


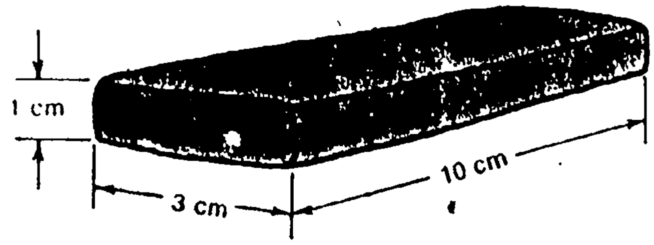

Figure 3

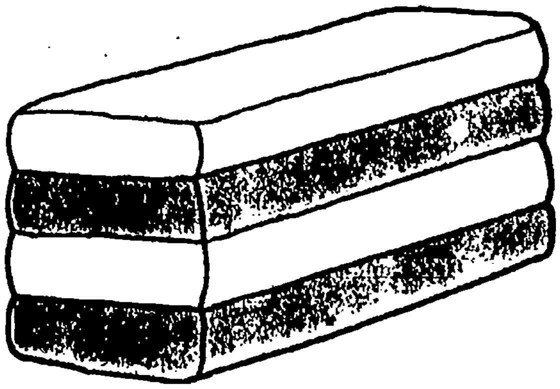
In this model of mountain uplift, the great weight of the sediments on the ocean floor pushed downward, causing slippage along the fault.

# 18 Uplift of Mountains Due to Folding

One theory to explain how the crust is pushed up to form mountains is based on the continental drift model for the earth's crust. According to this model, the collision of crustal plates causes pressure that results in a folding of the crust. To make a model that explains layered and folded features of the crust, you will need two colors of modeling clay.

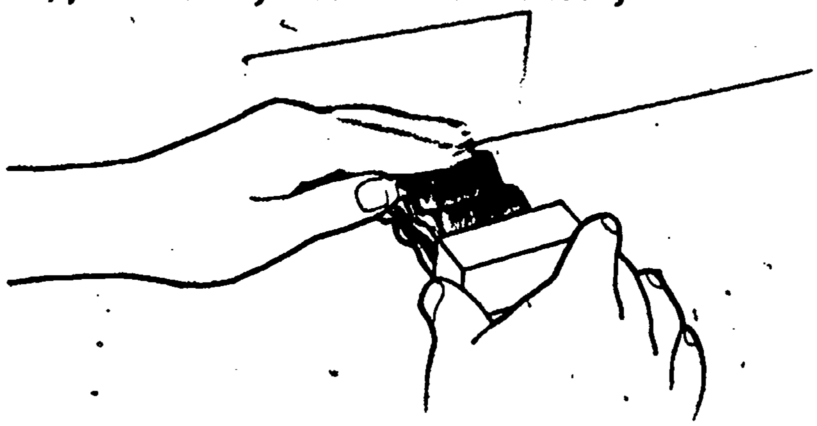
**ACTIVITY 1. Flatten or cut the clay into strips 1 cm by 3 cm by 10 cm. Make two strips of each color.**



**ACTIVITY 2. Stack the strips, alternating the colors.**

**ACTIVITY 3. Place the narrow end of the clay block against the wall, protecting the wall with a piece of paper. Using a block of wood at the opposite end and, steadying it with one hand, push the clay block hard and steadily.**



Look carefully at the side of the clay block. The layers represent beds of sediments. The dips represent valleys and the humps mountains.

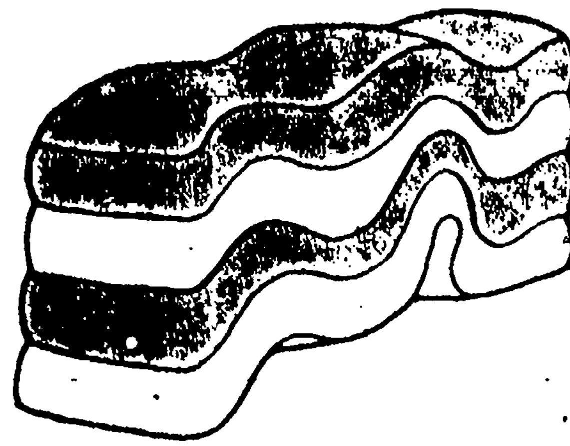


**Figure 1**

When you look at the earth, you cannot always see the folding this clearly because a side view is not always exposed. But sometimes there is other evidence of folding.

**ACTIVITY 4. Slice off the top one fourth of your clay block. Then look down at the top of it.**

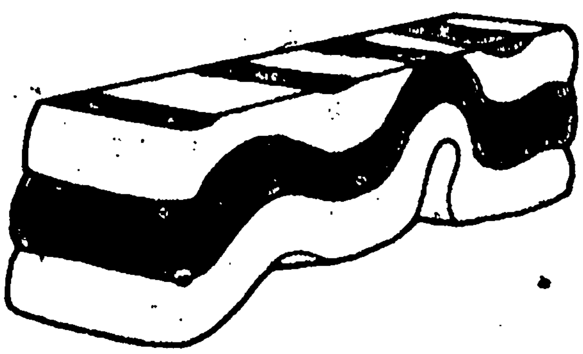
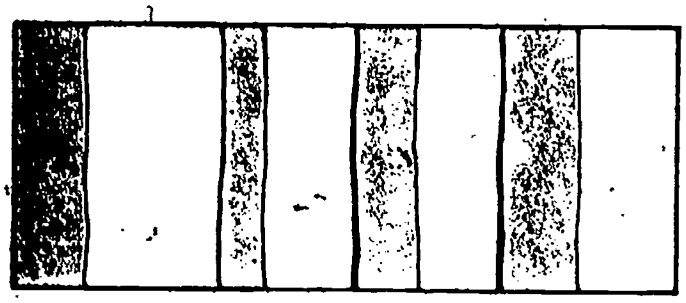


**Figure 2**

This newly revealed surface represents a section of country where erosion has removed the top part of the folding. As you can see in Figure 2, removing the top section of the crust shows the strips or bands formed by the folded layers.



Top view

You can recognize where bed 4 on your modeling clay block repeats itself on the top easily enough. However, when folded rock is exposed in several places miles apart on the surface of the earth, the job is not easy. A geologist has to identify the properties of the rocks. He must look at the way they dip into the earth and see what rocks occur next to one another.

The Appalachian region of the United States has many folds. Figure 3 shows a situation very much like the one that

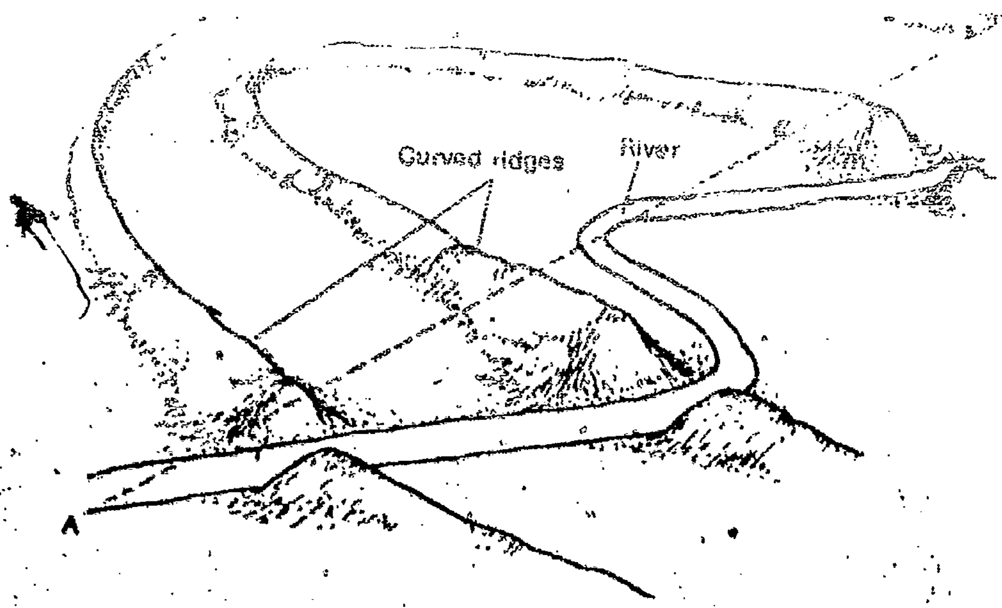



Figure 3

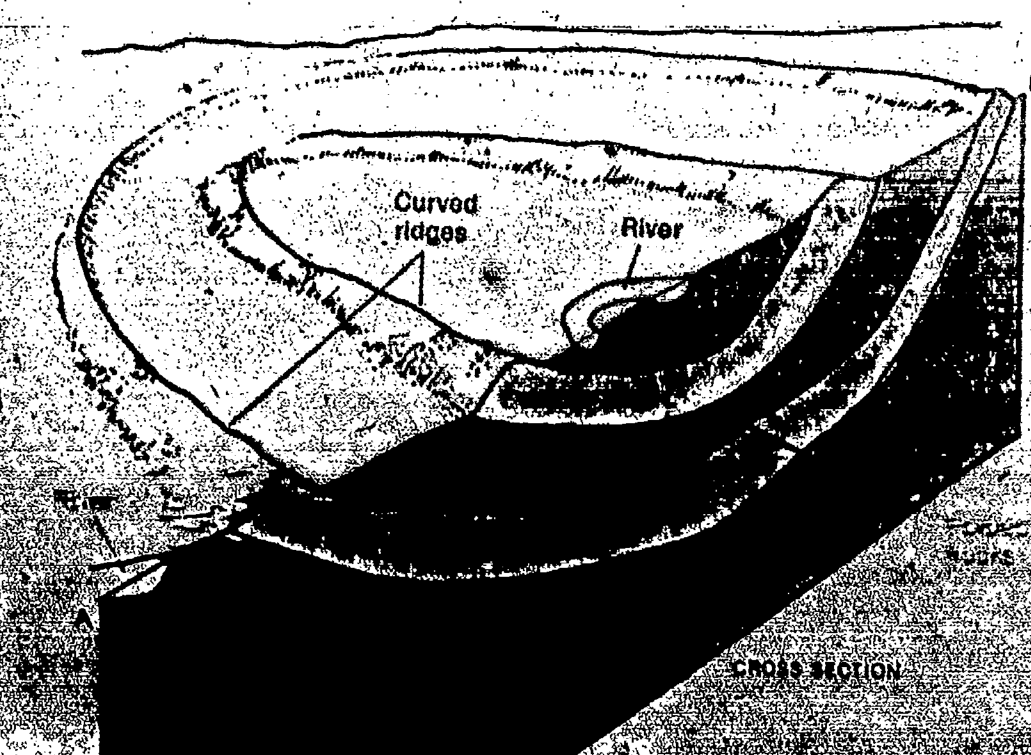



Figure 4

The photograph in Figure 5 shows actual folds in a railway cutting at Bakersville, North Carolina. These folds are much smaller than the Cove Mountain folding.

Figure 6

# 19 Old and Young Mountains

Suppose someone asked you which of the two mountains shown in Figures 1 and 2 is older. Although this is a very complex question, it is possible to give a general answer. This resource deals with the way to do this.

The problem in determining the age of a mountain is that two quite different sets of forces must be considered. At the same time that mountains are being pushed up from below, they are being worn down from above by water, wind, and ice. What you see as you look at a mountain is the result of both of these sets of forces.

Figure 1

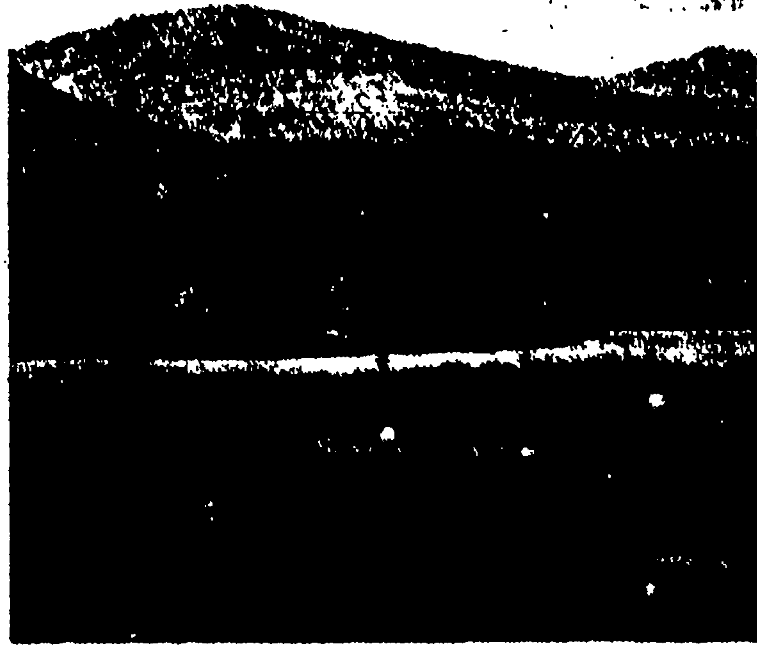


Figure 2

If the uplift has been quite a bit greater than the wearing away, you should expect high peaks, steep mountain sides, deep narrow valleys, and swiftly flowing streams (Figure 1). You might think of such mountains as "young." The mountains shown in Figure 1 began "growing" about 70 million years ago and continue to be uplifted today.

On the other hand, if wearing away has exceeded uplift, or if uplift has stopped, you find rounded hills and broad valleys (Figure 2). These are "old" mountains. The ones shown in Figure 2 are believed to have stopped "growing" about 230 million years ago.

# 20 Snow to Ice

CLUSTER D
(Resources 20–23)

This resource deals with the process by which snow turns into glacial ice (Figure 1).

When snowflakes are examined closely, they are seen always to be six-sided (hexagonal). Because no two snowflakes appear the same, there are millions and millions of variations of this hexagonal form. In spite of their variety, however, all snowflakes are quite delicate with lots of open space. For this reason, freshly fallen snow tends to be rather loose, light in weight, and not hard like ice.

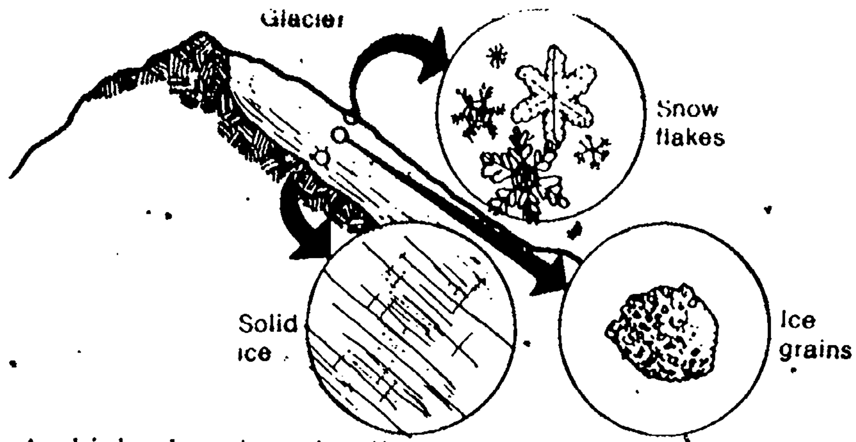



Figure 1

At high elevations in the mountains, snowfall often exceeds the rate of melting. This results in peaks that remain snow covered the year around. As snow accumulation increases, there is greater and greater pressure exerted on the snowflakes at the bottom. In time, the flakes lose their delicate structure and become loosely packed ice grains. This process may take approximately a year, depending upon the weather.

With further packing and the addition of water from melting snow, the granular ice may recrystallize and gradually turn to solid ice. At a depth of about 15 meters, ice particles over a centimeter across are common. At a depth of about 30 meters, the pressure is great enough to cause the particles to lose their form and fuse into solid ice. In cold climates, this change from snow to granular ice and, finally, to solid ice can take up to 300 years.

# 21 The Size and Movement of Glaciers

Measurements show clearly that the lower edges of glaciers may alternately move up or down the sides of mountains. Nisqually Glacier, on the side of Washington's Mount Rainier, moved back more than 1,200 meters between 1857 and 1944. On the other hand, the Black Rapids Glacier in Alaska moved forward almost five kilometers during five months in 1936. What causes glaciers to retreat and advance? That's what this resource is about.

Let's begin by examining what happens at the head and foot of a typical glacier. Notice that the head of the glacier in Figure 1 is well up the mountain slope, where cold temperatures keep snow present throughout the year. The fallen snows gradually turn to ice and add to the size of the glacier. At the same time, the foot of the glacier is being melted because of the higher temperatures lower down the mountainside. Gravity, helped by melting and refreezing of ice where it contacts rock, causes the ice to slide downward.

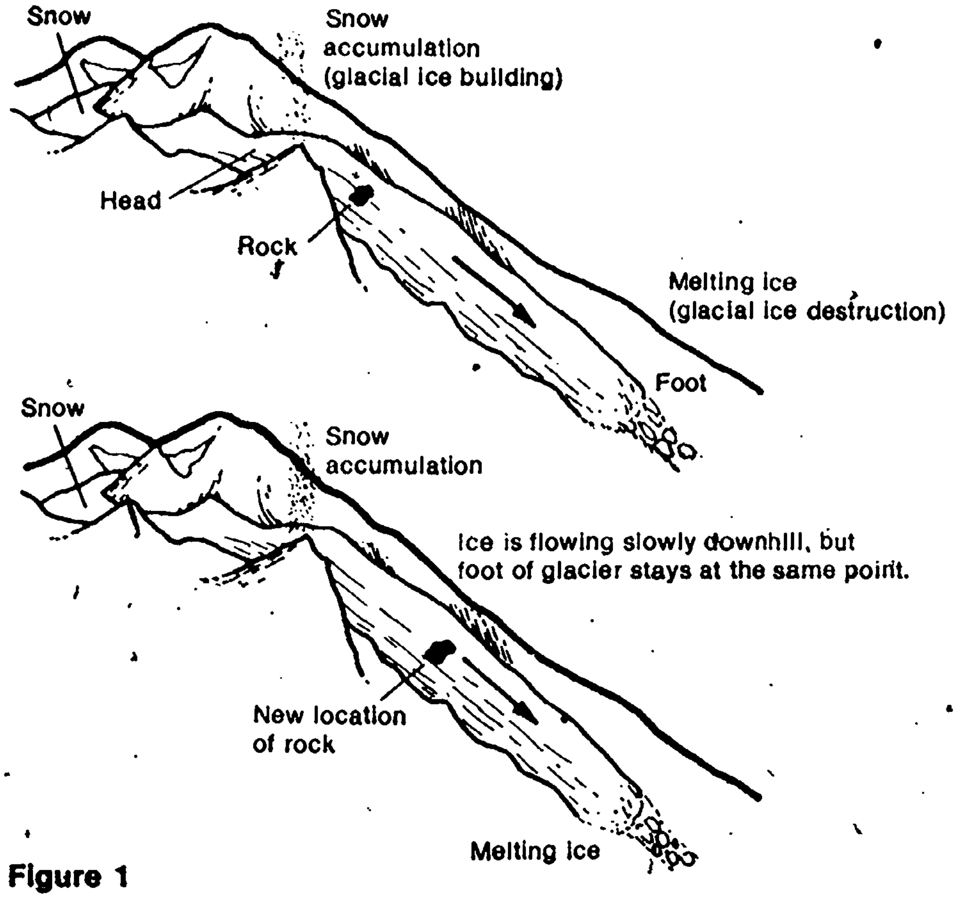



**Figure 1**

Often the creation of new ice at the head of a glacier equals the rate of melting at the foot. In this case, although ice gradually flows down the hill, the foot of the glacier remains at about the same point.

But at other times, either the rate of melting or the rate of ice buildup increases with no change in the other. Under these conditions, the foot of the glacier would move either up or down the mountainside (see Figure 2).

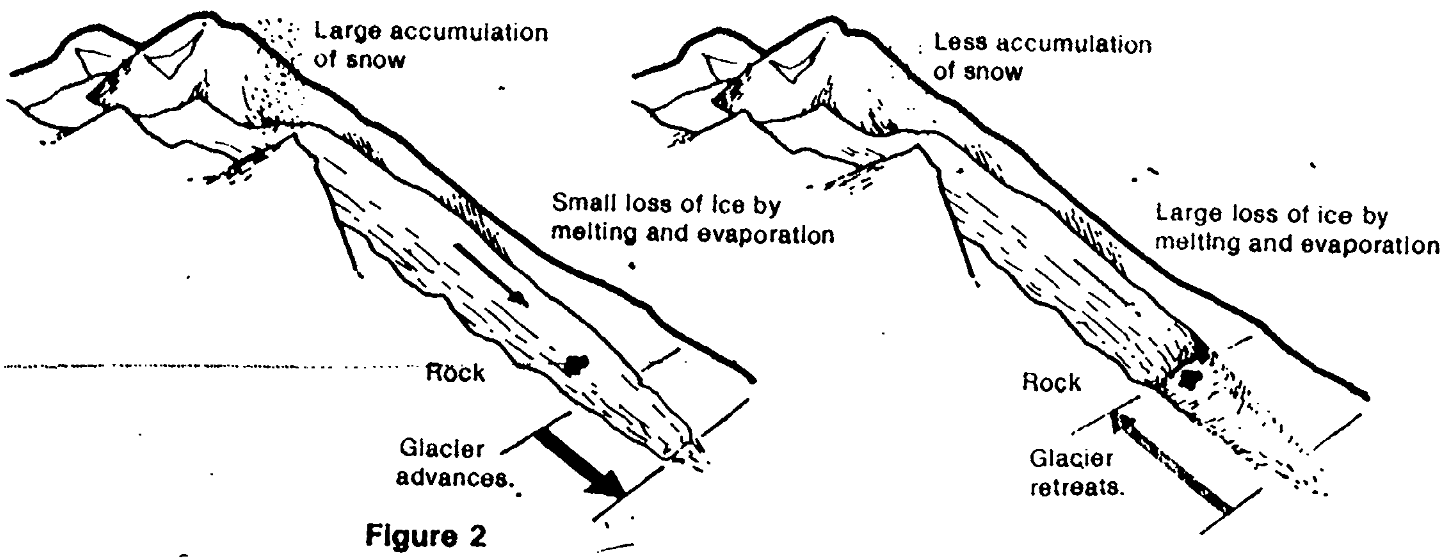



**Figure 2**

Causes: More snowfall or a drop in temperature results in less melting and evaporation.
Effect: Foot of glacier advances down the mountain.

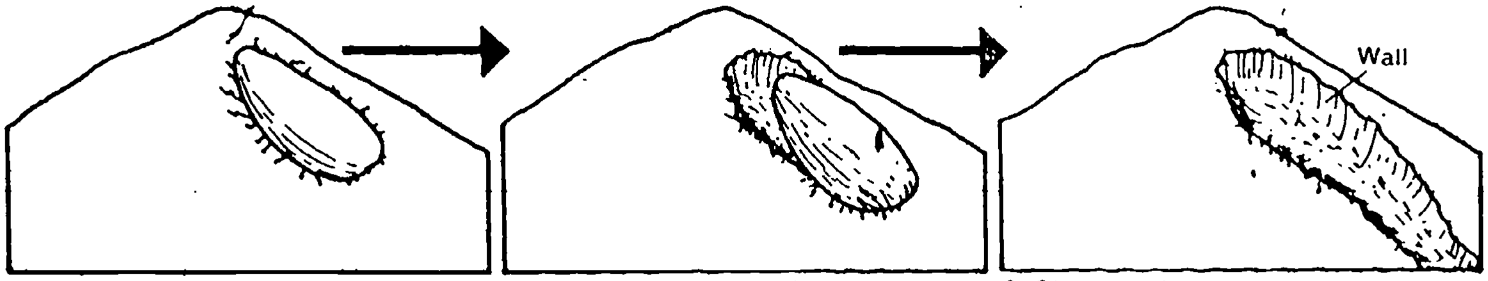
Causes: Less snowfall or higher temperature results in more melting and evaporation.
Effect: Foot of glacier retreats up the mountain.

# 22 Effects of Glacial Carving

As glaciers move, they grind, carve, and pluck at the rocky faces of mountains. This action produces many of the troughs, bowls, ridges, and sheer cliffs that compose some of the world's most beautiful scenery. This resource deals with the erosive action of glaciers upon mountains. It also identifies some of the common features that this kind of erosion produces.

As glaciers move down a mountainside, they often pull rocks away from the area in which they began. Over a period of time, this plucking forms a large bowl, or *cirque*, at the head of the glacier. As plucking continues, the cirque grows larger and deeper, often producing a wall many hundreds of meters high and a bowl equally deep. Melting of the glacier frequently turns the bowl of the cirque into a small lake called a *tarn*. Figure 1 diagrams the process by which cirques are formed. Figure 2 shows an actual cirque and tarn.

Figure 1




A. Snow piles up into glacier. Rocks under snow crack.

B. Glacier moves down the mountain carrying broken rocks.

C. Glacier melts, leaving a cirque.

Figure 2

Glacial plucking often produces several cirques on the same mountain. Sharp ridges and many-sided peaks called *horns* are two results of this process. Figure 3 diagrams the way these features are formed, and Figure 4 shows a typical example, the famous Matterhorn in Switzerland.

A glacier sometimes grinds at rock surfaces like a piece of steel wool or sandpaper. Look at Figures 5 and 6. You can almost see the glacier that once occupied these areas smoothing and polishing the rock surfaces shown.

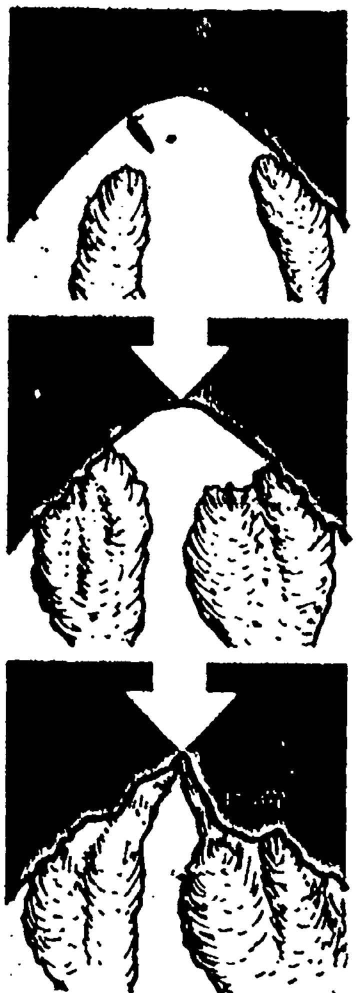


Figure 3

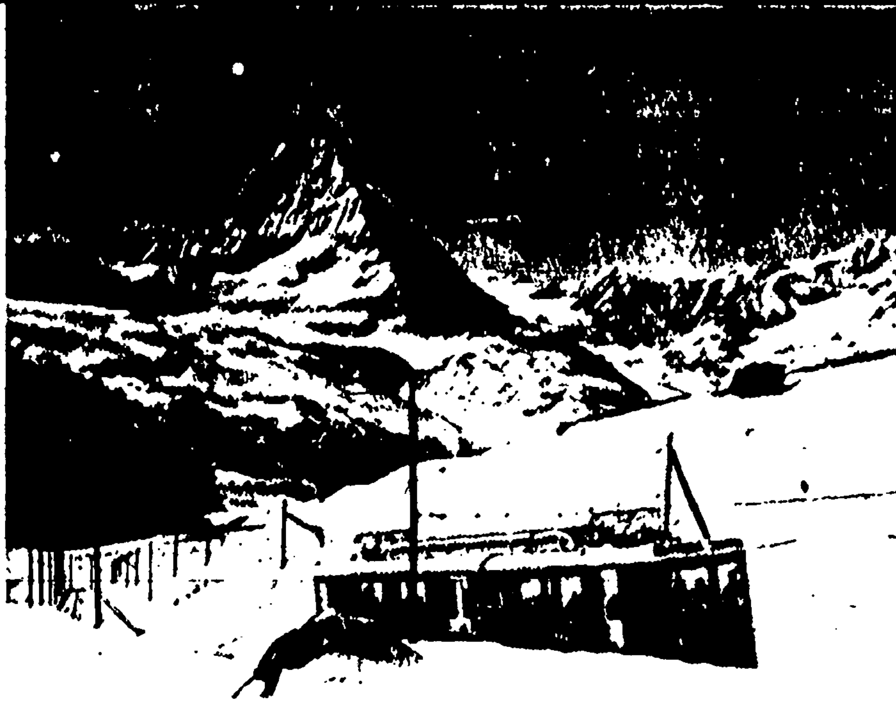


Figure 4

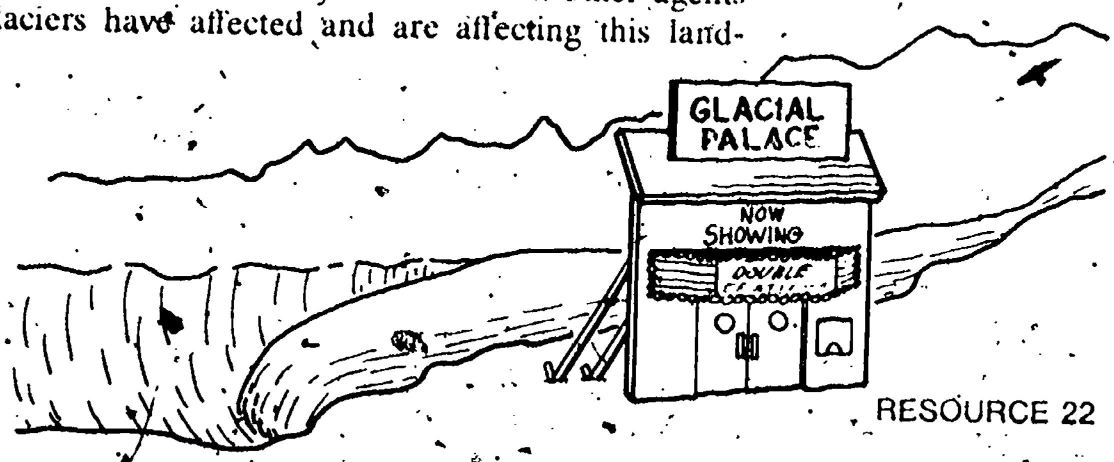
Figure 5

Figure 6

Perhaps the most important effect produced by moving glaciers is shown in Figure 7. This U-shaped valley is quite typical of the trough carved by glaciers. It stands in sharp contrast to the V-shaped canyons and gullies that are cut by moving water. (The next resource deals with the reasons for this difference.)

**Figure 7**

Figure 8 shows a number of the glacial features you've studied, all located in a relatively small area. How many additional glacial features can you find? What other agents besides glaciers have affected and are affecting this landscape?



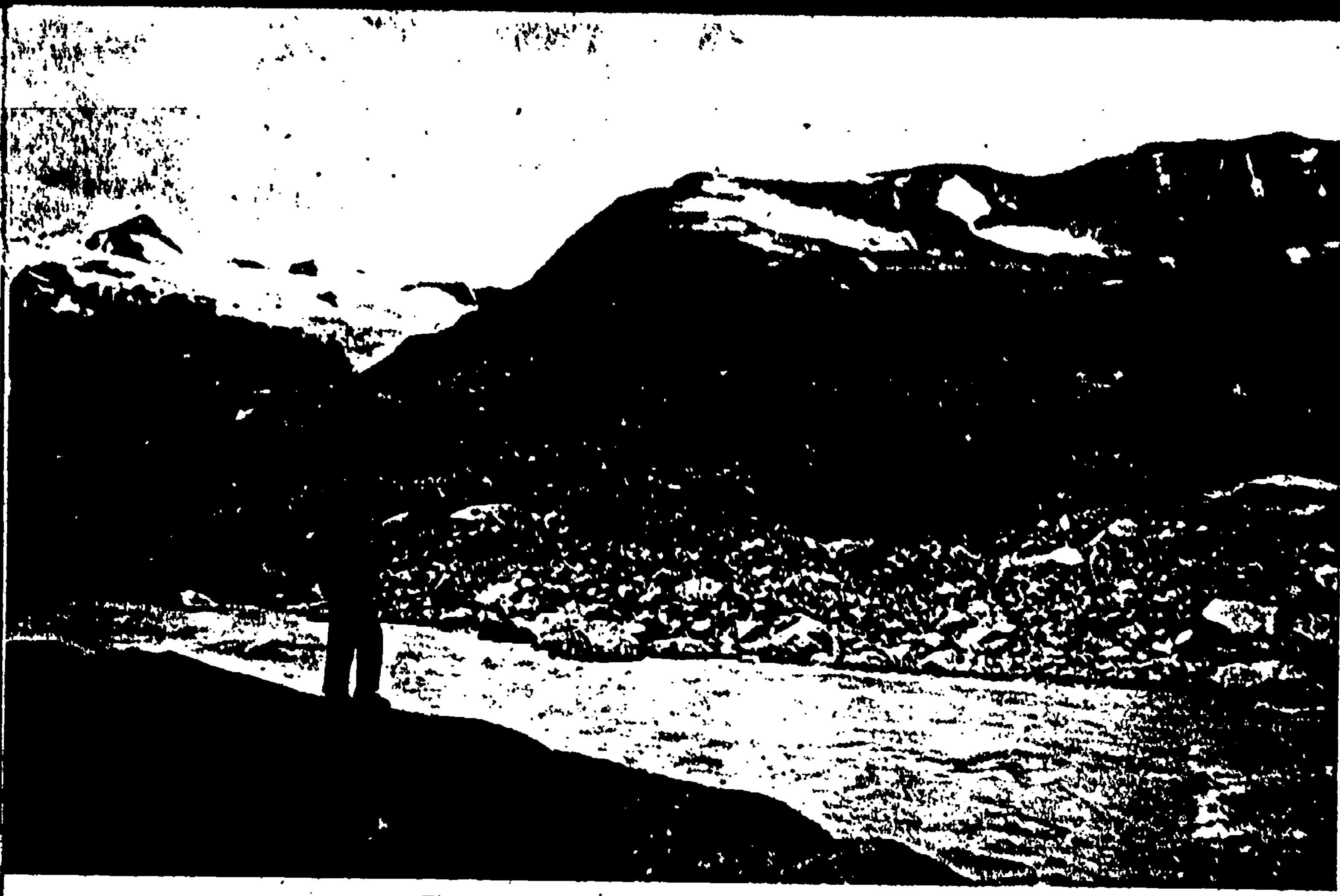


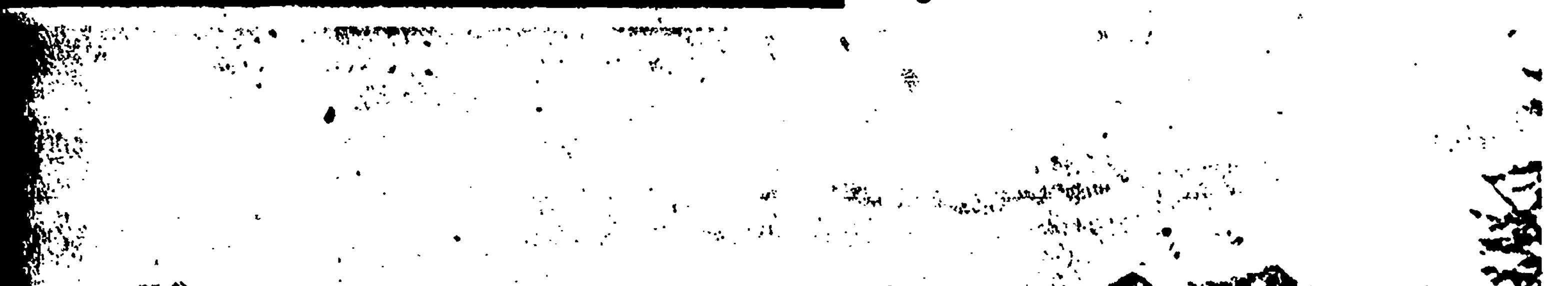
Figure 8

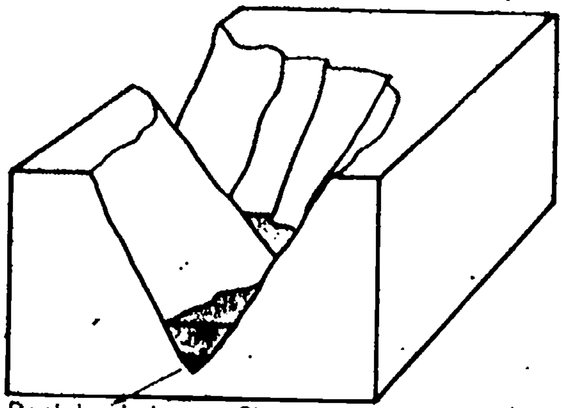
# 23 How Glaciers Form U-shaped Valleys and Hanging Valleys

One of the most prominent features of many glacial landscapes is the huge valleys. These valleys stand in sharp contrast to the valleys carved by rivers. Compare the shape of the typical river valley in Figure 1 with the shape of the typical old glacial valley in Figure 2. Figure 3 on page 96 is a diagrammatic sketch of these two kinds of valleys.

Figure 1

Figure 2





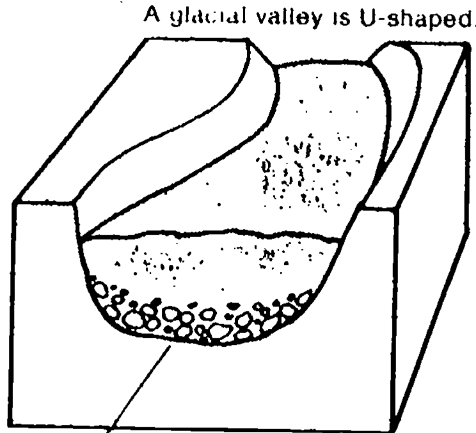




**Figure 3**

A fast-flowing mountain river rolls stones and pebbles along the stream bed, causing a grinding action. This digs the bed deeper along a narrow channel and cuts sharp bends.

When a glacier moves down the mountainside, it forms a huge, wide, slow-moving mass. Pebbles and boulders are embedded in the ice being dragged along. Instead of cutting downward like a saw cut, it grinds a wide, U-shaped path, which can only bend in long, smooth curves.

**Figure 4**

If you have access to a refrigerator, freeze a tray of ice with pebbles and stones in it. Then try pushing the ice through the sand-silt mixture in a stream table to compare it with stream action.

In Figure 4, you can see the wide masses of ice forming the big South Sawyer Glacier in Alaska and two tributary glaciers feeding into it. Imagine the huge load of rock debris this ice is dragging along the valley floor.

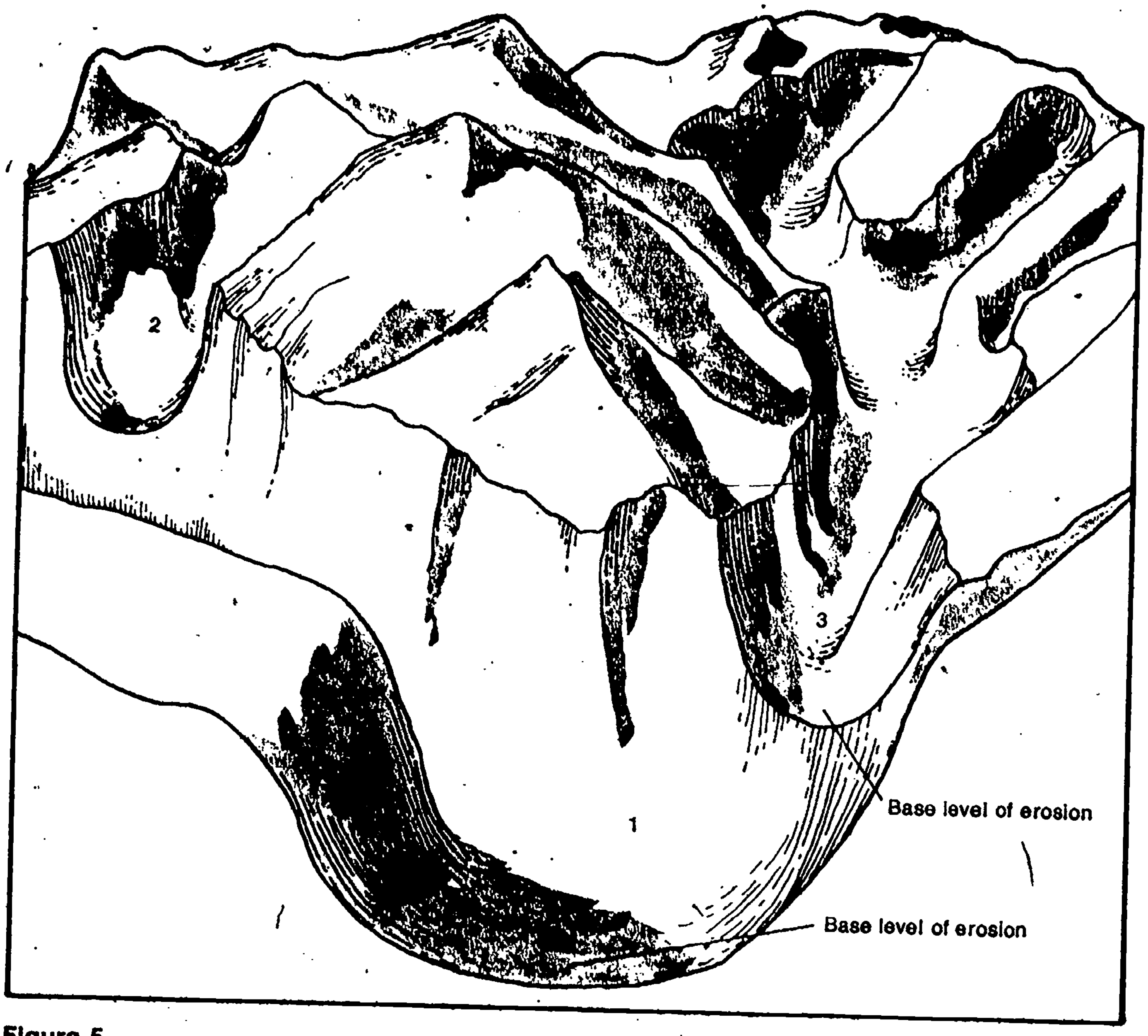


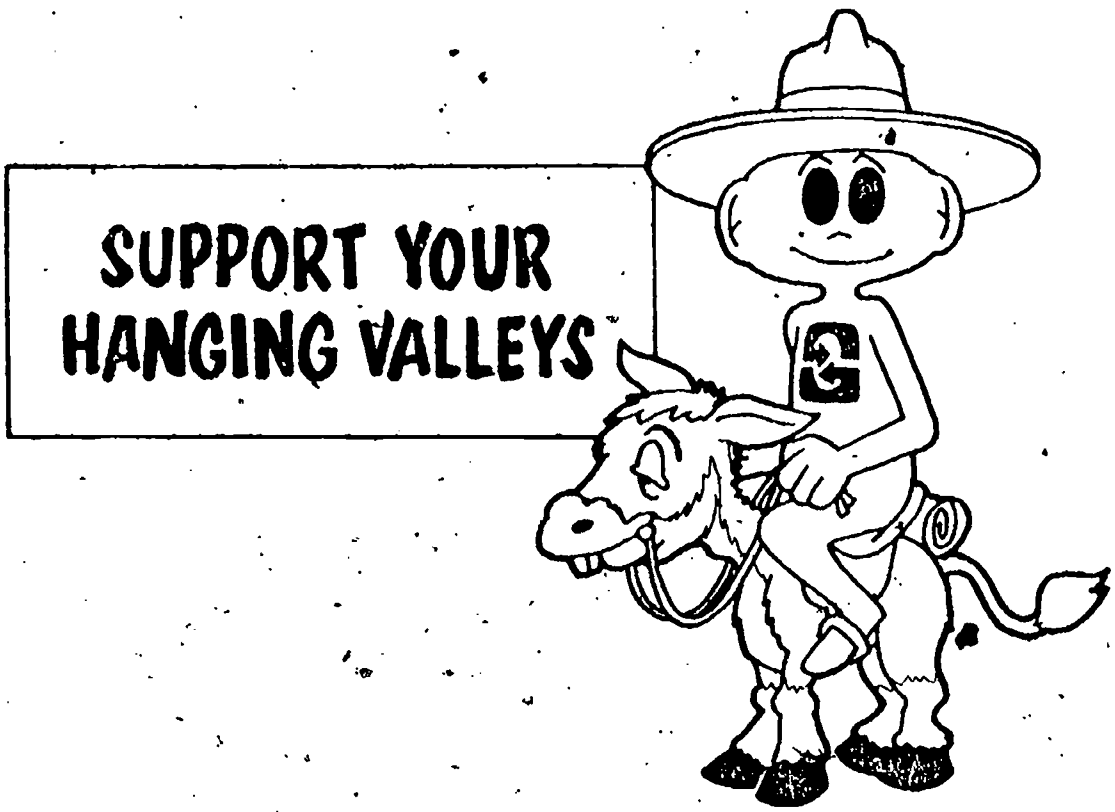

Figure 5

When a tributary river flows into another river, the base level of erosion is the bottom of the bigger river — both rivers meet at the same valley level. When a tributary glacier meets another glacier, the base level of each valley depends on how much ice it carries. A small glacier cuts a shallow valley, and a big glacier cuts a deep valley. The rock floor of a small glacial valley can be high up the wall of the big valley into which it flows. In old glaciated landscapes, these small tributary valleys can be seen as "hanging valleys."

Figure 5 shows how the landscape illustrated in Figure 4 could look in the future if the ice melts. The U-shaped valley (1) formed by the main glacier and the hanging valleys (2, 3) formed by the tributary glaciers have been labeled to help you compare the diagram with the photograph.

**Figure 6**

There are many spectacular hanging valleys in the United States. Yosemite National Park in the Sierra Nevada, California, is famous for its glacial valley landscape. Figure 6 shows a typical hanging valley in Yosemite. It is what remains from a small tributary glacier of the last ice age and can be seen at the right, high above the big U-shaped valley that was carved by the main glacier.



# The Midlands, A Pathway to the Sea

Chapter 3

The largest part of the United States does not have spectacular mountain peaks, crashing surf, or seacoast bathing beaches. Instead, it is covered by flat plains or gently rolling hills, which are cut through here and there by rivers that sometimes lie in fairly deep valleys. It is this midland area (Section B), between mountains and sea, that you will study in this chapter.

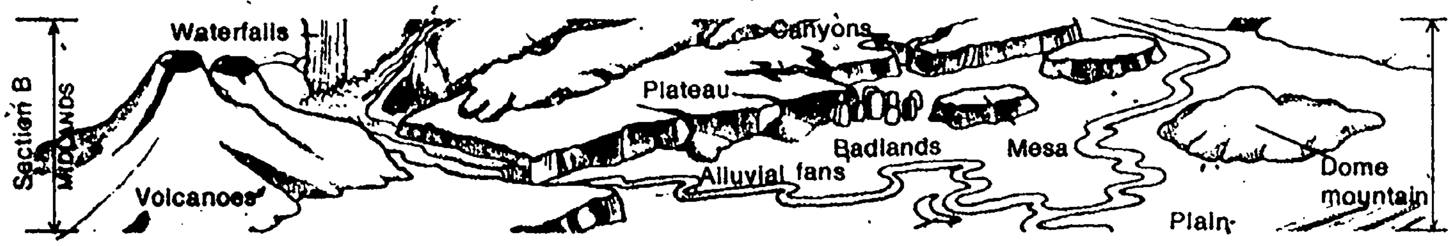



Figure 3-1

Figure 3-1 contains many of the important features of the midlands region. Features from many parts of the country have been combined into this one diagram. Figure 3-2 gives you some idea of how much land in the United States can be described as midlands.

Before going on, take a close look at the features shown in Figure 3-1. By the end of your study, you should be able to describe how the midland features were formed and to predict what the midlands might look like in the future.

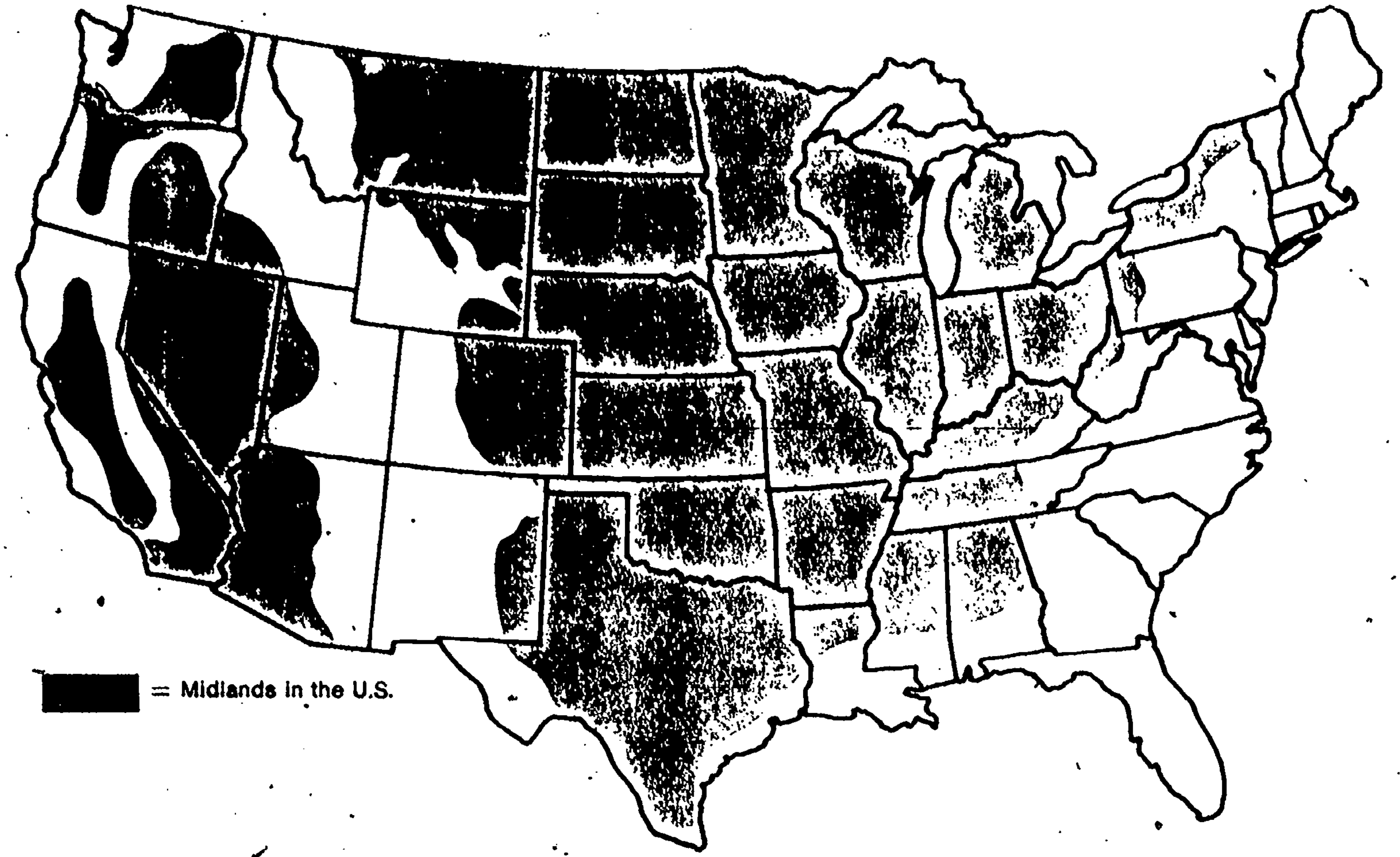



Figure 3-2

**Rocks in the midlands**

Many parts of the midlands are flat and contain rocks buried in the earth. Often, however, these rocks are exposed in riverbeds and roadcuts. Take a look at the layered rocks exposed in the roadcut in Figure 3-3. Layered rocks like these are found almost everywhere in the midlands.

Figure 3-3

□ 3-1. Based on what you learned in Chapter 2, how do you think this layered rock was formed, and what does its presence tell you about the geologic history of the area?

If you look back to Figure 2-4 (Chapter 2), you will find that the major portion of the midlands is composed of flat-lying rocks. In fact, the central portion of the United States is made up of sedimentary rocks that were formed in a marine environment. Fossil animals and plants that lived in the sea are found in rocks throughout the Midwest. But you will note on the map in Figure 2-4 that there are also igneous rocks and, in scattered locations, metamorphics.

The major agent shaping the midlands is the river. If you studied Volume 1 of ISCS, you learned about energy and discovered that you could describe energy as either potential or kinetic. Let's see how a river's kinetic (mechanical) energy is used to shape the midlands.

You know that when an object falls, it loses potential energy. At the same time, it picks up speed and gains kinetic energy. The water in a river that starts high in the mountains goes through a similar process on its way to the sea.

□ 3-2. When does a river have high kinetic energy and when does it have high potential energy?

Take a look at Figure 3-4. The river at the top of De Soto Falls in Alabama has kinetic energy of the sort just discussed. But it also has a great deal of potential energy because of its height—well above the base of the falls. As the water plunges over the falls, its kinetic energy increases.

At the same time, its potential energy decreases. Notice in Figure 3-5 that when the water reaches the bottom of the falls, it crashes into the rocks and slows down again.

□ 3-3. Locate on a map in Cluster A the source areas (areas where rivers begin) of the rivers that provide the kinetic energy to erode and shape the midlands. Why do they generally begin in these locations?

TO CLUSTER A

Figure 3-4

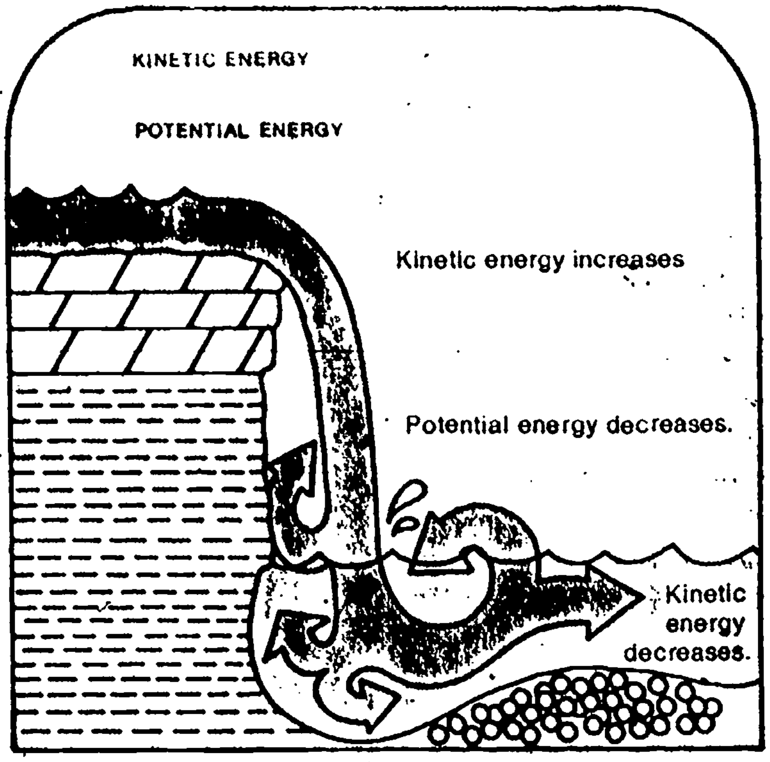



Figure 3-5

## The beginnings of a river

Many rivers begin in the mountains, sometimes from glaciers such as the one in Figure 3-6. Notice the stream braiding its way from the glacier. Notice also the kind of material through which the stream flows.

Figure 3-6

Rivers that begin in the mountains usually flow downhill in a torrent. The water in them is quite clear because the particles of rock being moved by the river are rather large. The lack of fine sand and silt prevents the stream from being muddy.

Figure 3-7


**The stream table**

In order to study the work of rivers in the classroom, it will be necessary for you to use a stream table. In order to solve many of the resource problems, you will have to set up an artificial stream, using the table.

One of the problems in interpreting the natural landscape is that many important variables act at the same time. The stream table will allow you to control some of the important variables that are uncontrollable in nature. For example, you'll be able to do such things as create a river, speed it up or slow it down, or make it flow through types of material that you select. These possibilities can help greatly in deciding how real rivers behave.

The standard setup is similar for all stream-table experiments. Take a careful look at Figure 3-8 and notice the parts that are used.

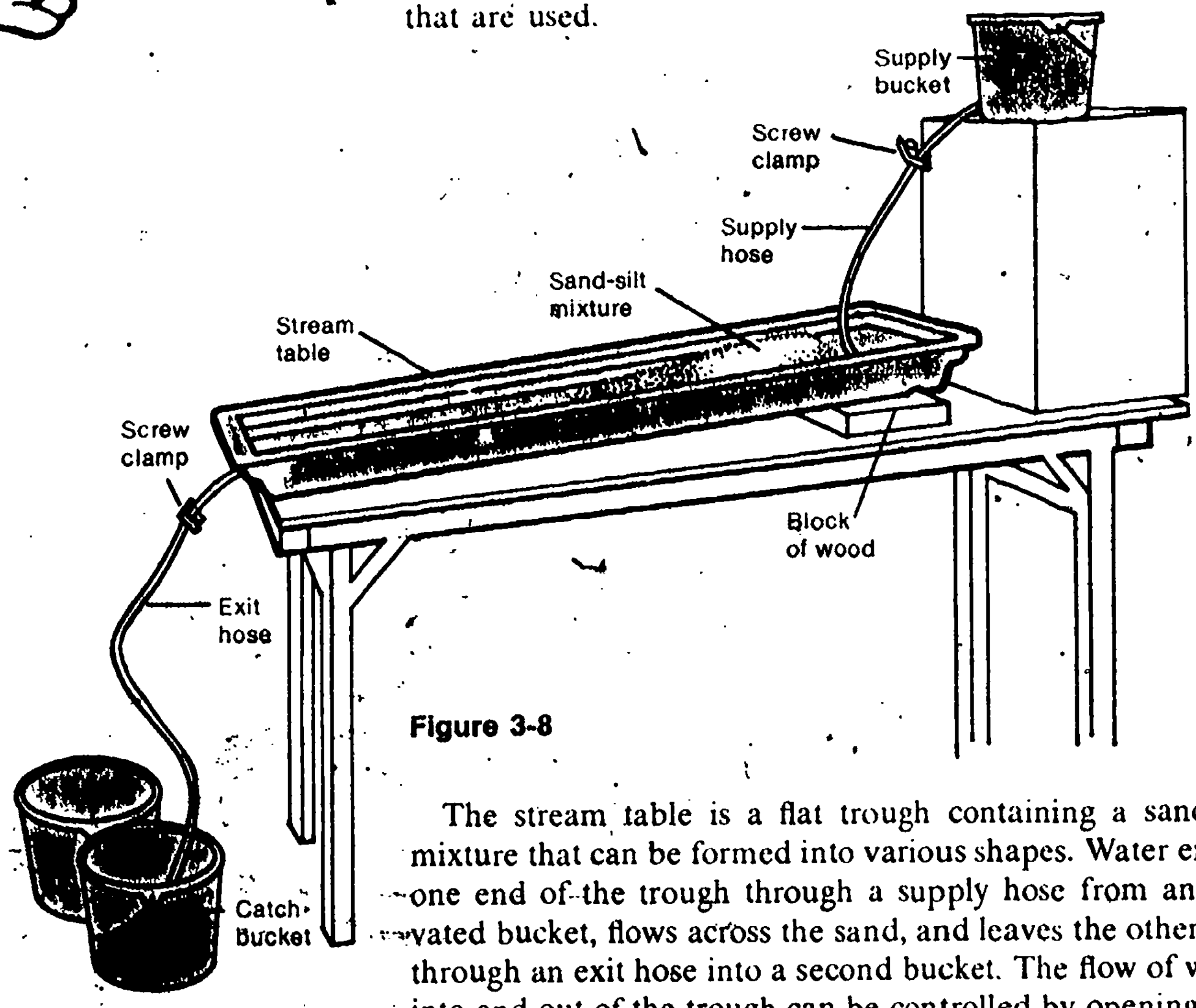



**Figure 3-8**

The stream table is a flat trough containing a sand-silt mixture that can be formed into various shapes. Water enters one end of the trough through a supply hose from an elevated bucket, flows across the sand, and leaves the other end through an exit hose into a second bucket. The flow of water into and out of the trough can be controlled by opening and closing screw clamps. The slope of the trough can be changed by moving a support (such as a brick or a wooden block) back and forth.

Here is a list of the variables your stream table will let you control for experiments. Set up a stream table and study them.

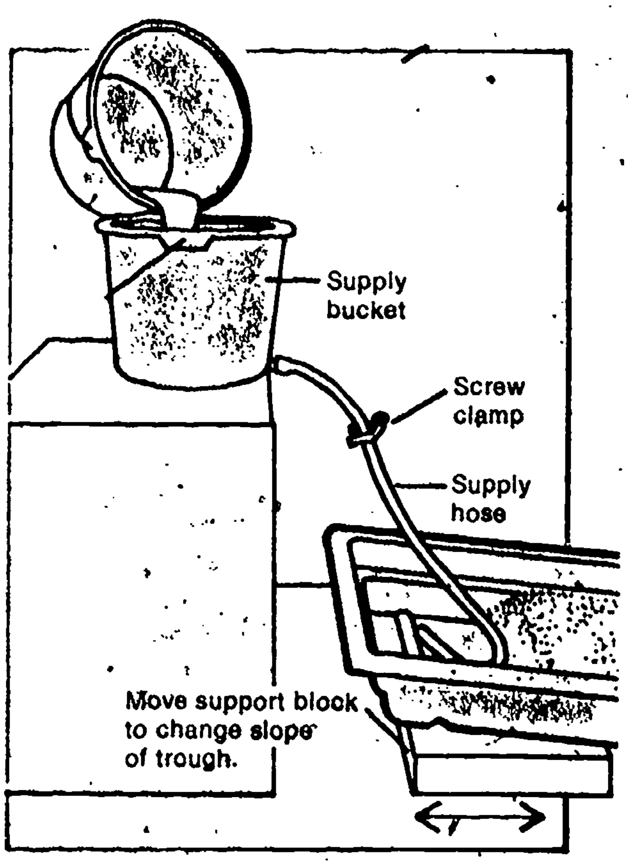
1. Rate of flow in a stream
2. Rate of flow leaving a lake
3. Making a reservoir
4. Slope of the stream

1. *To Control the Rate of Flow from the Supply Bucket*

Most of the stream-table experiments call for you to adjust the rate of flow of water into the reservoir to a certain number of milliliters per second. Doing this is easy. You simply time how long it takes (in seconds) for the supply hose to fill a 100-milliliter beaker. You can then calculate the rate of flow like this (the example assumes that it takes five seconds to fill the beaker):

$$\frac{100 \text{ ml (volume of water)}}{5 \text{ sec (time)}} = 20 \text{ ml/sec (rate of flow)}$$

**ACTIVITY 3-1. Set up the stream table and pour water into the supply bucket. To reduce the rate of flow, tighten the screw clamp. Opening the clamp increases the flow. Adjust the clamp so that you get a rate of flow of 10 ml/second. (Note: The rate of flow values given in the resources are approximate and can be varied up or down by 2 ml/second. Thus, any rate from 8 ml/second to 12 ml/second will do for a rate of 10 ml/second.)**




When you are sure that you have a flow of approximately 10 ml per second, change the flow to 5 ml per second.

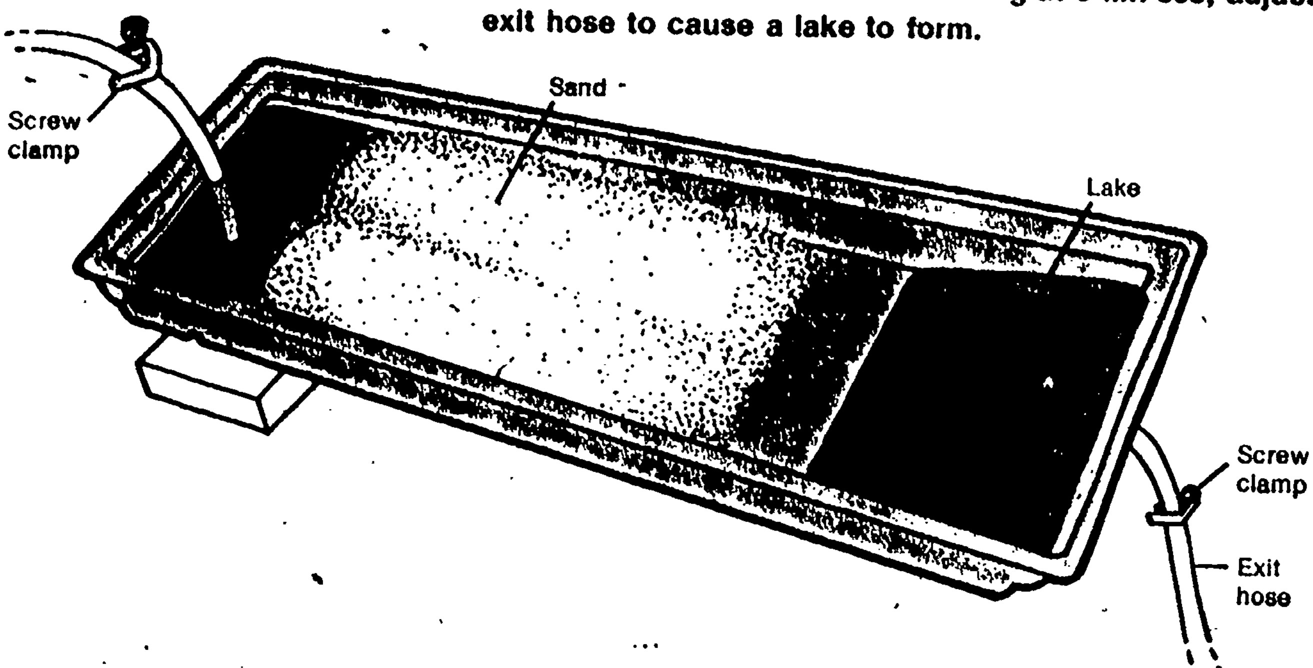
You must keep water in the supply bucket at all times. To help you do this, an extra bucket has been supplied. When you see the supply bucket becoming empty, replace the full catch bucket with the extra bucket and transfer the water to the supply bucket. You will probably have to do this every 5 minutes or so.

**Caution** *Watch the catch bucket. Don't let it overflow!*

## 2. *To Control the Flow of Water Leaving the Stream Table*

Some resources ask you to form a lake at the bottom of the stream table. You can control the formation and depth of such a lake by adjusting the screw clamp on the exit hose. If you change the amount of water entering the stream table, the lake level will also change unless you readjust the exit-hose screw clamp.

**ACTIVITY 3-2. With the water flowing at 5 ml/sec, adjust the exit hose to cause a lake to form.**



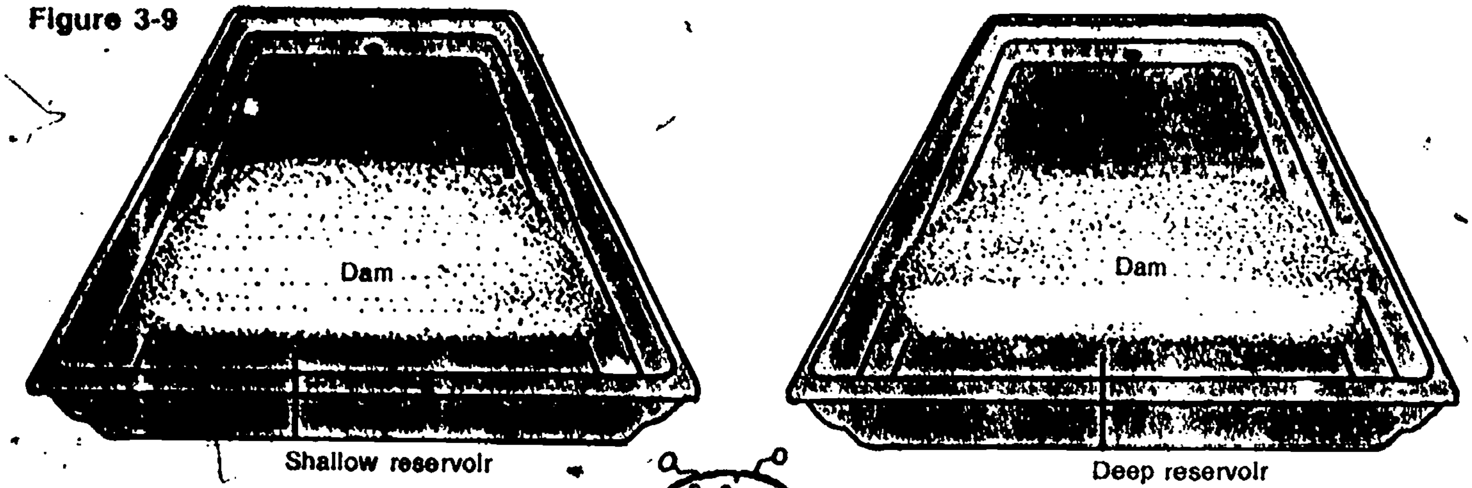

## 3. *To Make a Reservoir*

Some activities call for a reservoir at the upper end of the stream table. This is used to observe the effect of a wide, thin sheet of water. In general, a shallow reservoir molded near the top of the stream table will serve the purpose. However, you may wish to mold a larger dam when your activities call for a thick layer of sand and silt. Pile up the sand and silt with your hands or use a small board. Figure 3-9 shows where and how to do this.

## 4. *To Adjust the Slope of the Table*

Most resources call for you to raise the upper end of the stream table a certain number of centimeters above the table. To do this, simply slip a support under the stream table. Then move it back and forth to get the appropriate height.

Figure 3-9



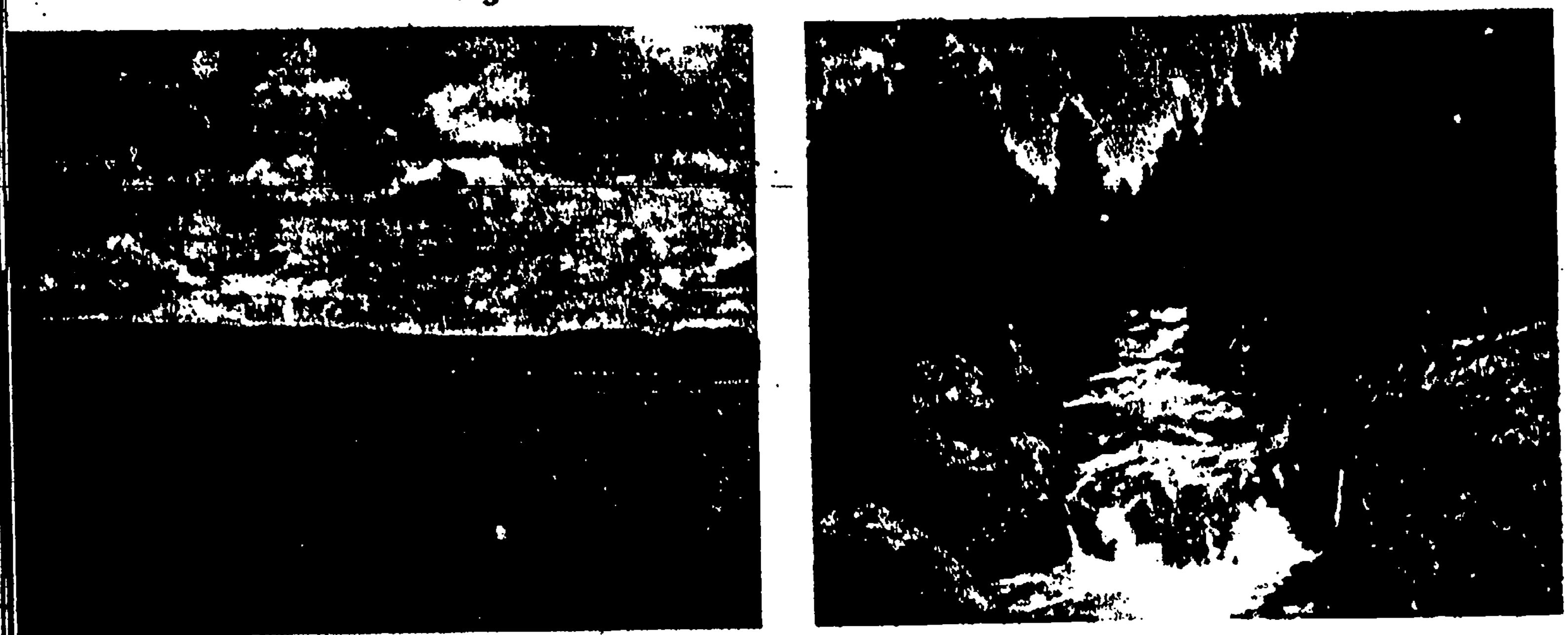

THINGS TO WATCH FOR

1. Watch the catch bucket. You must keep your eye on the catch bucket to keep it from overflowing. You can avoid the problem in some activities by pouring less than a full bucket of water into the supply system to start with. Any time you use more than one full bucket of water, you will need a third bucket to trade positions with the catch bucket before it's too late.
2. Be sure that the water-supply pail is set on a box or other support about 30 cm above the table.
3. Keep the supply hose and clamp attached at all times to control the water flow.
4. Do not remove the sand-silt mixture from the stream table when you finish an experiment. The next person using the table will need the same material.
5. The stream table isn't a perfect model. You will not get exactly the same effects that a real river would produce. Remember that the particle sizes you use are very much out of proportion to the volume of water flowing through a real stream.

### The river at work

Figure 3-10 shows two different views of a river. In the picture on the right, the water is flowing swiftly, and there are many rapids in the stream channel. In the picture on the left, the river is sluggish, with no rapids, and the surrounding land is very flat.

Figure 3-10

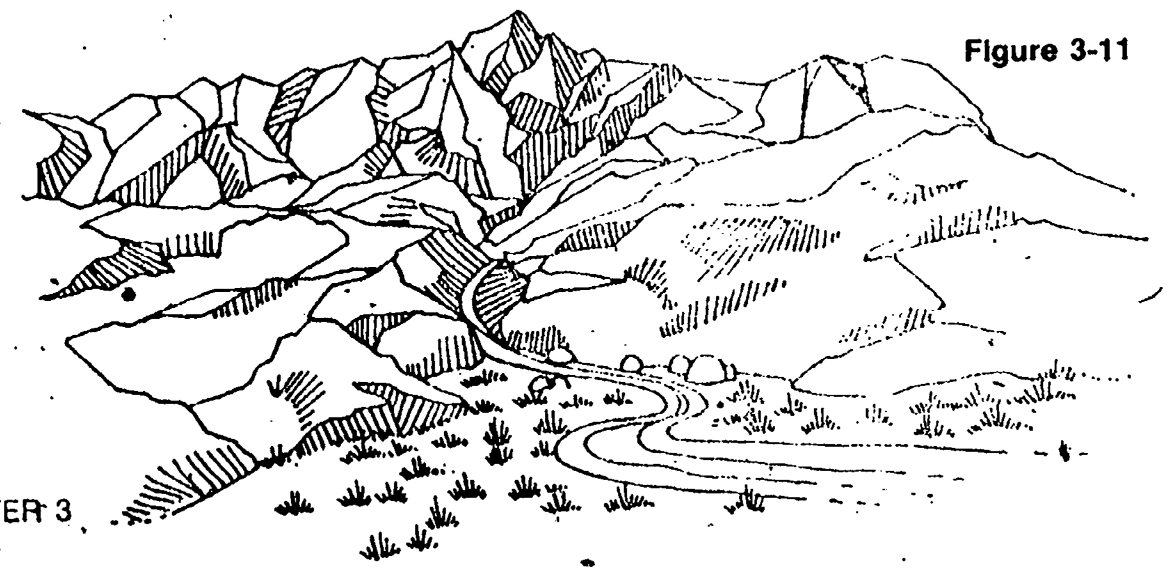


TO CLUSTER B

☐3-4. What factors cause rivers to flow swiftly, to slow down, and to carry away rock and soil?

When a stream reaches the foot of a mountain, it may suddenly spill out onto the valley floor, as shown in Figure 3-11. There it widens and slows down.

Figure 3-11



For example, look at Figure 3-12, which shows two small streams. Note the great width of the stream shown on the left. Then compare this fast-moving stream with the one on the right. Note the deposits that fan out on the valley floor.

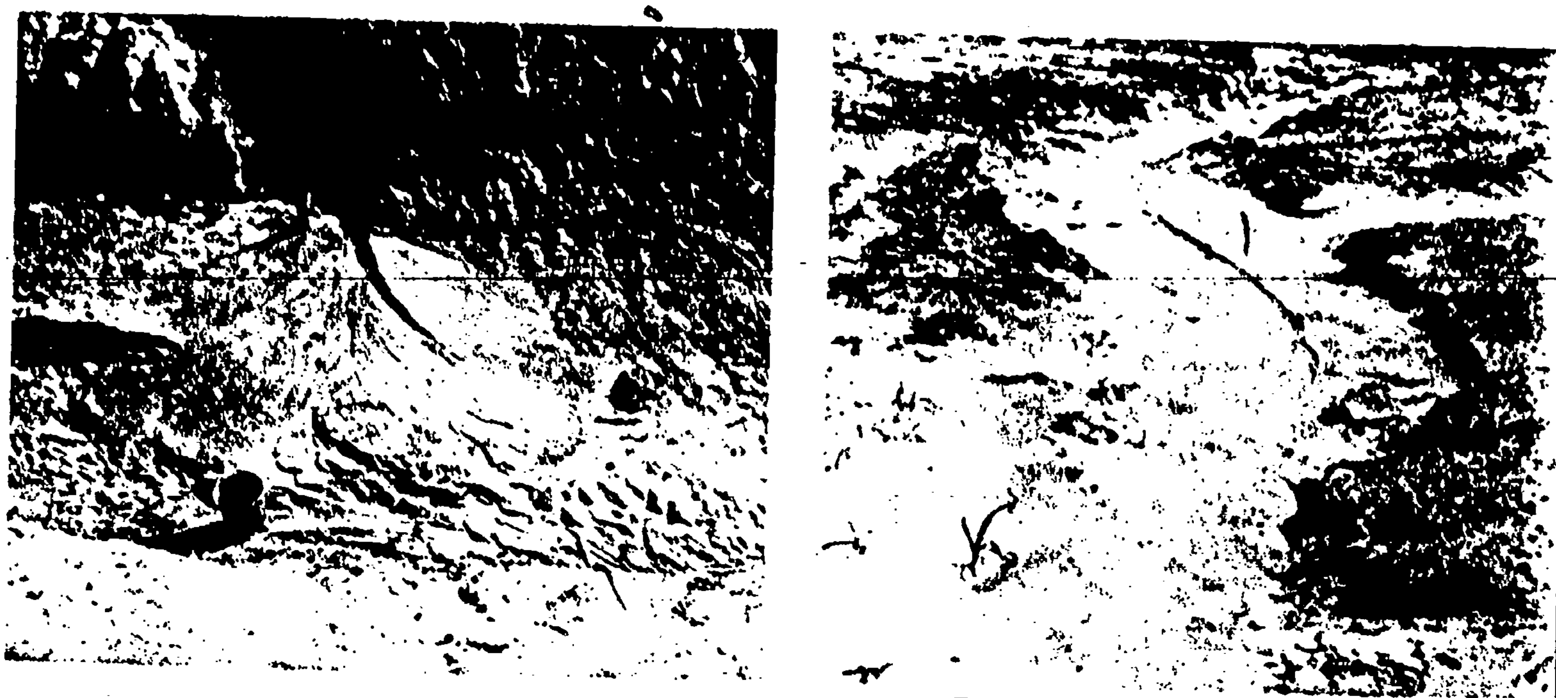


Figure 3-12

☐**3-5.** Why do deposits occur at the floor of the valley as in Figure 3-12 (right)? List several variables that affect the deposition and explain your answer in terms of the change of the water's potential into kinetic energy.

#### Special erosion features of rivers

Up to this point in this chapter you have investigated some of the factors that control rivers that erode the midlands. In this section you will be studying some of the special features of the landscapes that are due to erosion by rivers.

To study these features, we are going to ask you to make predictions about specific features and events before checking the resources. Here's how it works. You will find descriptions of several numbered features, along with two or more photographs or diagrams. In addition you will find a specific statement asking you to make a prediction. Read carefully through the descriptions and examine the figures. Then select *one* that you would like to investigate.

**TO CLUSTER D** ➔

[ ] **3-6.** Write a prediction concerning one of the features and enter it in Table 3-1 of your Record Book. Test your prediction by consulting Cluster D of the resources. If you are interested, go back and make predictions about the remaining features.

**Table 3-1**

| Feature | Your prediction | Results of Test | |
|---|---|---|---|
| | | Accept prediction. | Reject prediction. Revise if rejected. |
| Waterfalls (Figs. 3-13 and 3-14) | | | |
| Gullies (Fig. 3-15) | | | |
| Meanders (Figs. 3-16, 3-17, and 3-18) | | | |

*Feature 1: Waterfalls*

**Figure 3-13**

2

Figure 3-13 shows two views of Niagara Falls in New York State. The top of these falls is a flat plain with gently rolling hills. Actually, the plain rests about 175 meters (570 feet) above sea level. The falls are more than 50 meters (167 feet) high. Each year the falls cut back into the plain about 1½ meters (5 feet). During the last thousand years, the brink of the falls has moved more than 1,200 meters (4,000 feet). This has resulted in the long canyon that the falls crash into today.

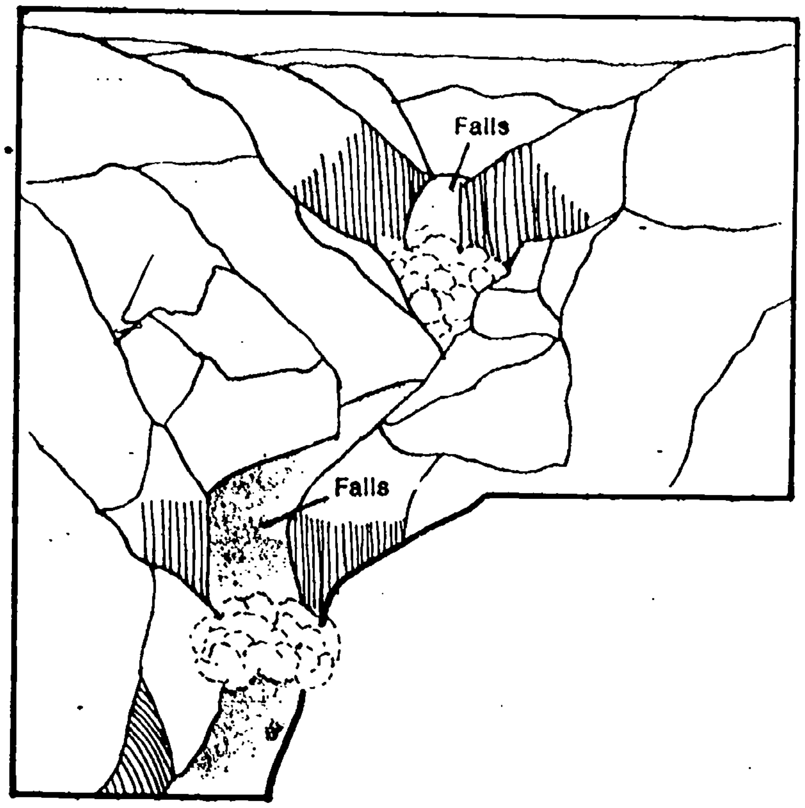



**Figure 3-14a**

**Figure 3-14b**

Another good example of the cutting back of the brink of a waterfall is the famous Grand Canyon of the Yellowstone River in Wyoming (Figure 3-14b). In fact, several brinks in the river are being cut back at the same time as the water falls to one level, and then to another level, and so on. Here there is a sequence of waterfalls, not a single-level waterfall as there is at Niagara. (The same section of the Yellowstone River that appears in the photograph is shown in Figure 3-14a.)

*Prediction 1*

Assuming that a difference in rock hardness is responsible for the location of both waterfalls, where in each figure (3-13 and 3-14) do you *predict* the layer or layers of hard rock are located? Make simple sketches of each figure and label the locations.

Figure 3-15a

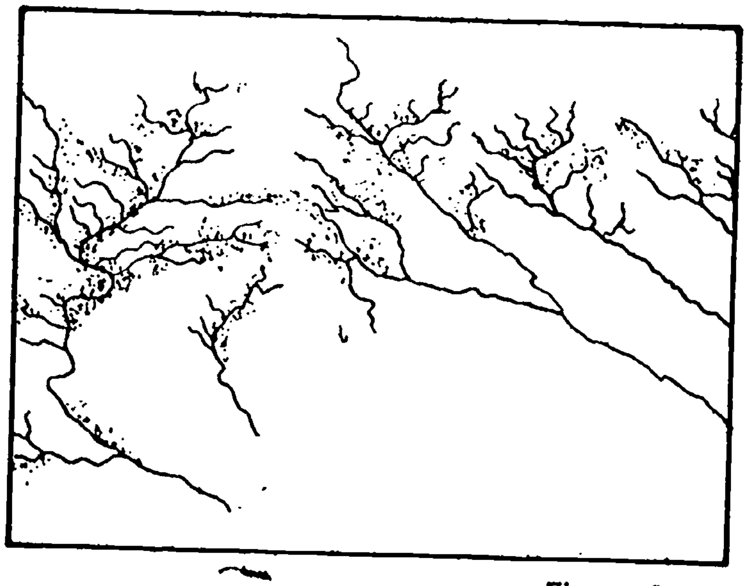


Figure 3-15b

*Feature 2: Gullies*

Figure 3-15a is an aerial view of a flat hill (plateau) in South Dakota. The dark, branchlike features are gullies. The gullies stand out because they are lined with plants that grow there because of the extra water.

*Prediction 2*

From looking at both the picture and the drawing in Figure 3-15, what do you *predict* is (1) the direction that the water flows in the gullies and (2) the direction that the gullies tend to grow and get larger? Make a sketch and label.

*Feature 3: Meanders*

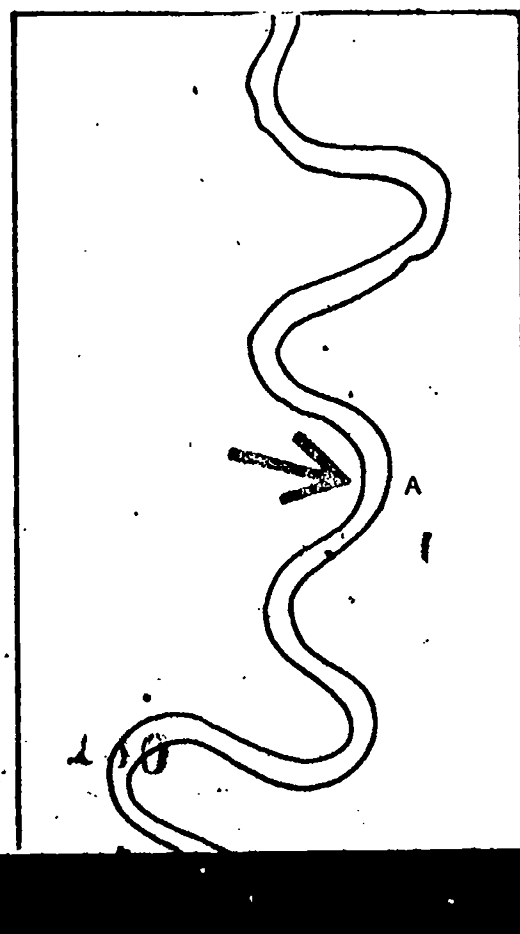
One of the most common features of a river is a bend or a meander. Figure 3-16 shows a bend in the Little Missouri River near Medora, North Dakota.

Figure 3-16

Here the kinetic energy of the stream is being used to cut away at the bank of the stream rather than to cut down through the rocks.

Figure 3-17a

Figure 3-17b



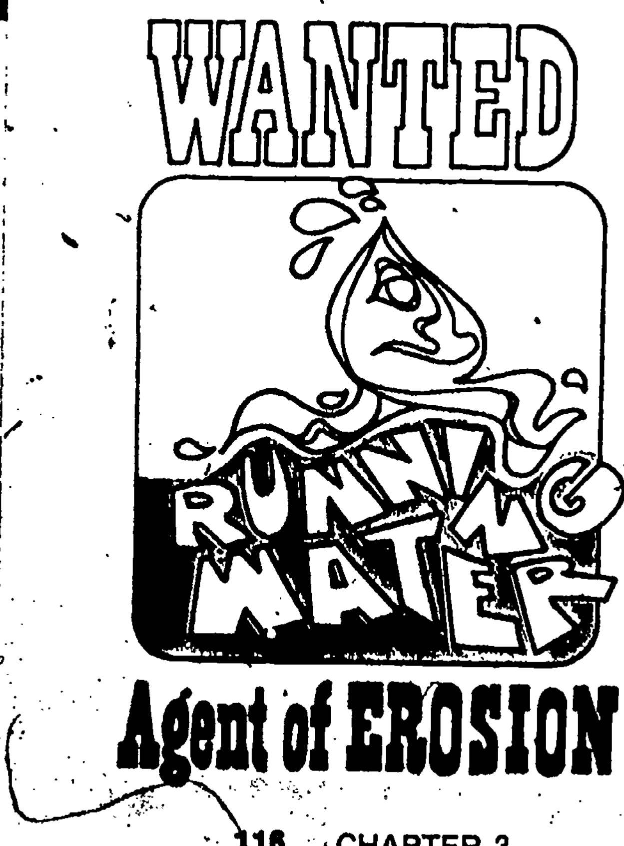
The Apalachicola River in northwestern Florida is another good example of a river's doing work other than downcutting into rocks. An aerial photograph of part of this river is shown in Figure 3-17a. The water in the photograph flows toward the bottom of the page.

Figure 3-18

Figure 3-18 shows a Montana river meandering down a gently sloping valley. Notice that the pattern of trees suggests that the river bends have swung from the far side to the near side of the valley.

*Prediction 3*

If the black arrow in Figure 3-17 points to deposits of sand, predict where other similar deposits of sand would be found, and whether the water at that point will be flowing faster, or slower, than at point A directly across the stream from the arrow. What do you predict will happen to the land in Figure 3-18 that the arrow is pointing at?




**Other forces that shape the midlands**

It is obvious that water has a good deal to do with shaping the landscape. Water is important both as a means of adding land in some places and as a means of wearing away land elsewhere. But other forces are also important in forming the midlands. Let's look at some of these.

The two photographs in Figure 3-19 were taken seven years apart. Wind caused the motion of the sand dune that you see.

Figure 3-19

3-7. Based on evidence in the photograph, in what direction do you think the sand has moved? Which photograph (left or right) was taken first?

*Conclusion*

In this chapter you have been primarily concerned with the process of erosion as it affects the midlands. Figure 3-20 is the same diagram you saw on the first page of this chapter. If you've done your work well, you should be able to describe and interpret the features as shown. You should also be able to make predictions about the area and what it might look like in the future.

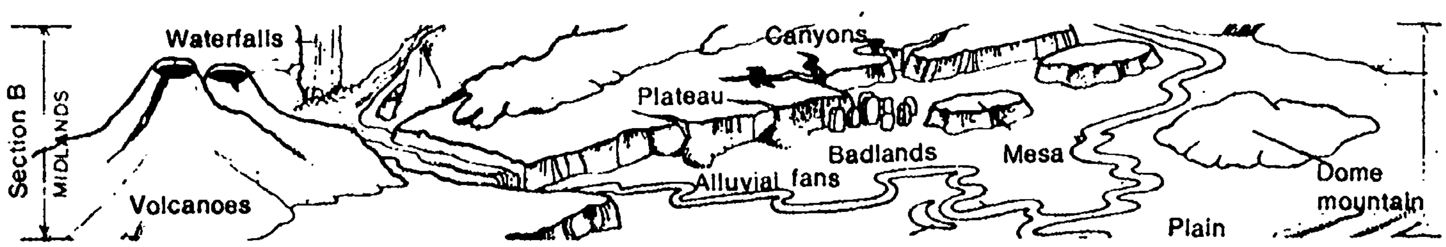
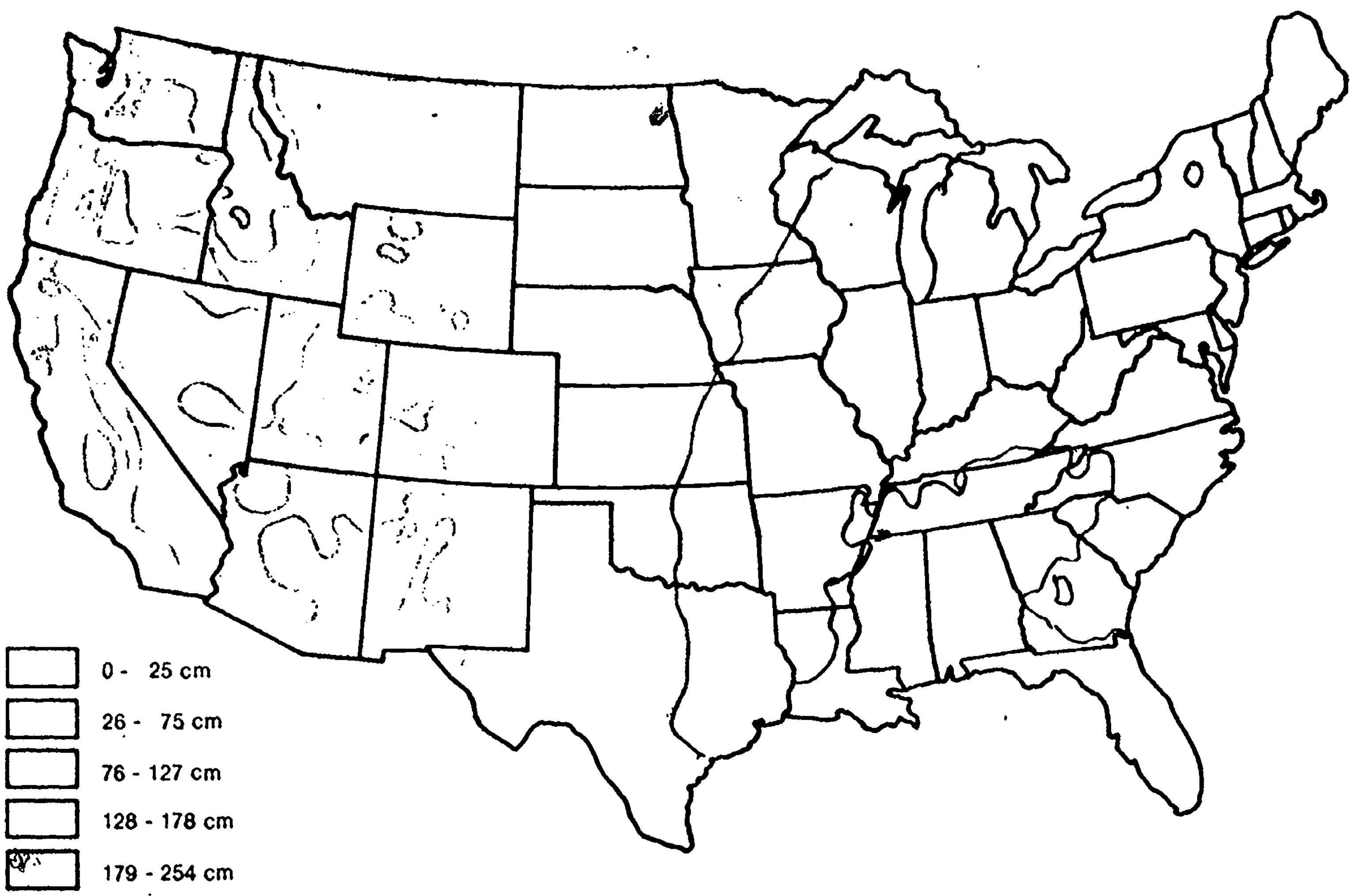



Figure 3-20

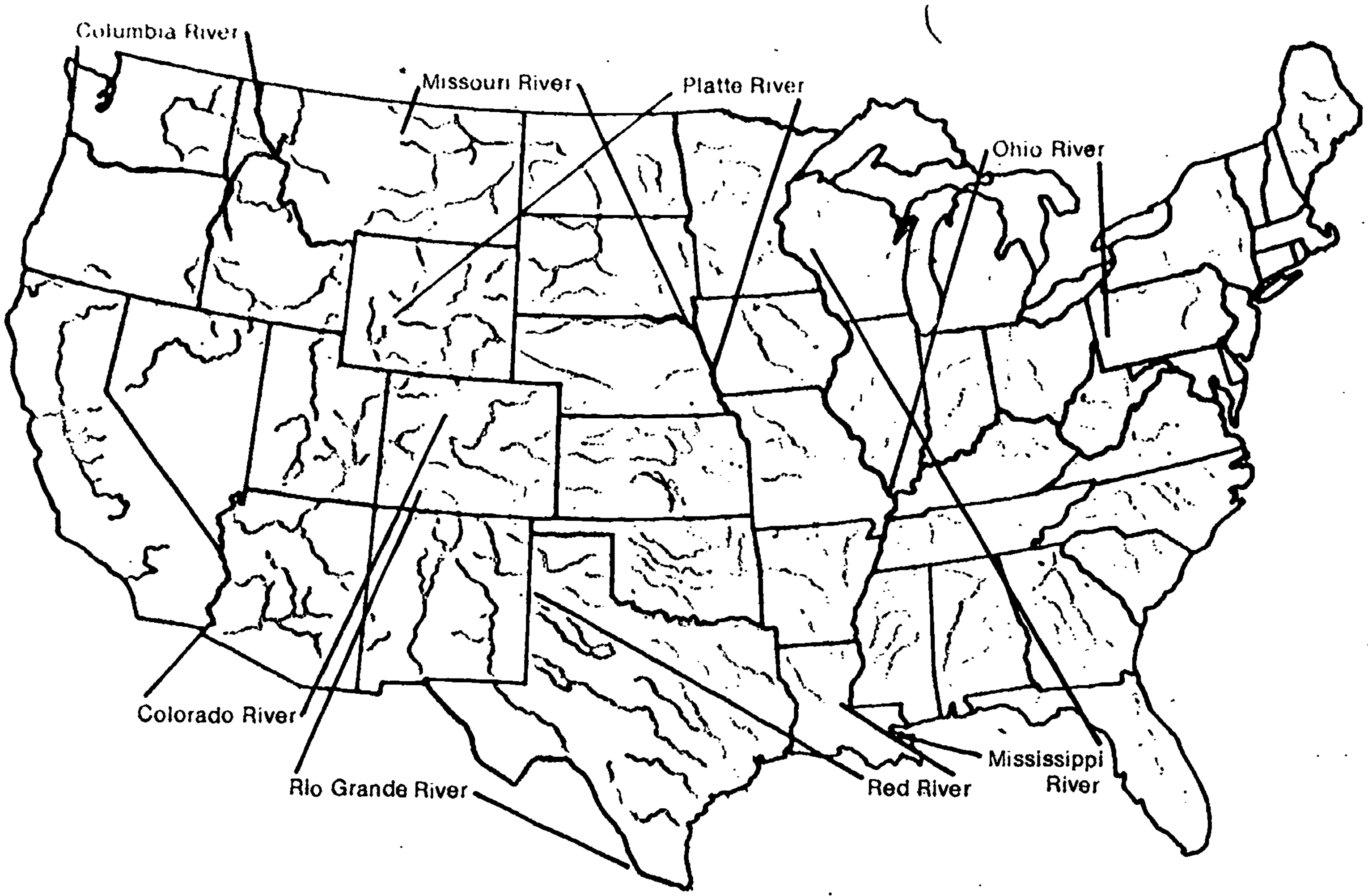
**Before going on, do Self-Evaluation 3 in your Record Book.**

CLUSTER A
(Resources 24–26)

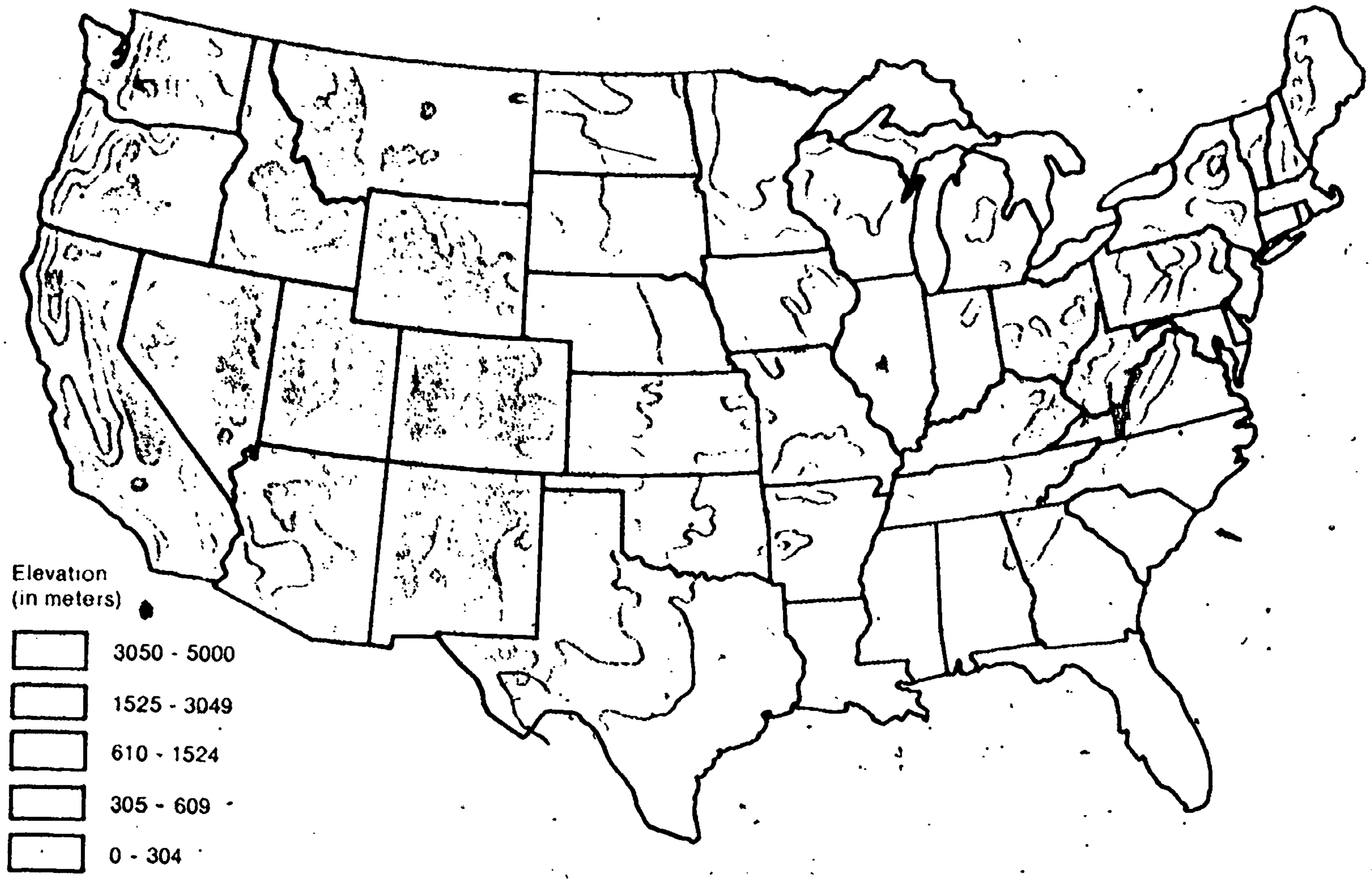
# Average Annual Precipitation in the United States



# 2[illegible] River Systems Map of the United States



26 Elevation Map of the United States



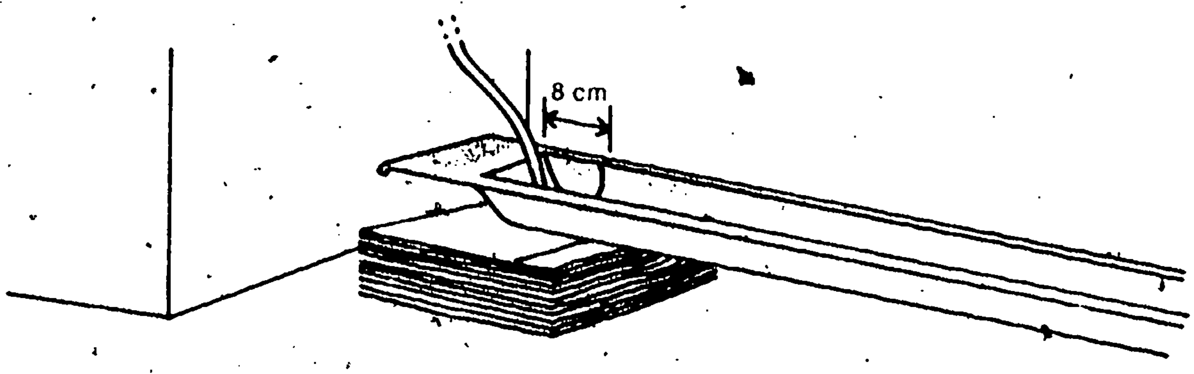
27 **Variables Affecting Rate of Stream Flow**

CLUSTER B
(Resources 27–30).

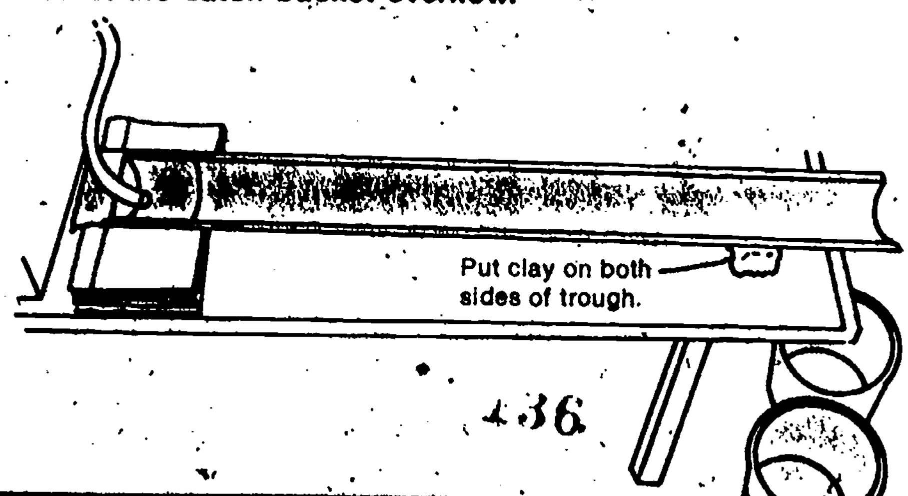
Rivers and streams can be raging torrents or slow-moving trickles. In this resource, you will try to determine what variables affect the speed at which water flows. You will also investigate whether or not the speed at which a river flows is the same from bank to bank. To do the experiments, you will need a partner and this equipment:

| | |
|---|---|
| 1 stream trough | Food coloring |
| 1 dropper | Supply of gravel |
| 1 wax pencil | Modeling clay |
| 1 water-supply system for the stream trough | 30-cm ruler |

**ACTIVITY 1. With a wax pencil, mark a starting line 8 cm from the upper end of the trough. Elevate the upper end of the trough 4 cm.**




**ACTIVITY 2. Set up the water supply system as shown. Adjust the water flow into the trough to 10 ml/sec. Be sure to keep the supply bucket at least half full of water at all times. Do not let the catch bucket overflow!**



**ACTIVITY 3. Add a drop of food coloring to the water as it flows past the starting line. Time how long it takes the dye to reach the end of the trough. Calculate the speed in centimeters per second, and record your data under Trial 1 in Table 1 of your Record Book.**

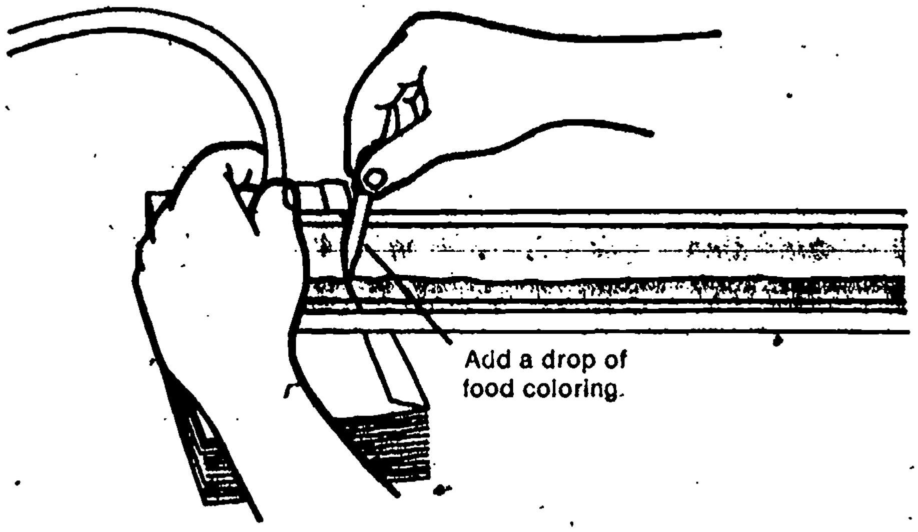



**Table 1**

| | Slope (in cm) | Rate of Flow into Trough (in ml/sec) | Trough Bed | Speed (in cm/sec) |
|---|---|---|---|---|
| Trial 1 | 4 | 10 | Normal | |
| Trial 2 | 8 | 10 | Normal | |
| Trial 3 | 12 | 10 | Normal | |
| Trial 4 | 4 | 20 | Normal | |
| Trial 5 | 4 | 10 | Gravel-covered | |

Next, you will carefully and regularly change the slope of the trough, the amount of water flowing through the trough, and the bed over which the water flows. You will then decide whether or not changing these variables affects the rate of flow down the trough.

Set up and carry out Trials 2 through 5 as described in Table 1. Measure the rate of flow down the trough for each trial and enter your results in the table. Notice that increasing the rate of flow has the effect of increasing the volume of water in the trough. Note also that Trial 5 calls for you to spread a layer of gravel along the stream bed.

If you did careful work, you found that increased slope, increased volume of water, and a smooth bed all cause the water to flow faster down the trough. These factors influence the rate of flow of water in natural streams, too. Rivers flow faster on steep slopes, when swollen by rains or melting snow at certain seasons of the year, or when flowing through beds with few obstacles.

One of the questions posed at the beginning of this resource is whether or not the rate of flow in rivers is the same from bank to bank. You and your partner can use the trough you've set up to answer this question, too. To do this, set up the apparatus as described in Activities 1 and 2. Then add a drop of food coloring and watch it closely as it moves down the trough. Try to decide which shape in Figure 1 most closely resembles the front edge of the drop.

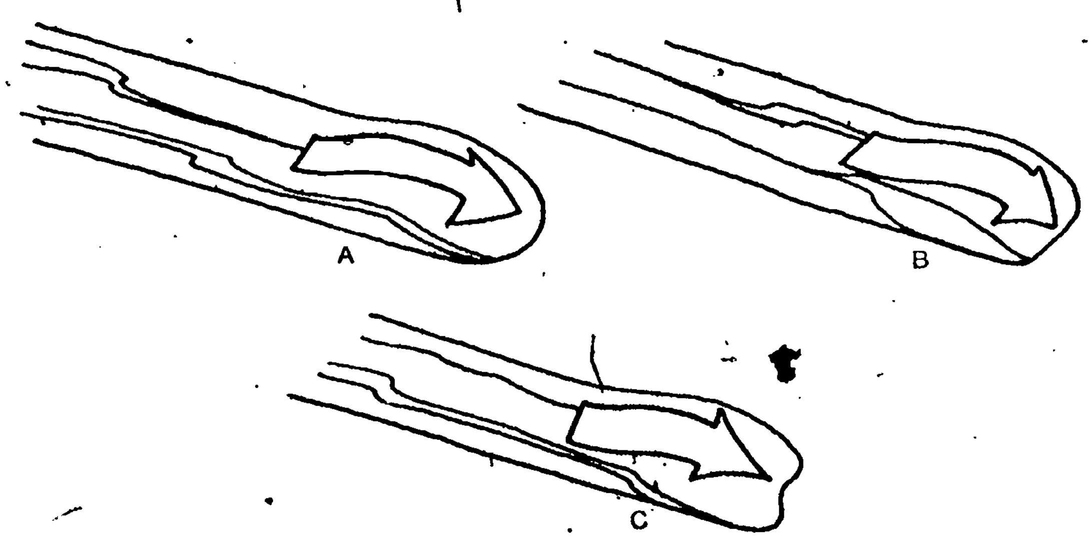



**Figure 1**

You probably found that the front edge of the drop looked most like A above. This tells you that the stream was flowing faster in the center, and slower along the sides, of the trough. Natural rivers and streams flow this way, too. How do you explain this difference in speed from bank to bank?

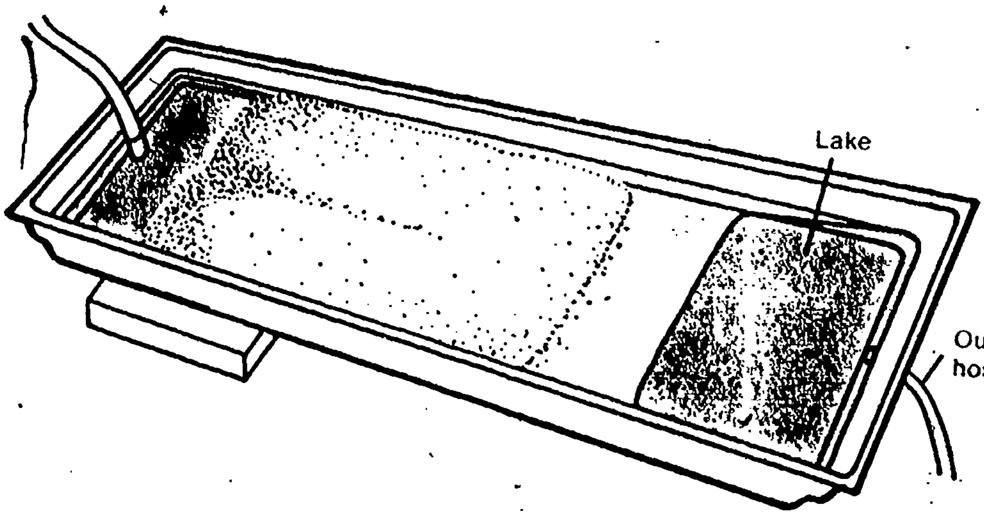
# 23 Particle-carrying Capacity and Rate of Stream Flow

How big a rock can a stream carry along? Depends upon the stream, you say? Sure, it's pretty obvious that fast-moving streams have greater kinetic energy and, therefore, can carry bigger rocks. But the rate of flow of streams is not constant—they speed up and slow down many times over their courses. What happens to the materials being carried by a river when its rate of flow changes? That's what this resource is all about.

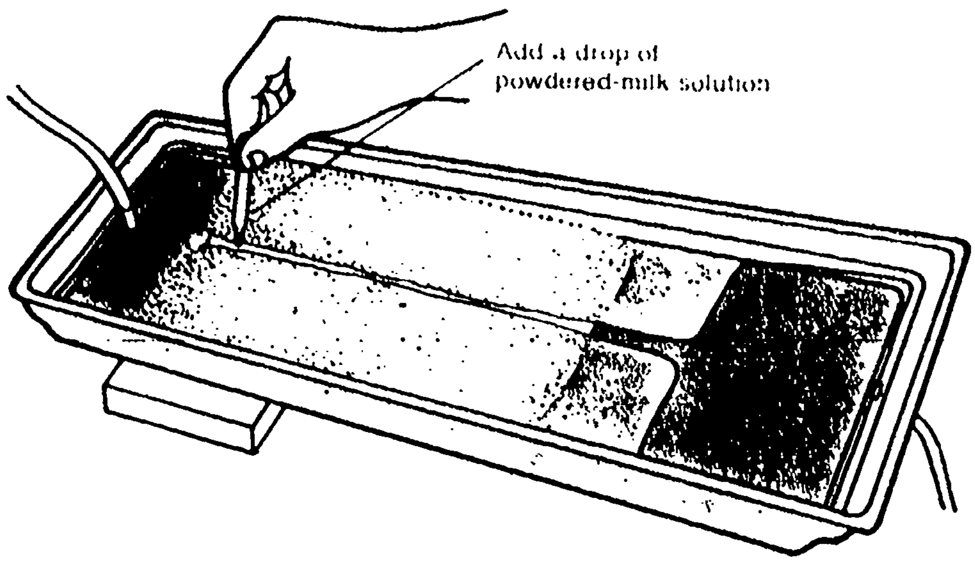
For these activities, you will need the following materials:

1 complete stream-table setup
1 powdered-milk solution
1 dropper

**ACTIVITY 1. Set up the stream table as shown. Use a bucket to fill the lake until water just leaves the outlet hose. Adjust the inlet water flow to 3–5 ml/sec.**



**ACTIVITY 2.** **Add a drop of powdered-milk solution to the water and note the places where the stream's rate of flow changes. Note also where particles of sand and silt are deposited by the stream.**




If you did your work well, you should have found a relationship between the number and size of sand particles dropped by the stream and the changes in the stream's rate of flow. As the stream slows down (loses kinetic energy), it drops part of its load; as it speeds up (gains kinetic energy), it picks up additional material.

This general process works in nature as well as on the stream table. Take a look at Figure 1. Can you predict at which points the stream is moving slowly and at which points it picks up speed?

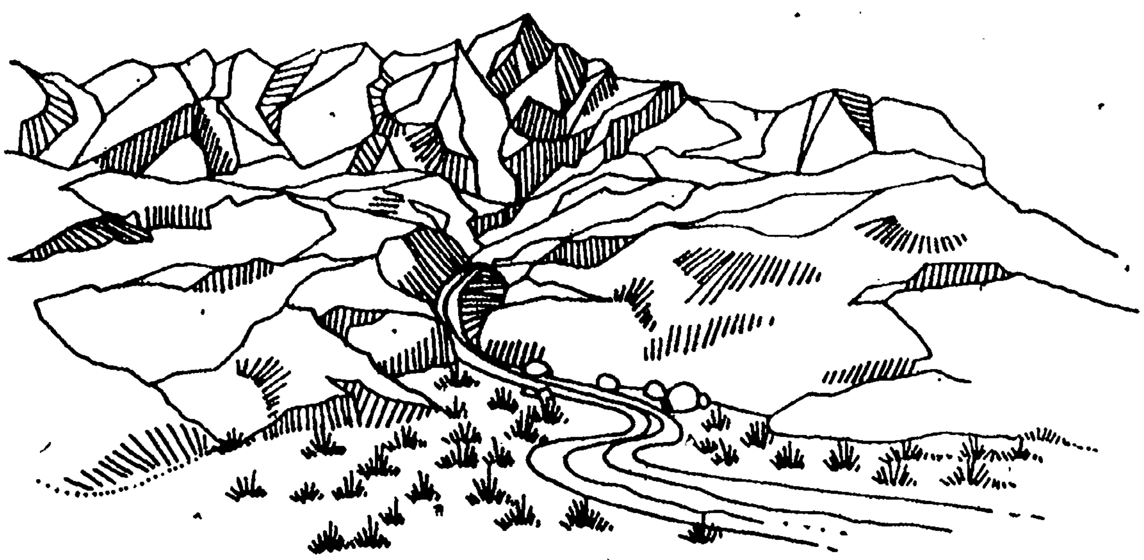
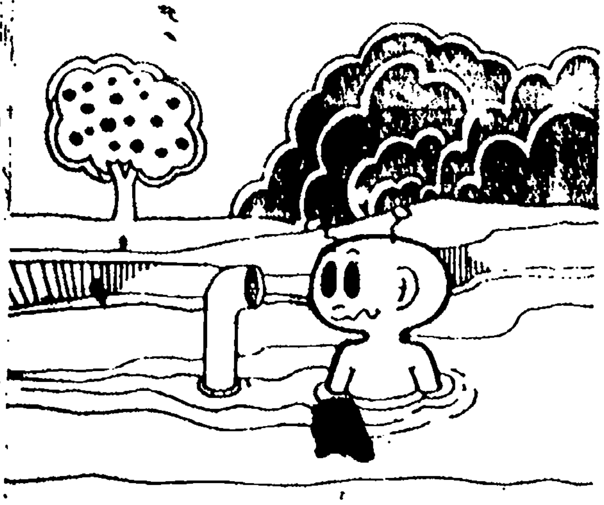


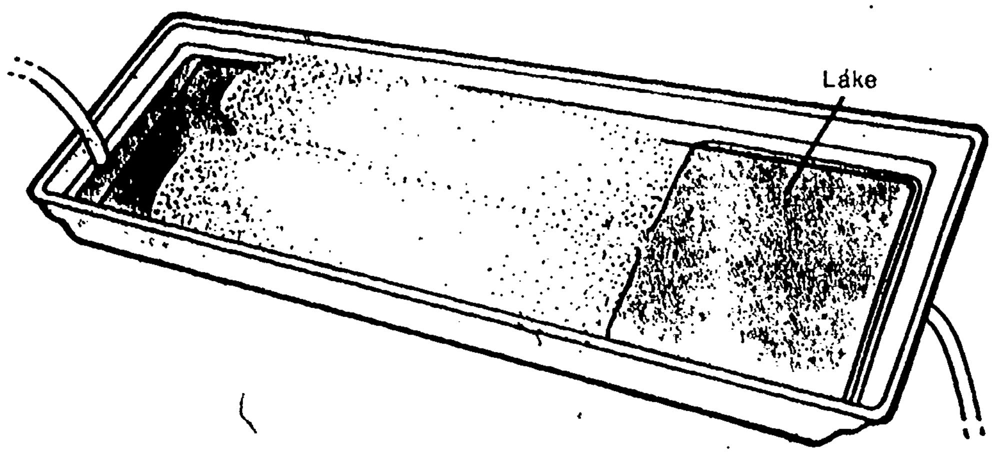
**Figure 1**



# 29 How Deep a Channel Can a Stream Cut?

This resource will help you find out if there is any limit to how deep a channel a river can cut. You will need a partner and a complete stream-table setup.

**ACTIVITY 1. Arrange the sand mixture on the stream table as shown. Be sure to give the proper slope to the sand. Notice that the stream table itself is level and that the lake level comes up to the edge of the sand. Adjust the water flow into the reservoir to 5 ml/sec. Notice how deeply the stream cuts into the sand.**



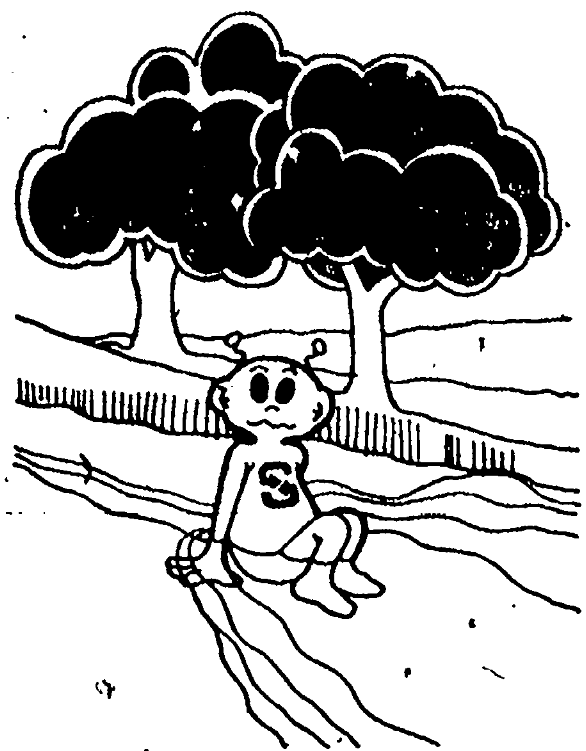

When the stream stops cutting, compare the depth of the gully with the level of the surface of the lake. You should find that they are approximately the same. A stream cannot cut a gully, canyon, or valley whose bottom is lower than the surface of the lake (or sea) into which it flows. You can see this more clearly by changing the slope of the sand in your stream table.

Repeat Activity 1, with the reservoir end of the stream table raised one centimeter. Notice what effect changing the slope has upon how deep a channel is cut. Notice also that the stream still cuts only to the level of the surface of the lake.

The principle that a stream cuts to the level of the body of water into which it flows applies in nature as well as on the stream table. Take a look at Figures 1 and 2. How do you account for the difference in how deeply these two rivers have cut?

Figure 1

Figure 2



# 30 Effects of Obstacles upon Direction of Stream Flow

In this resource, you will study photographs of rivers flowing through several kinds of materials. Your problem will be to note and try to explain any changes in a river's course as a result of obstacles it encounters.

First, take a look at Figure 1. Notice that the river is flowing through an area of large rocks. As the river flows around some of the rocks (Figure 2), it is broken up into a series of small streams. (This is called *braiding*.)

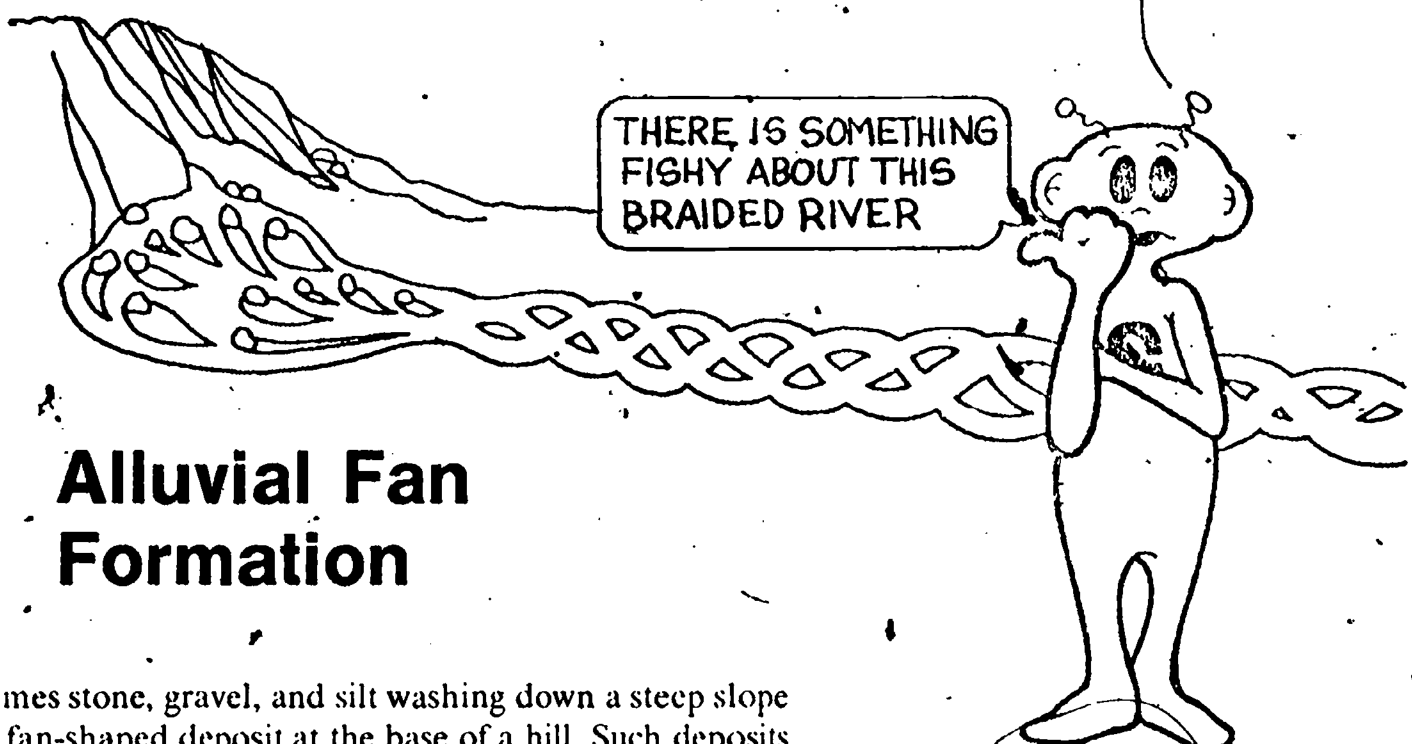
Figure 1

Figure 2

Take another look at Figure 2. Notice that the boulders that caused the braiding are located at the point where the mountain begins to level off. These rocks were very likely carried down from the mountain by the stream. They were dropped where they are because the stream lost speed (kinetic energy) as it hit the bottom of the slope. It is at points like this that one most often finds braiding of streams.

The river in Figure 3 is braided, too. What caused the splitting this time?

Figure 3




# 31 Alluvial Fan Formation

Sometimes stone, gravel, and silt washing down a steep slope form a fan-shaped deposit at the base of a hill. Such deposits are called *alluvial fans.* Figure 1 shows several alluvial fans in Death Valley.

In this resource, you will have a chance to investigate for yourself how and why alluvial fans form. To do it, you will need a partner and a complete stream-table setup.

CLUSTER C
(Resources 31 and 32)

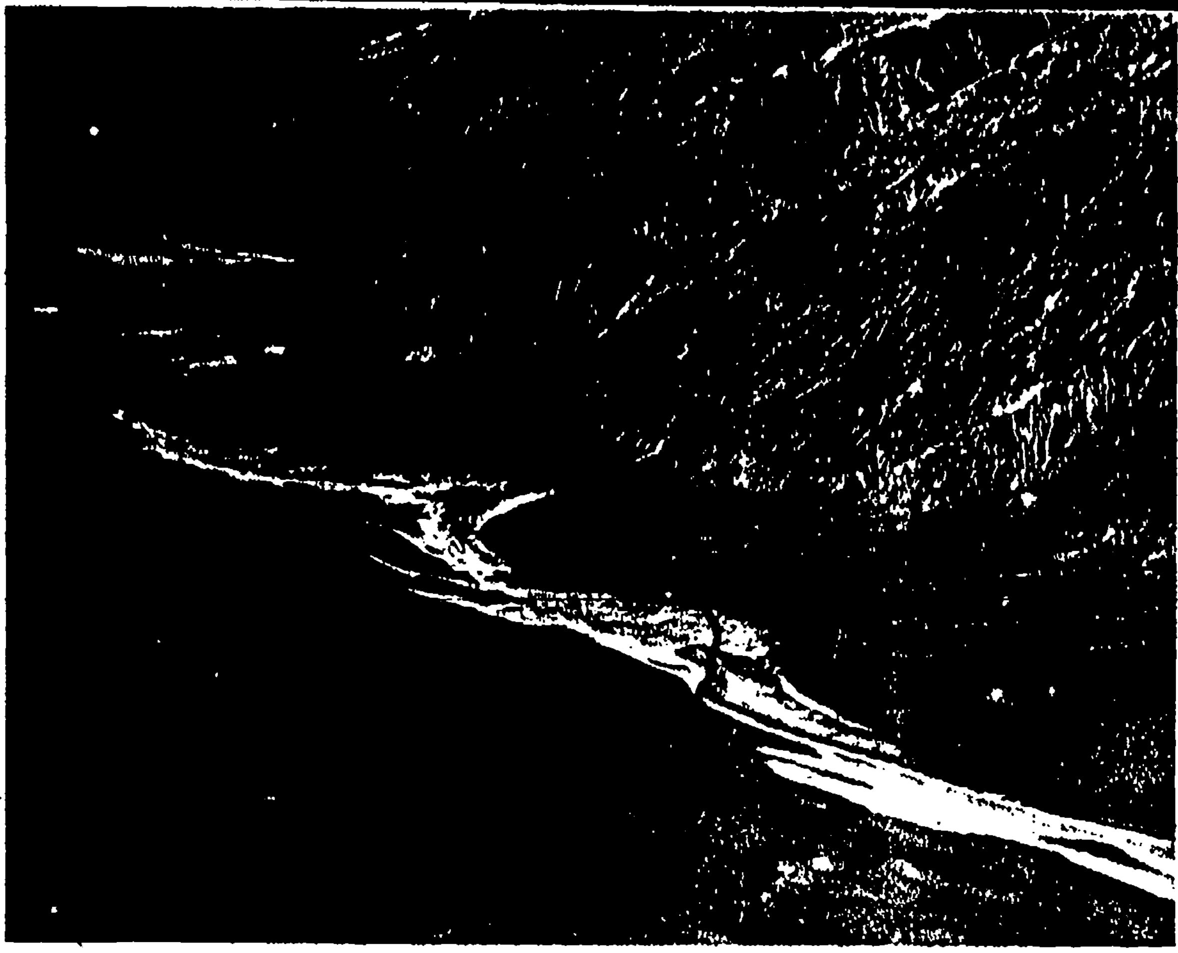
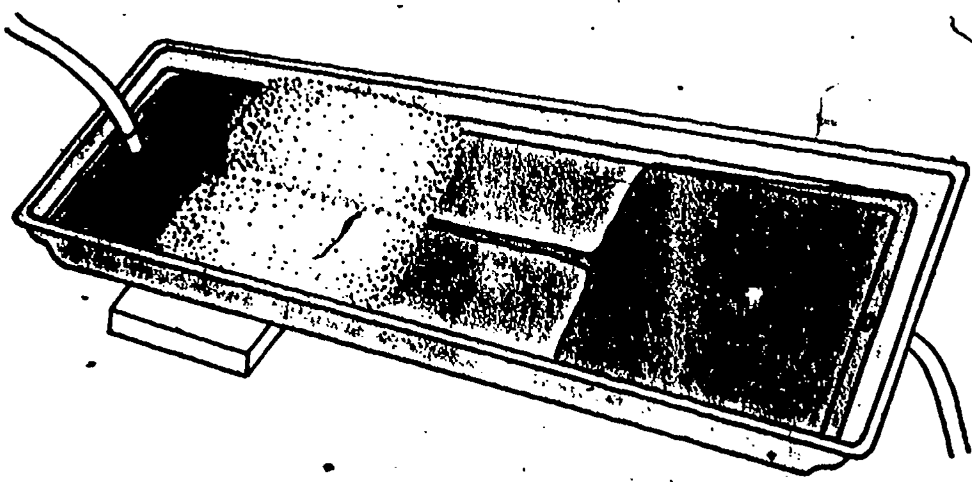


Figure 1

**ACTIVITY 1. Set up the stream table as shown. Adjust the rate of flow into the reservoir to 5 ml/sec. Allow the water to flow for several minutes. Observe what happens.**



Did you get an alluvial fan to form? Once you have succeeded in getting an alluvial fan to form, you are on your own. Vary the procedure outlined in Activity 1 in any way that you like. Keep in mind that you are trying to learn the conditions present when alluvial fans form. Here are some variables you may want to experiment with.

1. Amount of water flowing down the hill
2. Looseness of the materials over which the water flows
3. Steepness of the slope the water flows over
4. Change in the water's rate of flow

Figure 2

Figure 2 shows some white areas in addition to the alluvial fans. The water that brought down the material that formed the fan carried dissolved materials with it as well. In a dry area like Death Valley, water evaporates very quickly, leaving the dissolved material behind. The white material in Figure 2 is mostly salt.

# 32 Delta Formation and Changes in Sea Level

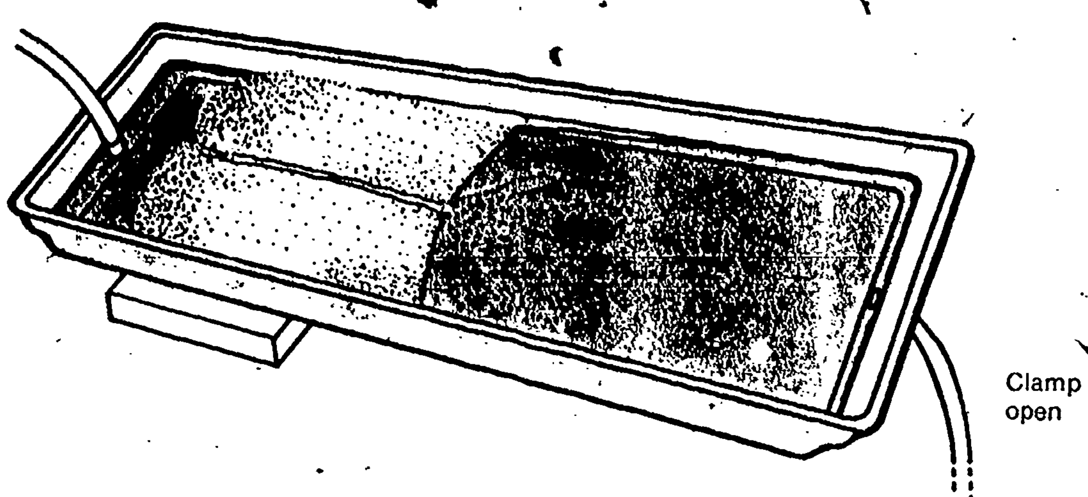
Soil, sand, and gravel dropped at the mouths of rivers build up into fan-shaped deposits called *deltas*. The one at the mouth of the Nile grew slowly over thousands of years, but you can make a simulated delta in a few minutes.

Get the complete stream-table setup and a knife for shaping the sand. Then do the following activity.

**Important Note:** The stream-table activity is an attempt to reproduce natural conditions as closely as possible, but it is most important to remember that it is not a natural stream. The size of particles in relation to the size of the stream and to the rate of flow is not the same as in nature. Neither is the time.

**ACTIVITY 1. Set up your stream table as shown. Adjust the rate of flow into the reservoir to 5 ml/sec. Allow the water to flow for about 10 minutes.**

**Carefully watch the buildup of the delta and note what happens to particles of different sizes. Leave the delta in place for the next experiment.**



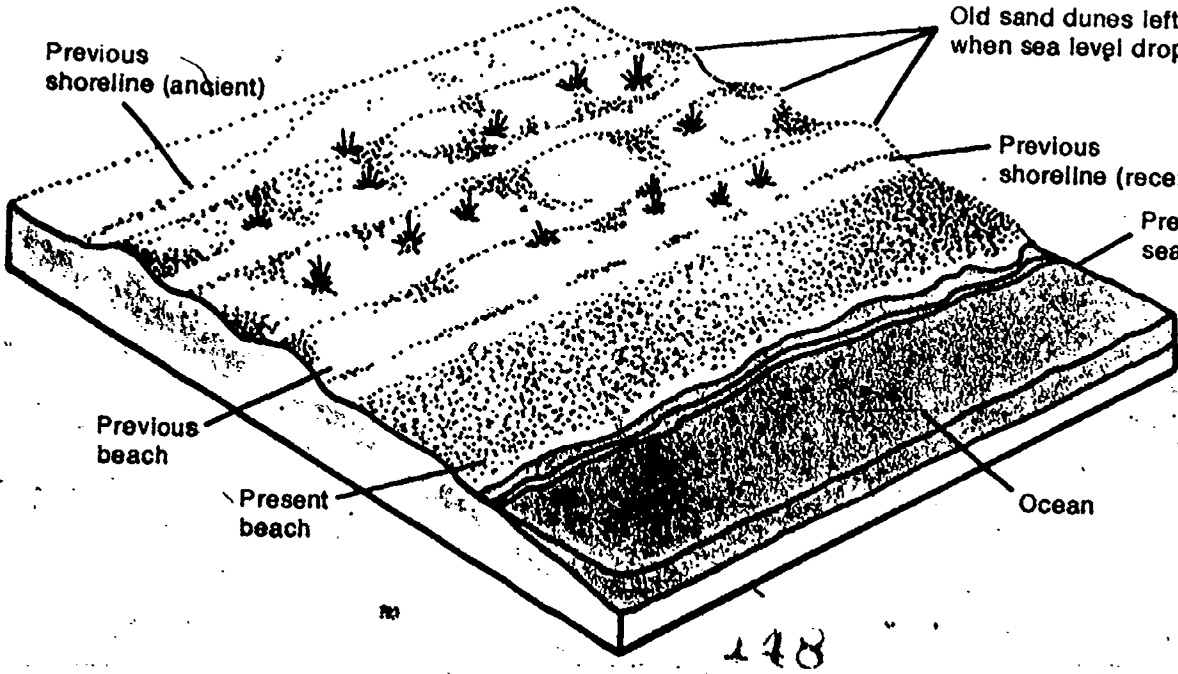

Where are the finer particles deposited? Compared with the coarse sand grains, are they closer to or farther from the shoreline?

What you have just seen in the stream table is very much like what happens at the mouth of a large river. As the river flows into a sea or lake, it slows down, and its ability to carry sediments (particles) is reduced. As a result, its load is dropped, and a delta is gradually built up from the deposited sediments. The fine particles are deposited in the deeper, stiller water.

There is much evidence that the level of the seas has changed many times in the past. If the land were to sink a little or the sea level were to rise a little, then the position of the shoreline could move some distance. For example, Figures 1 and 2 show how the shoreline has moved on Florida's Gulf Coast. (Figure 1 is an aerial photograph, and Figure 2 is a diagram to help you understand the photograph.)

Figure 1


Figure 2



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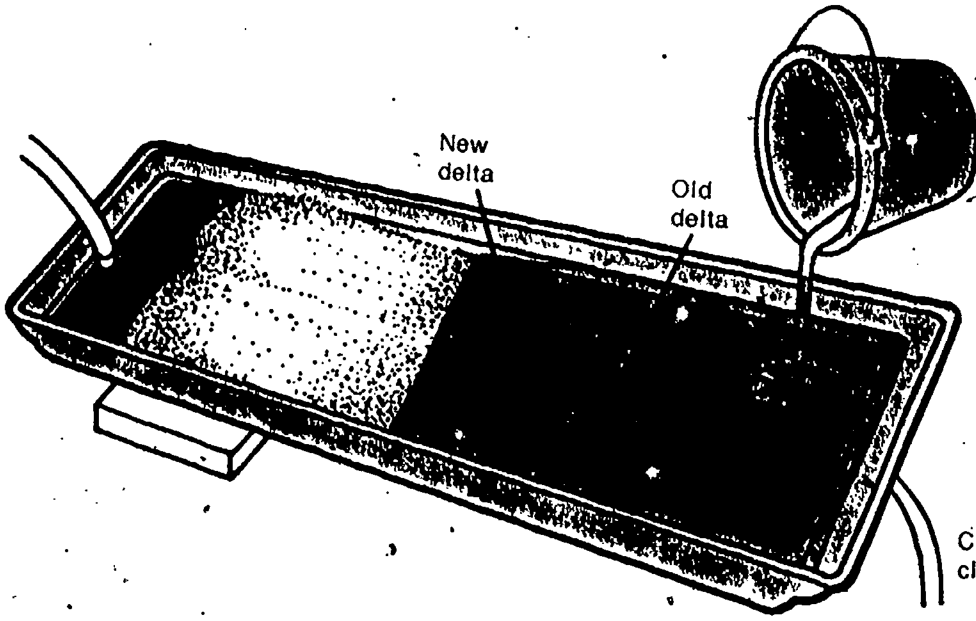
You can use the stream table to model the effect of the changing sea level upon deposition of materials.

**ACTIVITY 2. With the delta from the previous experiment still in place, carefully raise the lake level as shown. Without disturbing the delta you formed, replace the sand-silt mixture at the top of the table and allow the water to run for another 10 minutes. The rate of flow should once again be 5 ml/sec. Notice how the sand is deposited this time.**




You should see a new delta forming on top of part of the original one. When you see the second delta forming clearly, try simulating flood periods by pouring a baby-food jar of water quickly into the reservoir every half minute. Move the jar as you pour to stir up the silt. After about 10 minutes, stop the water flow and completely drain the stream table.

You should now have two deltas, one overlapping the other, as shown in Figure 3.

You have observed that deposition of sediment in a delta sorts out the size of the grains. And you should realize that a combination of rate of the stream flow and deepness of the water determines where the particles deposit. This double delta effect—the position of one delta on top of another—occurs when change of sea level takes place for some reason (by melting of continental glaciers, for example).

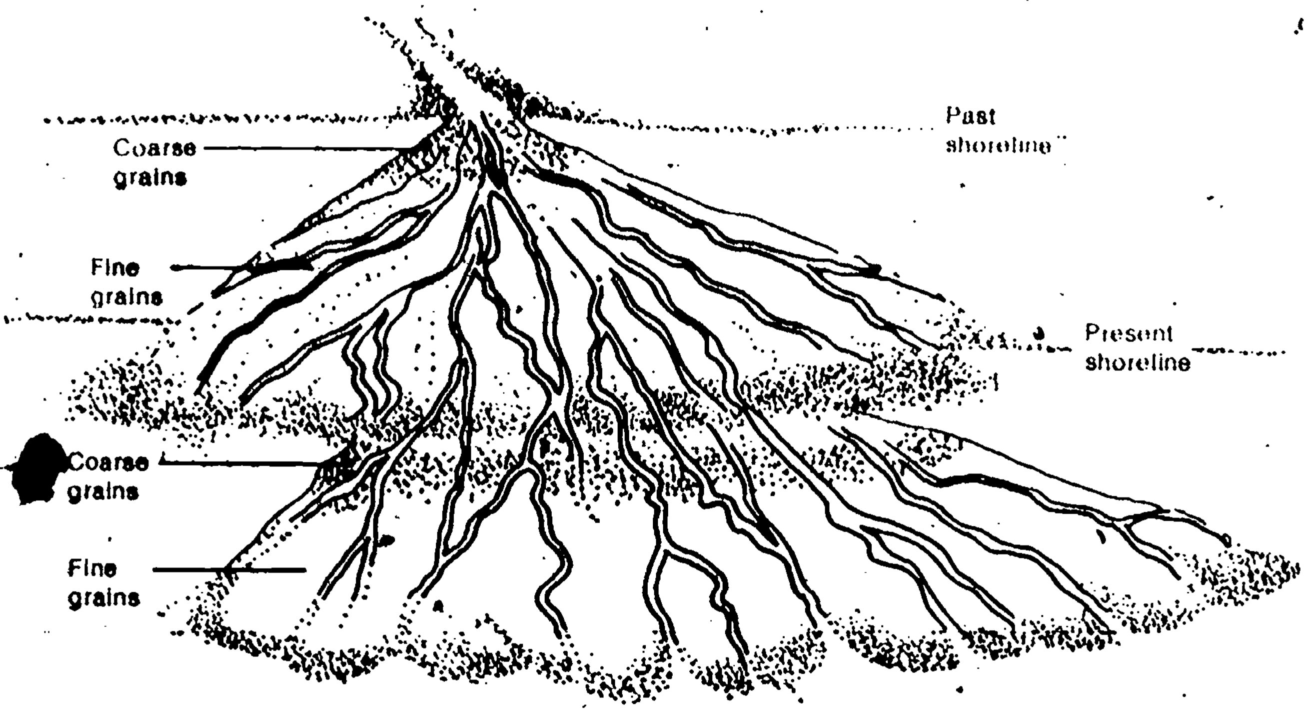



Figure 3

# 33 Waterfalls and Rock Hardness

CLUSTER D
(Resources 33–36)

This resource deals with the interaction of waterfalls and the crust of the earth. You will learn how the hardness of the rock and its structure affect the shape of the falls.

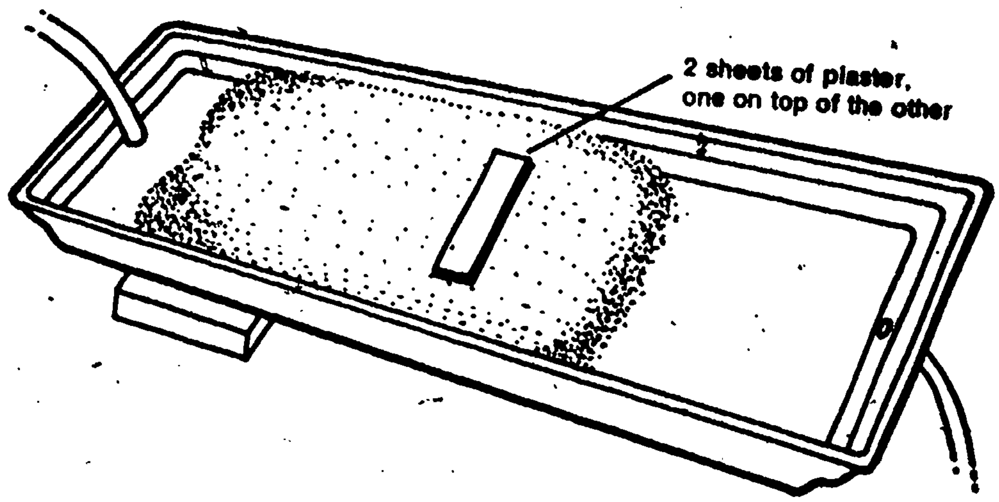
Figure 1 shows a waterfall in Indiana that is tumbling over a ledge of rock. Can you guess how the hardness of the rock at the top of the waterfall differs from the hardness of the rock at the bottom?

With your stream table, you can test the effect of relative hardness and work out a model for the process taking place. To do the activities that follow, you will need a partner and the following materials:

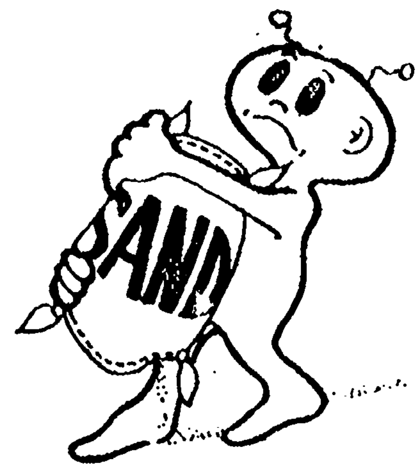
- 1 complete stream-table setup
- 2 sheets of plaster, about 0.3 cm thick by 5 cm wide by 10 cm long

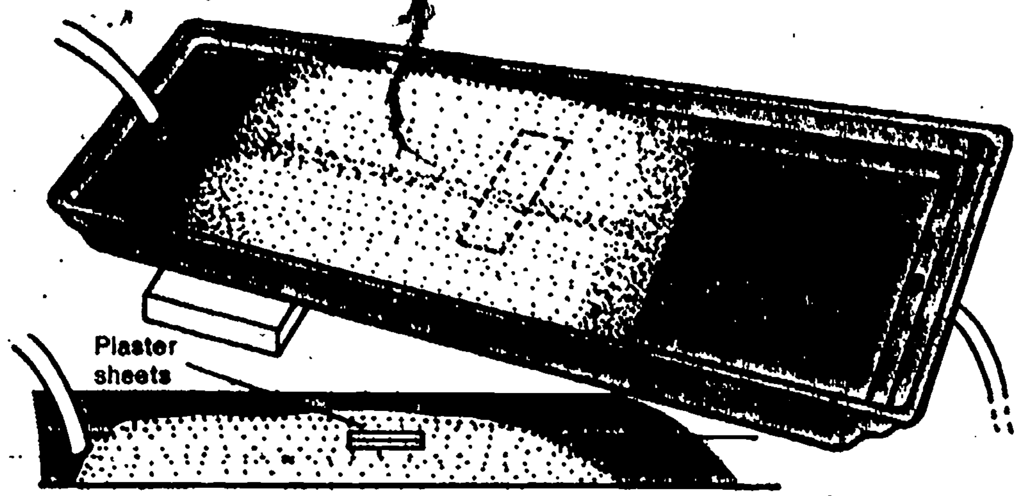
Figure 1

ACTIVITY 1. Set up the stream table and sand mixture as shown. Make a layer of sand-silt mixture about 3 cm deep. Place two sheets of thin plaster on the layer as shown.

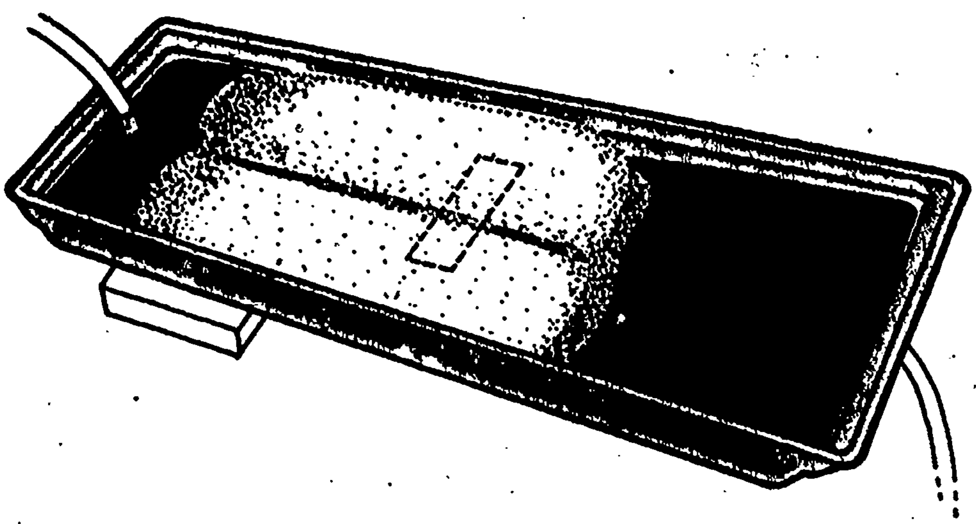


ACTIVITY 2. Now cover the plaster with a layer of sand, and make a slight valley so that the stream will flow over the top of the buried plaster. Start the water flowing.




ACTIVITY 3. Adjust the water flow into the reservoir to 5 ml/sec. Let the water run down the valley until it has eroded enough to uncover the plaster. Allow erosion to continue for about 5 minutes after the plaster is uncovered.



The plaster represents layers of harder sediment or perhaps a lava flow between sediments. The sand-silt mixture represents softer rock above and below the harder rock. When the plaster becomes exposed, what happens to the rate of erosion upstream and downstream from it?

Now take a look at Figures 2, 3, and 4. These drawings show two possible effects of water flowing over falls like the one you just looked at. Try to decide logically, on the basis of what you've seen, which set best represents what is going on in Figure 1.

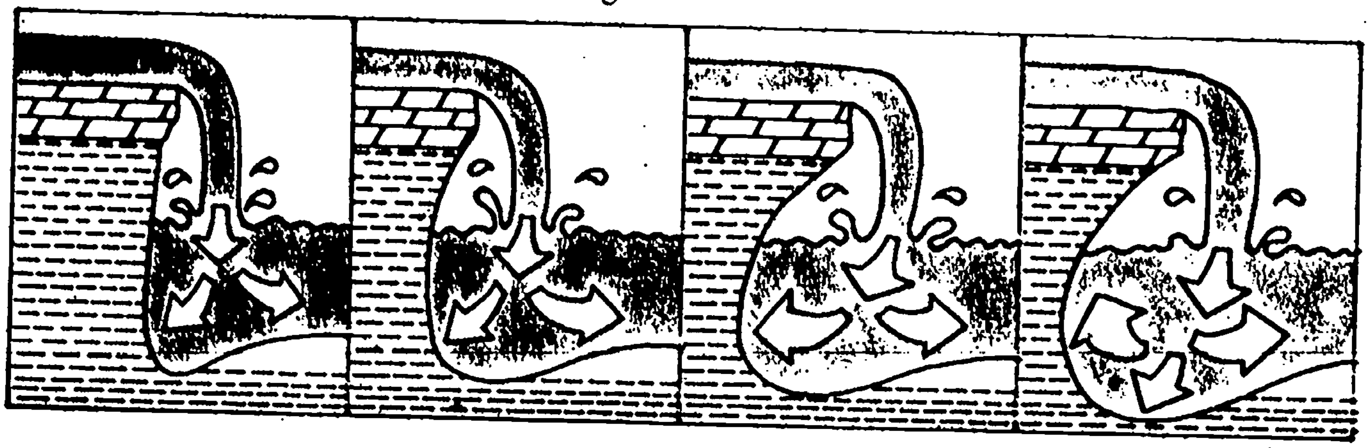


Figure 2

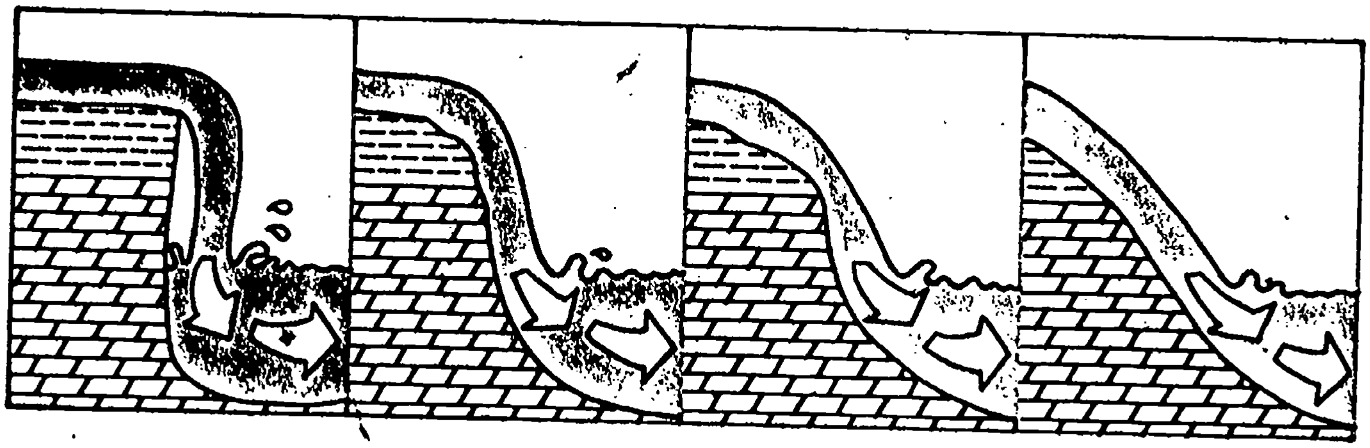


Figure 3

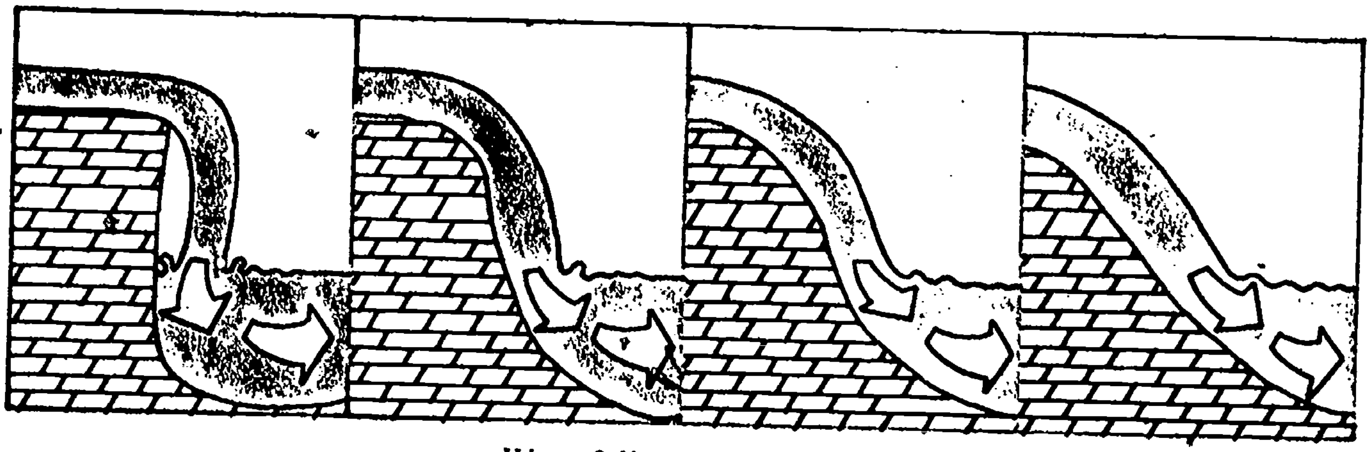


Figure 4

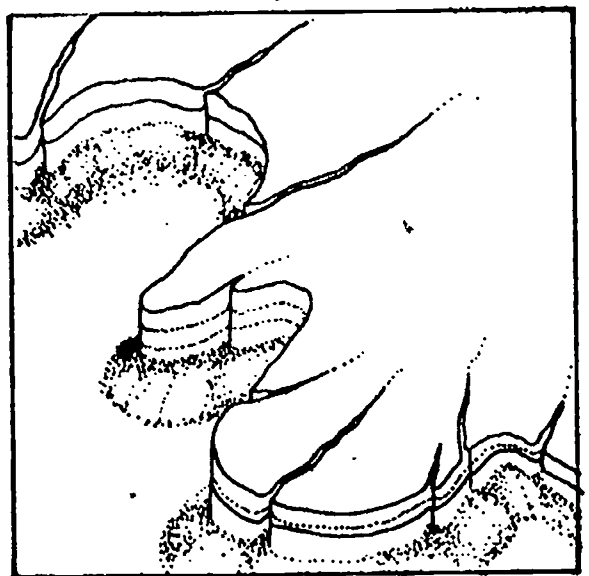
Waterfalls are common landscape features where water flows rapidly over a hard rock ledge. When the ledge rests on softer rock, the water will erode the softer rock faster than the top layer, resulting in a sharp edge to the falls as shown in Figure 2. Notice the pothole (deep pool) forming at the base of the falls and the flat chunks of rock that have broken off into it.

In Figure 3, the rock beneath the top layers is harder than that in the stream bed. The top layers, therefore, erode more quickly, making the edge more rounded. Notice that no pothole is formed.

In Figure 4, all the rock is made of one type of hard material, and the falls cut back slowly. No pothole is formed, and the shape of the falls changes very little as the river erodes away the rock.

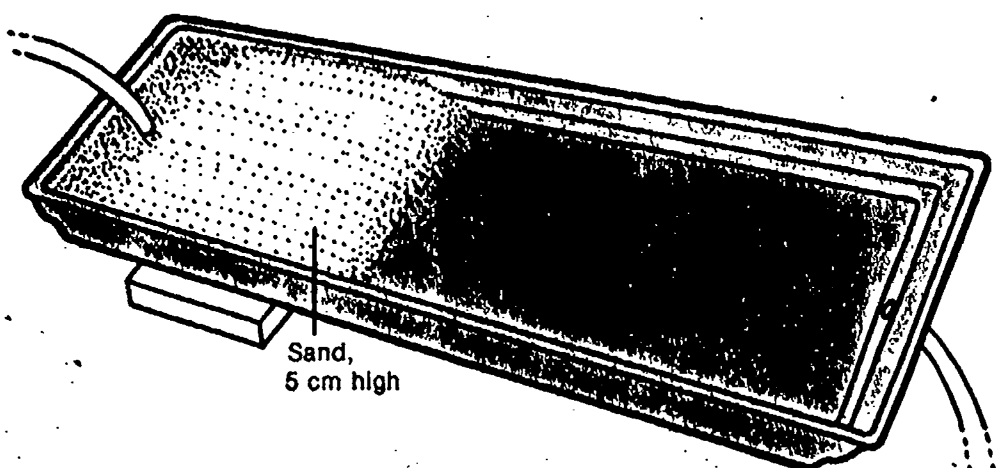
If you've done the resource on distinguishing rock types, you may be able to guess which rock types are shown and discussed above. Which do you think is igneous, metamorphic, and sedimentary?

# 34 Gullying and Erosion of a Plateau

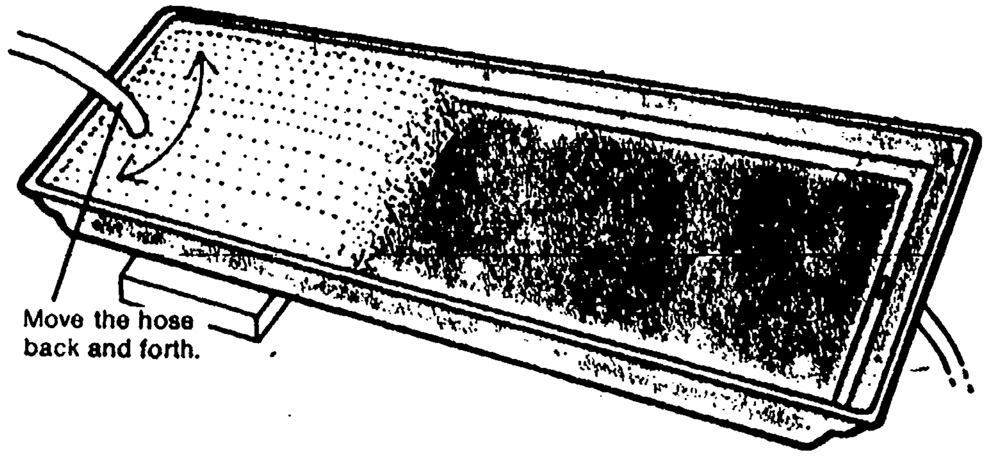


In this resource, you will study what happens when water runs off a flat-topped hill. To do the activities, you will need a complete stream-table setup and the help of a partner.

**ACTIVITY 1. Set up your apparatus as shown. Be sure that the flat-topped hill of sand is at least 5 cm high.**



**ACTIVITY 2. Adjust the rate of water flow to less than 3 ml/sec. Move the hose back and forth as the water falls on the hill. Notice what happens to the sand as the water runs off the hill. Try to decide why gullies begin to form and how they become longer.**



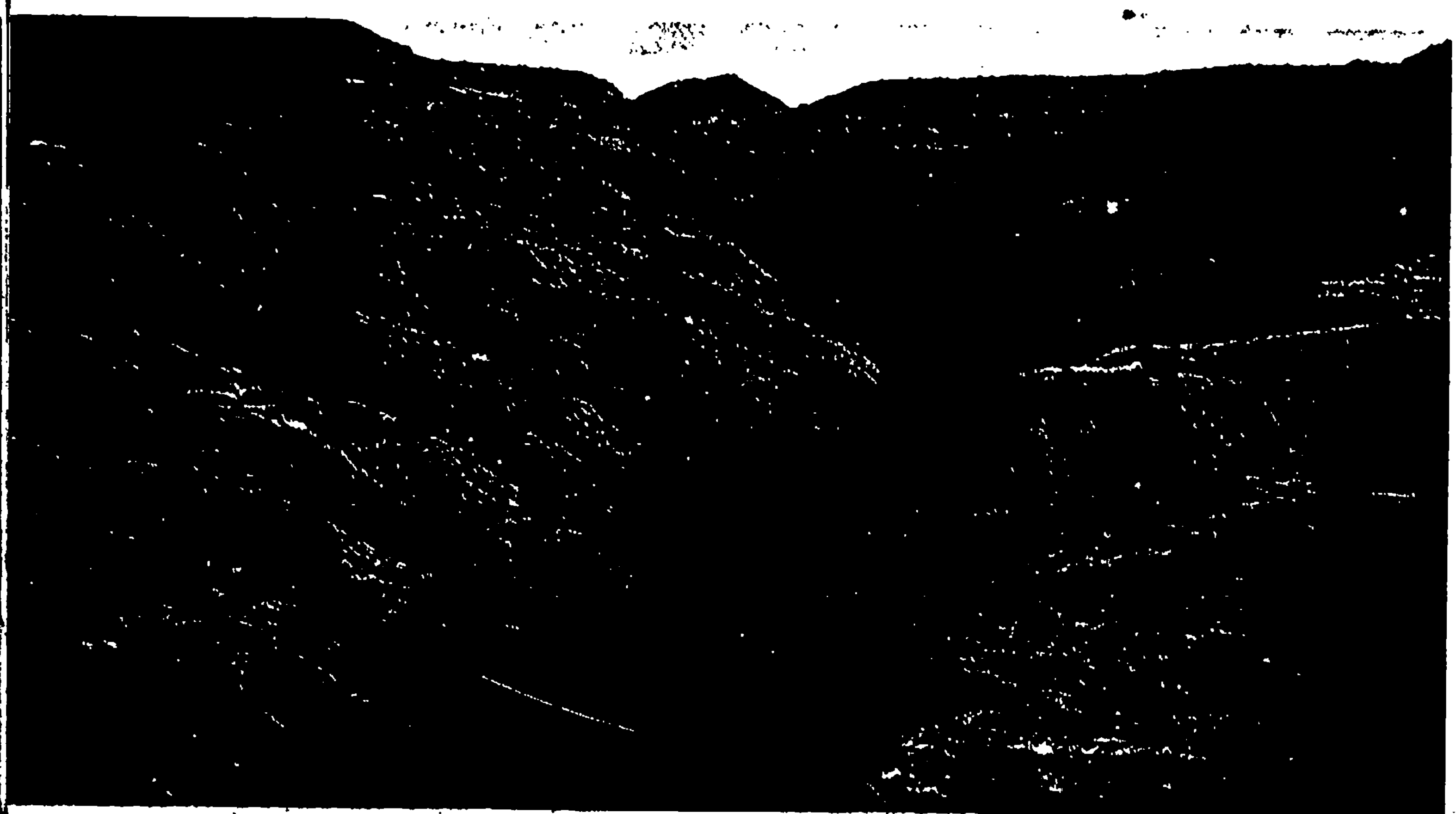



**Figure 1**

Figure 1 shows the effects of water running off a hill of fairly loose material. At one time, the area probably contained only a single gully. As water flowed into the main gully from the sides, the branches you see in the photograph formed.

Notice also that waterfalls have been formed at the tops of some of the gullies. During rainstorms, the water that pours over these falls gradually erodes away the tip of the gully. In this way, gullies become longer and longer. This process is known as *headward erosion.*

What's the difference between a gully and a canyon? Will the area in Figure 1 ever be a canyon? If you would like to know more about this, do the next resource.

# 35 Gullies and Canyons—A Comparison

Look at Figures 1 and 2. Although the small gully in Figure 2 doesn't look much like the Grand Canyon shown in Figure 1, there is a lot of similarity in the way they were formed. This resource will help you understand the differences between gullies and canyons.

**Figure 1**

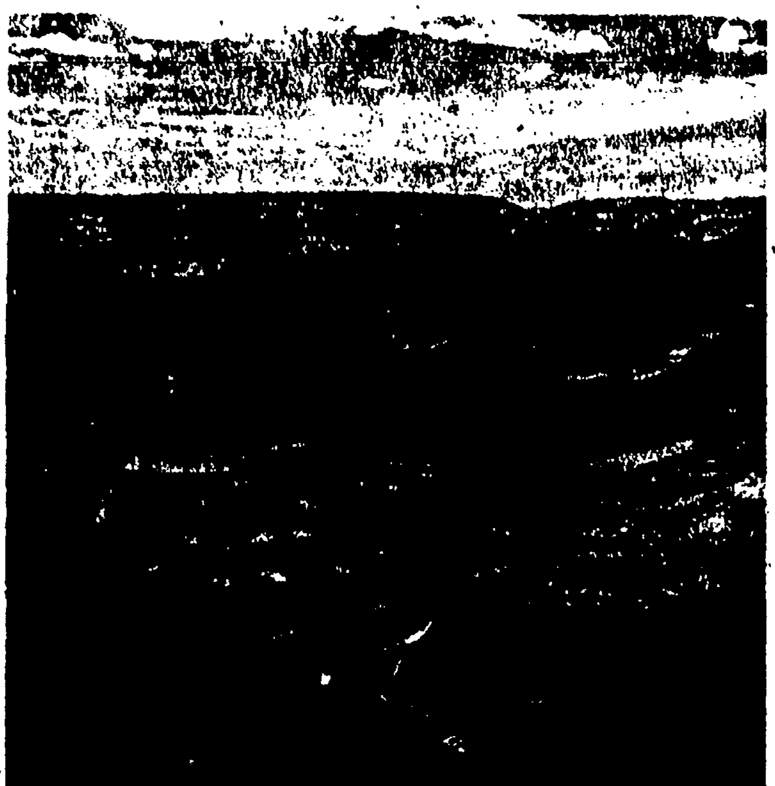


**Figure 2**

*Characteristics of Canyons*

1. The land being carved is usually hard rock that is quite resistant and breaks up into loose material very slowly.

2. Canyons usually form in a relatively dry climate. This means that very little water runs into the canyon from the sides.

3. The stream doing the carving of canyons usually originates in a much higher area.

4. Because the stream comes from a higher source, it moves through a canyon very rapidly.

5. The fast-moving stream in a canyon carries a large load of rocks. These rocks help to cause further erosion.

*Characteristics of Gullies*

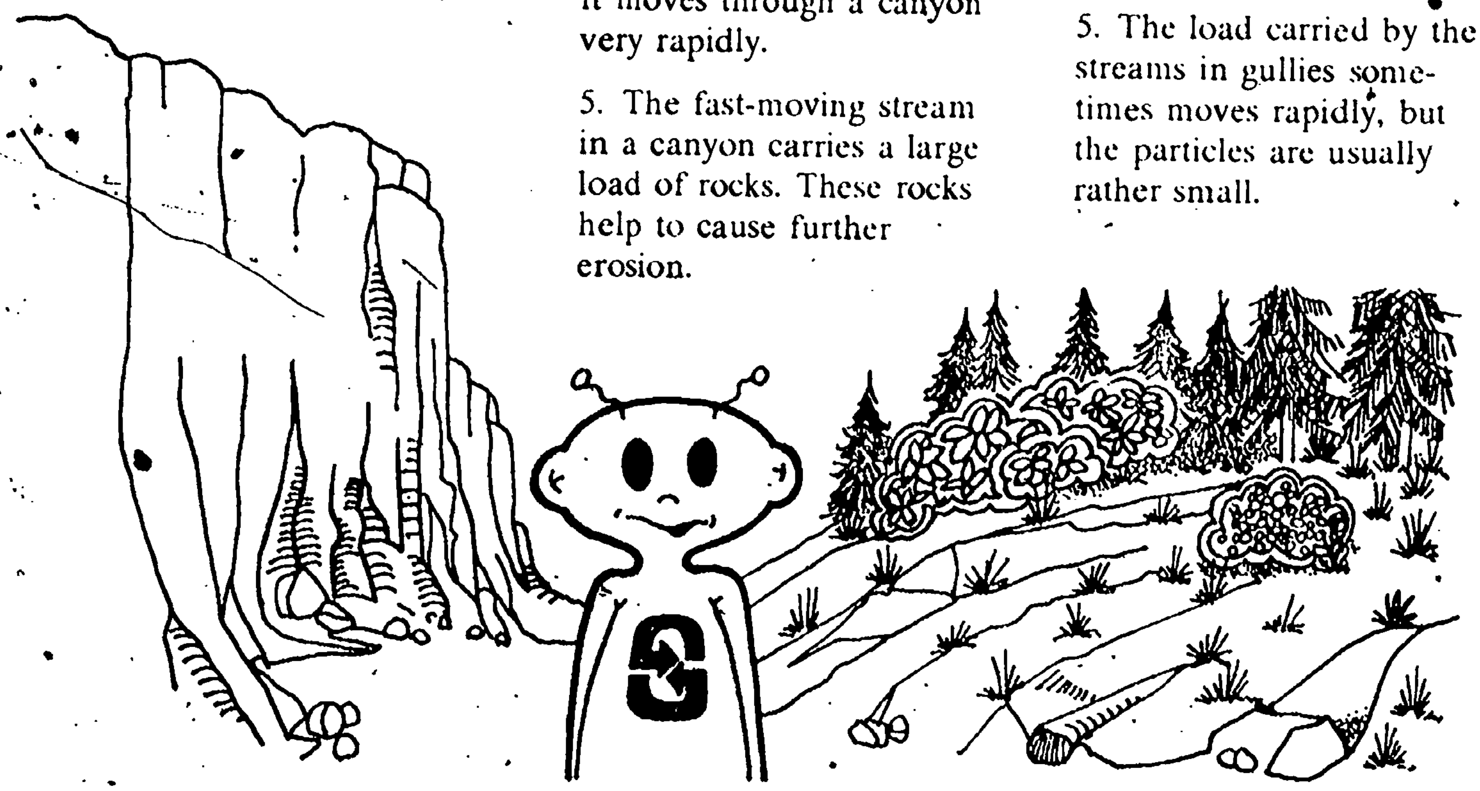
1. Loose materials from the sides of gullies wash easily into the stream at the base of a gully.

2. Rainfall is common where gullies form.

3. Runoff water from the surrounding land tumbles over the sides of the main gully and forms many branches.

4. Water flows through a gully at varying rates. The gully deepens most rapidly where the slope is steepest.

5. The load carried by the streams in gullies sometimes moves rapidly, but the particles are usually rather small.



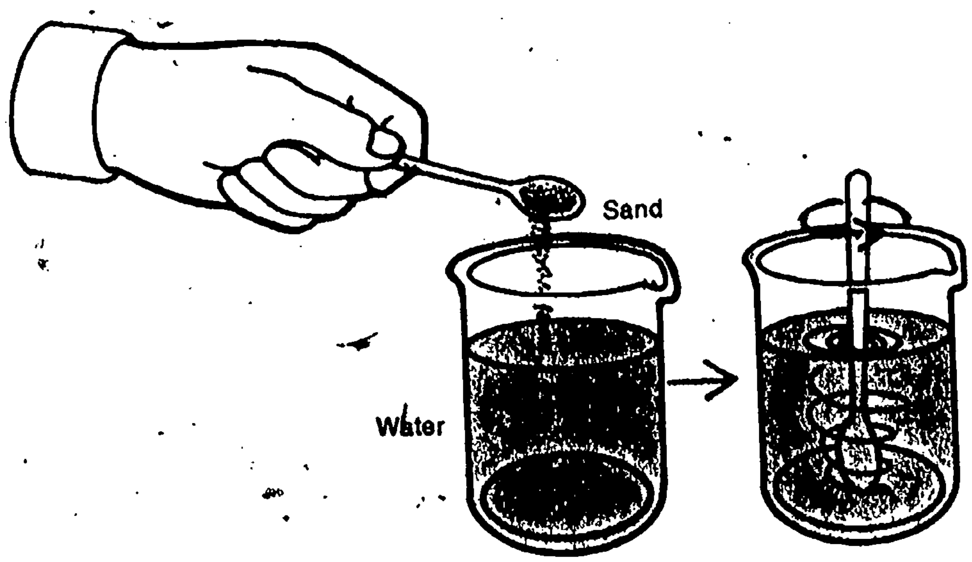
Taken as a whole, the characteristics of canyons tend to result in steep, almost vertical walls, while those of gullies produce gentle slopes. This is the most important difference between gullies and canyons.

# 36 Action of Water Moving in a Curved Path

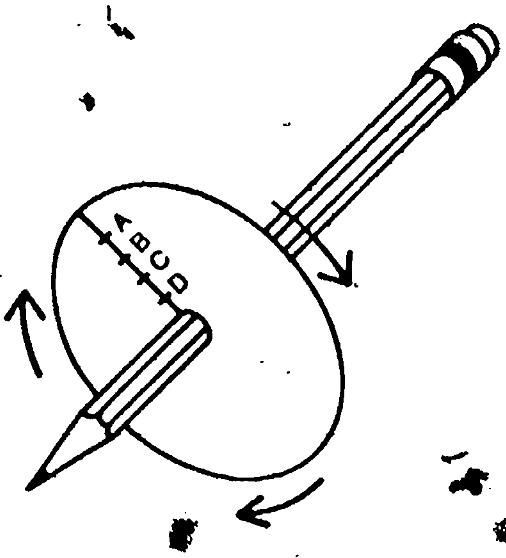
Most of the other resources deal with water flowing in a straight line. In nature, however, most rivers move through quite a number of curves. Does anything special happen to water that moves in a curved path? If so, does this produce any important effects at points like river bends? These are questions you will tackle in this resource. To answer them, you and a partner need these materials:

1 complete stream-table setup
1 paper disk, 6 cm in diameter
1 teaspoon white sand
1 beaker

First, get some water moving in a curved path and look at it.




**ACTIVITY 1. Place 1 teaspoon sand in a beaker three-fourths full of water. Stir the water until it swirls around in the beaker. Observe what happens to the sand.**



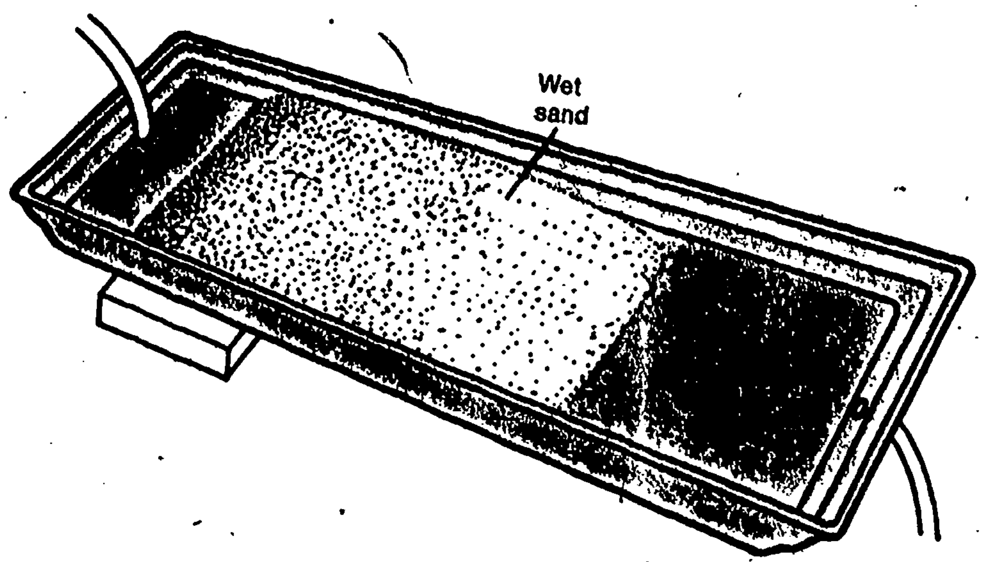

You may have been surprised to find that the sand in the swirling water piled up in the center of the beaker. Why did this happen? A simple experiment can help you decide.

**ACTIVITY 2. Mark the paper disk as shown. Push a pencil through the center of the disk and, holding the pencil between your palms, spin the disk slowly. Notice which letter moves fastest.**

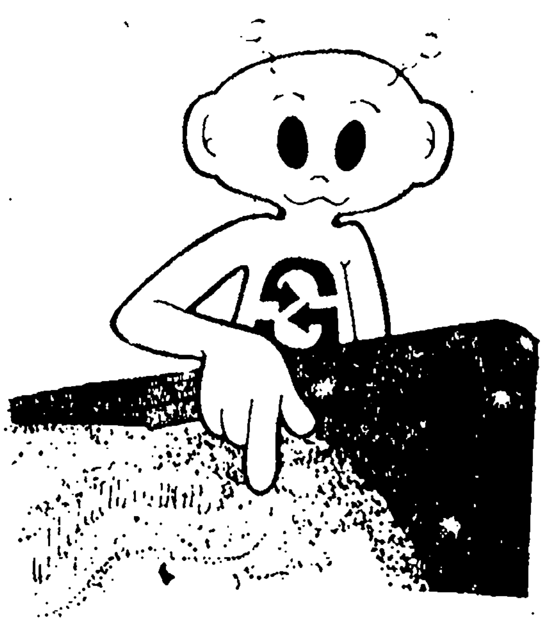
The water moving around near the outside of the beaker clearly traveled a greater distance in the same time than did the water near the center. Described another way, the water near the edge traveled at a greater speed (or velocity) than did the water in the center.

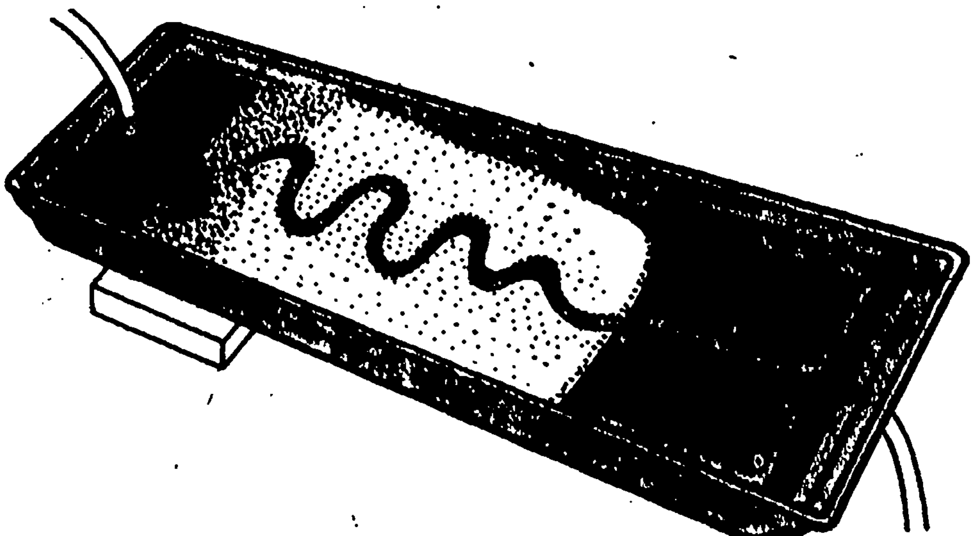
The slower water moves, the more likely it is to drop whatever load it is carrying. This fact is very important as water moves in a curved path. The next activity will allow you to learn still more about this.

**ACTIVITY 3. Arrange the sand on the stream table as shown. Be sure that the sand is wet, piled deeply enough, and contoured according to the sketch.**



**ACTIVITY 4. Trace a path with your finger as shown. The path should be cut almost to the bottom of the sand (about $2\frac{1}{2}$ cm deep). Adjust the flow of water into the reservoir to about 5 ml/sec, and allow the water to flow down the path for 20 minutes. Then turn off the water, but leave the sand in place.**





Now take a look at Figure 1, which shows the Apalachicola River in Florida, and Figure 2, which shows a small stream in North Dakota. Notice that sand is deposited on the inner parts of each river bend, where the water moves slowest. On the outer part of the curve, the water moves fast enough to keep the sand from falling out. In fact, the water erodes the outer bank away as it rounds the corner.

**Figure 1**

**Figure 2**

Figure 3 diagrams what a river does to the outer bank of a river bend. Notice that the water, along with the rocks and sand it carries, is thrown against the outer bank. This produces an undercutting of the bank and causes the rim of the bank to overhang more and more. Finally the rim collapses, becoming part of the load that will act on banks farther downstream.

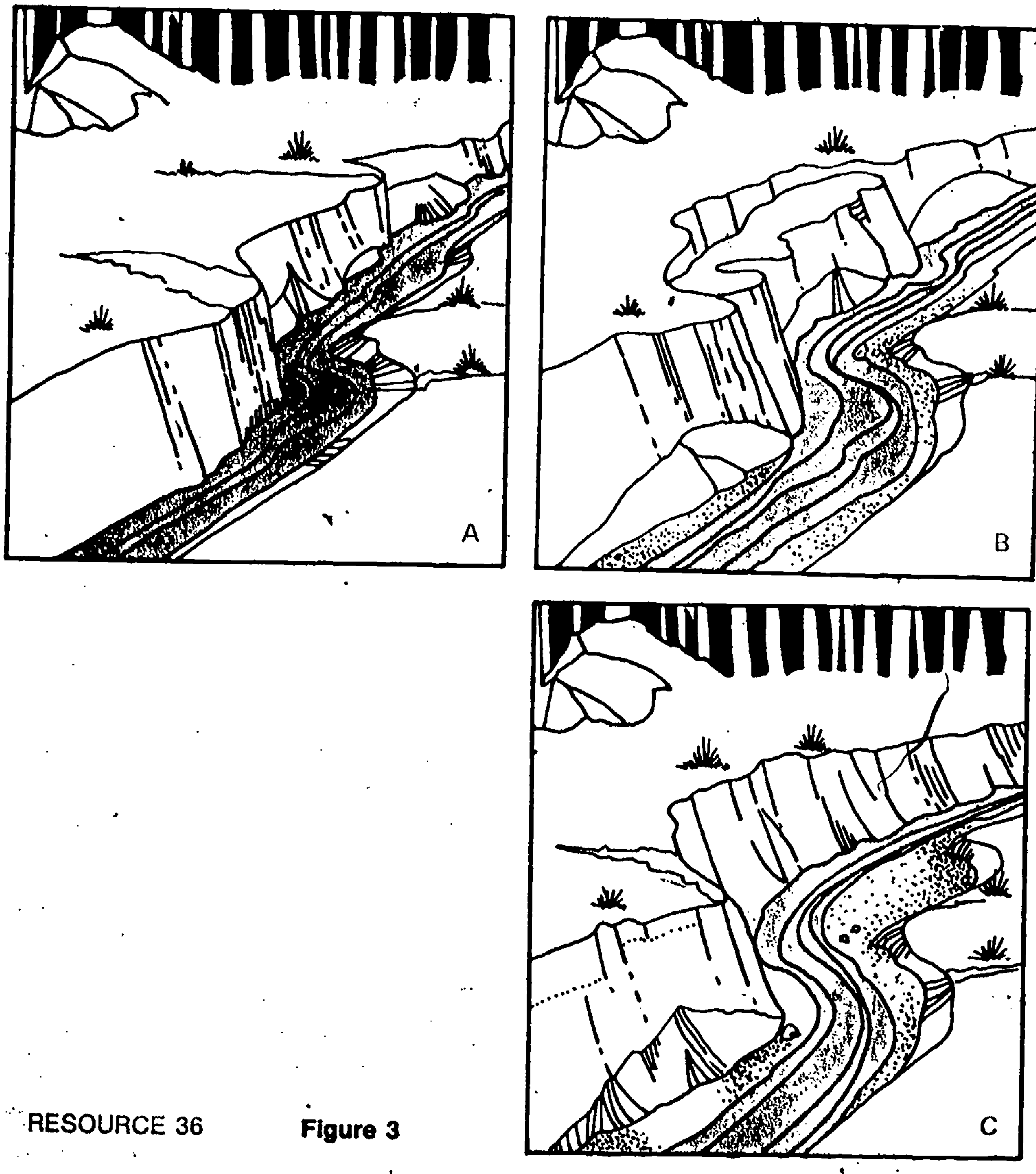


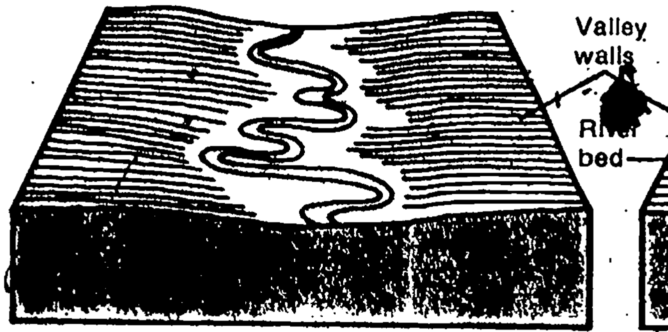



**Figure 3**

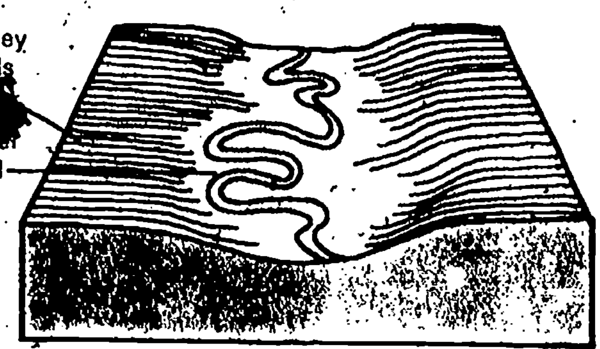
Notice that the cutting and deposition at the bends caused the stream to swing wider and wider. This is what happens in nature with fairly slow-moving rivers. But sometimes, during periods of heavy rain, these same rivers become flooded, and their rate of flow increases. You can duplicate this effect by increasing the rate of flow of water into the stream-table reservoir to 15 ml/sec. Notice what effect this has upon the meanders in the stream bed.

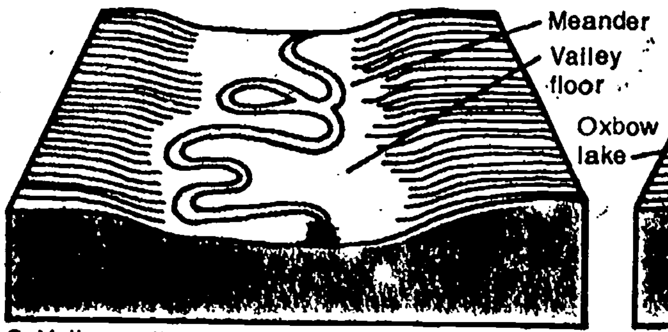
The big point shown by the activities you've just done is that a river can cut a valley much wider than itself. It does this by meandering slowly in its course. This action is summarized in the series of sketches in Figure 4.

**Figure 4**

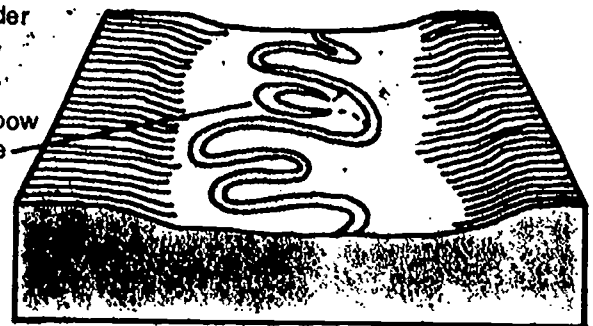


A. River meanders within valley walls.

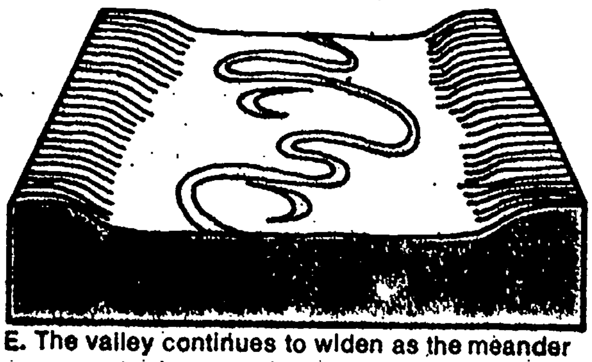

B. Position of river bed constantly changes.

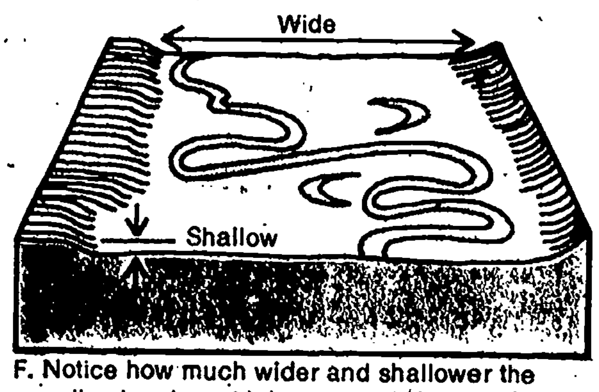


C. Valley walls widen as meander bend cuts into the valley walls, picking up rocks and soil, and depositing them along the valley floor.



D. Dotted lines show old river path. This oxbow lake was formed when the river shortened its path downhill.


E. The valley continues to widen as the meander moves to the opposite side of the valley.



F. Notice how much wider and shallower the valley has become because of the river carving away the valley walls.

CLUSTER E

# 37 Dunes on the Move

Behind many beaches and on many island desert plains, there are great piles of sand called *dunes*. St. George's Island, in the Gulf of Mexico, has many sand dunes. One of these dunes is shown in Figure 1. You can see the Gulf in the distance, beyond the dune.

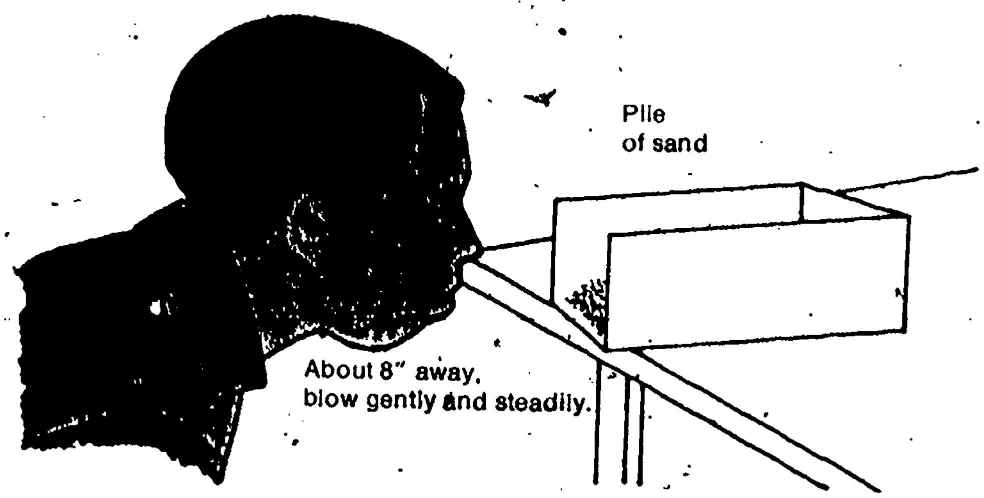
Figure 1

Predict how the pattern of markings was produced on the face of the dune. You can check your prediction by finding a partner to help you with this activity. You will need:

Cardboard box (size of shoe box), with one end removed
Handful of sand

**ACTIVITY 1. Build a small sand dune near the open end of your box. Put your mouth level with the bottom of the box, and blow gently but steadily. Move your head from side to side to distribute the wind evenly across the pile of sand.**

**Take turns with your partner until the sand pile moves about 10 cm (4 in).**




☐1. What happens to the sand on the side of the pile facing you? What happens on the other side?

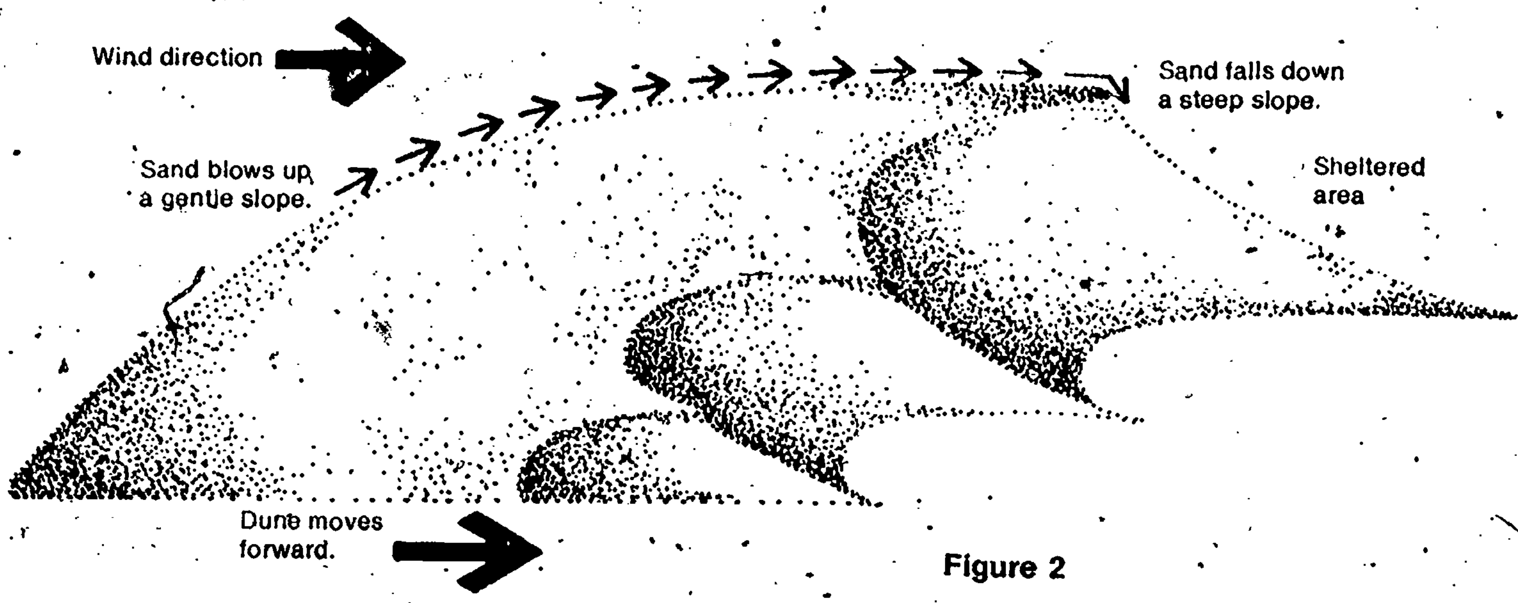



**Figure 2**

You have just simulated the action of the wind on beach or desert sand. In both places, the wind builds up piles of sand called *dunes*, as shown in Figure 2. Dunes can be moved considerable distances each year unless they encounter some obstacle that slows or stops their progress, as in Figure 3.

Figure 3

☐2. What agent is preventing the movement of the sand dune in Figure 3?

In the simulation experiment you carried out, you observed the sand grains rolling down the far side of the dune. Imagine a period of weather with little wind, followed by a period with strong wind, followed by another calm period, etc. Then look carefully at Figure 4, a close-up of the dune you examined in Figure 3.

Figure 4

[ ]3. What do you see at X, and what caused this feature?

[ ]4. In what way does the X feature differ from the structure of a sand deposit formed in water? (Hint: Don't guess  think about the simulation experiment results and look back to Resource 7.)

Bedding of this kind is called *dune bedding* and is one way of deciding whether a sedimentary rock is wind-deposited or water-deposited.

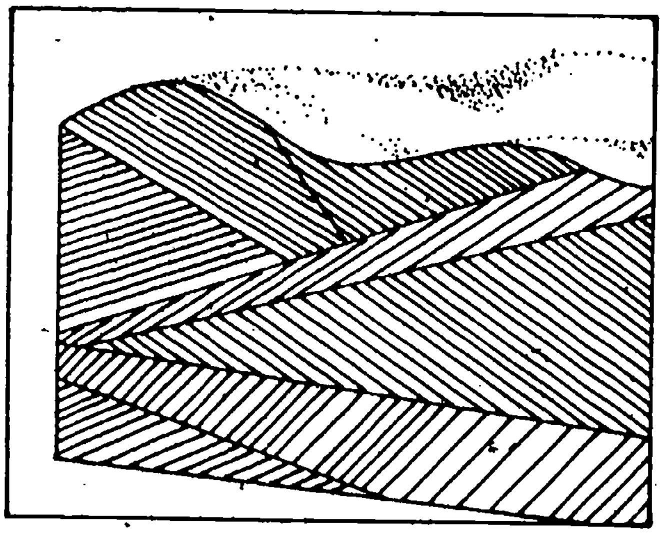


Figure 5A

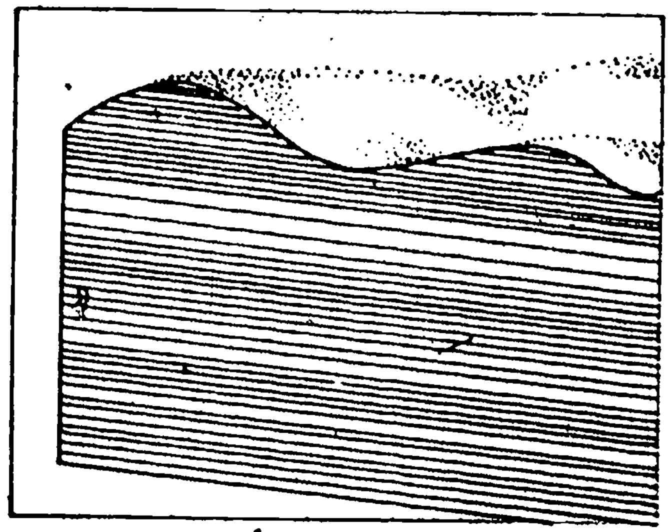
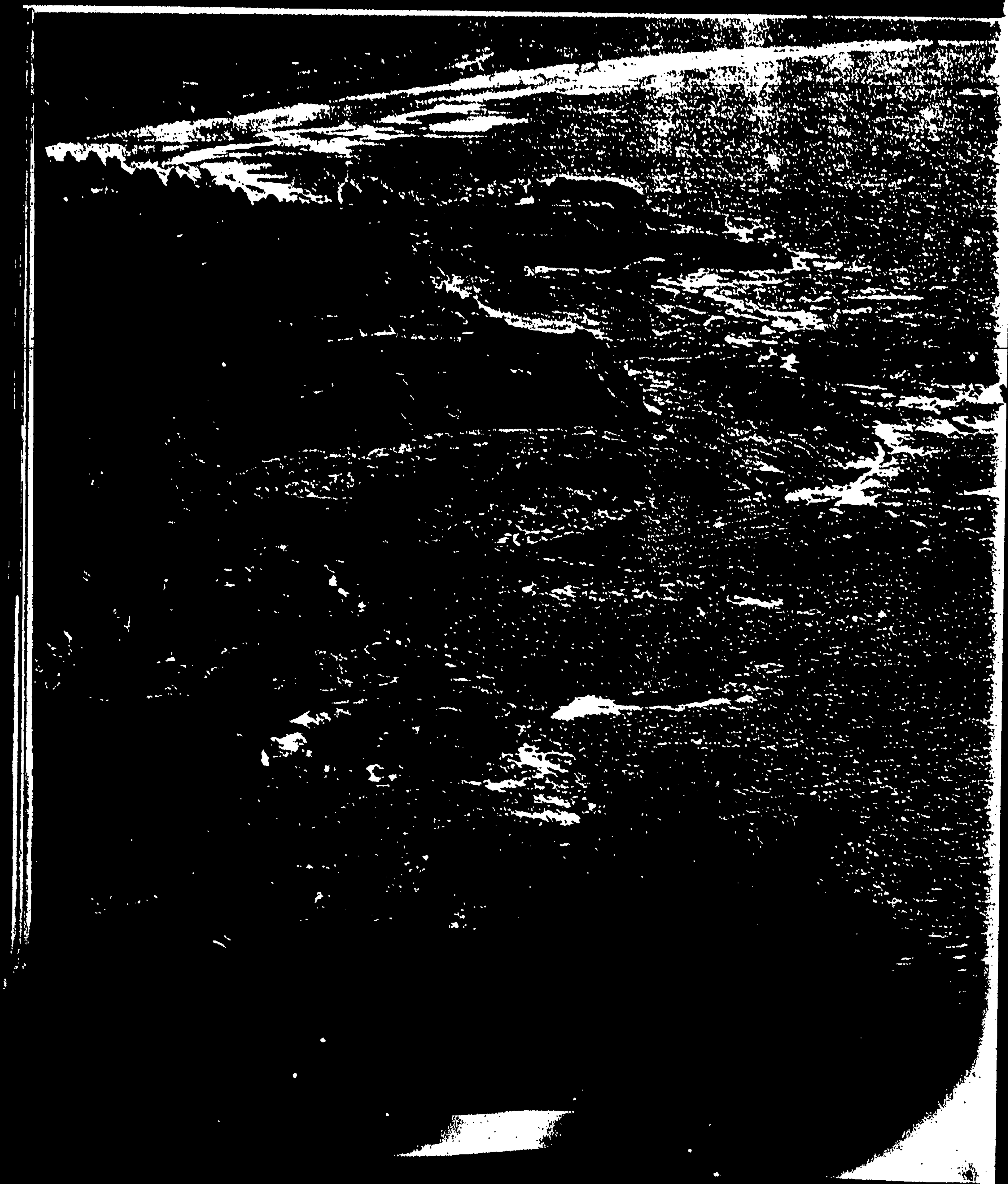


Figure 5B

[ ]5. Which figure (5A or 5B) represents dune bedding? What was the direction of the prevailing wind?

In this resource, you have looked at wind transport of sand. Sand grains are blown along near the ground and in the process become angular and sharp. They move up the face of dunes and fall down the other side. In this way, a dune may move long distances over a period of years. A new dune starts behind it, and soon a parallel set of dunes is marching across a landscape. Dunes bury objects in their path and may kill vegetation. If the vegetation can grow thick and tall enough not to be buried, it may eventually hold the sand and stop it from moving.



# The Shorelands

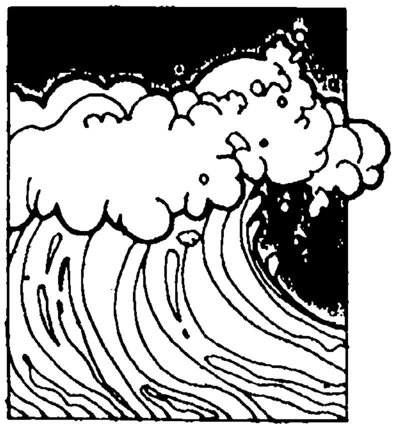
Chapter 4

If you've never tasted a peach, you can hardly imagine its flavor. Fortunately, the same problem doesn't exist with land features. The student who lives in an interior state like Iowa may still have a good idea of what the shorelands of the United States are like even though he has never visited them. In fact, he may have an even better idea than a resident of a coastal region. The latter may sometimes think that all coastlines are like his own, forgetting how varied are the lands that border our major lakes, the Gulf of Mexico, and the Pacific and Atlantic oceans. The geologic features of the shorelands are different in different regions.

Figure 4-1

Study Figure 4-1 carefully. You should be able to see many of the features of the shorelands sector that you first noted in Figure 1-4. Why is this coastline narrow and rocky in some places and wide and sandy in others? Why are some waves almost straight and others curved, and why do they break where they do? How did the coastline get to be the way it is, and what will it look like in the future?

These are not easy questions to answer. As you work through this chapter, you should find that you can explain how each feature of the shorelands was formed. And you may even predict what may happen to it in the future.



### The force of waves

Any surfer who has "wiped out" knows about the tremendous force of just a single wave. Chances are that he can't see how this same force changes the land. Over a period of time, however, he would be able to see the important changes. Look at the following sequence of photographs carefully. Then answer questions 4-1 and 4-2.

☐**4-1.** Which occurred more rapidly, the change from Figure 4-2 to 4-3 or the change from Figure 4-3 to 4-4?

☐**4-2.** Did the same forces of erosion that brought about the change seen in Figure 4-3 cause the change seen in Figure 4-4? Explain.

Figure 4-2

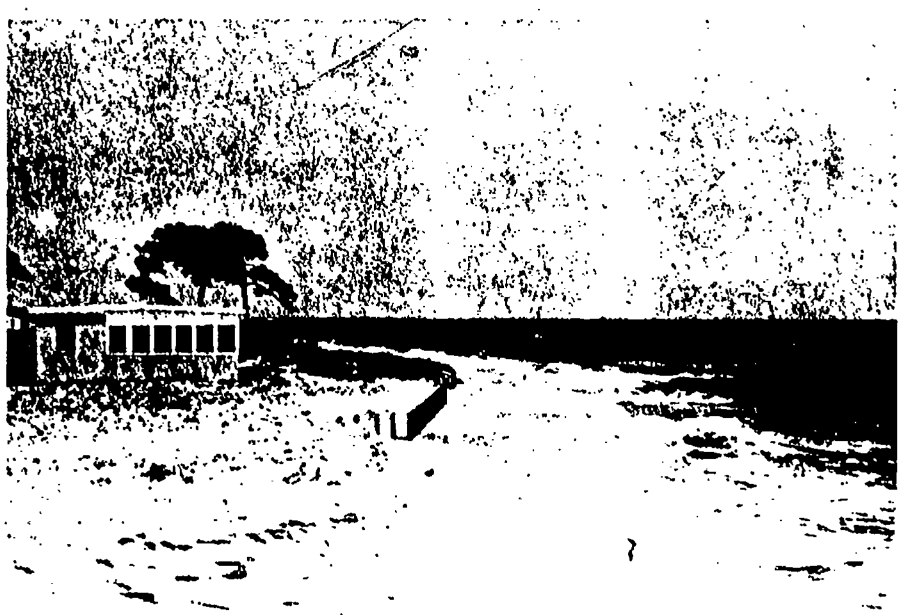
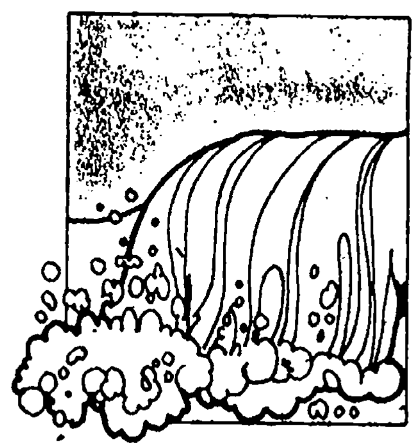


Figure 4-3

Figure 4-4

Were you able to guess what happened?

Those pictures in Figures 4-2, 4-3, and 4-4 were taken over a period of several years. The last picture was taken shortly after Hurricane Betsy hit. (If the owner of the beach cottage had read this chapter before he built the cottage, he might have chosen a different location! Perhaps you will see why as you continue reading.)



**Waves against the beach**

Most changes along the seashore are not as apparent as those just shown, however. When you go to the beach, you see the results of many different processes. Look at the two beaches shown in Figures 4-5 and 4-6.

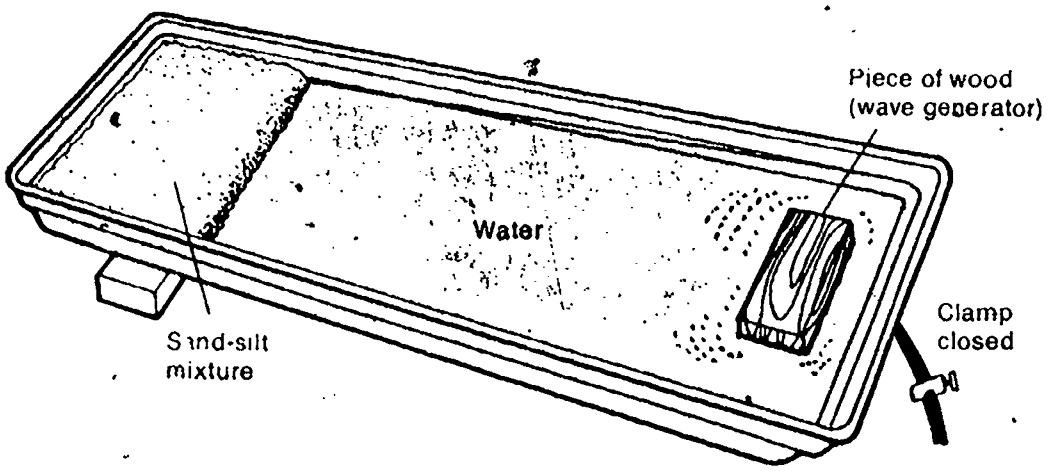
Figure 4-5

Figure 4-6

Figure 4-5 shows a beach in Florida along the Gulf of Mexico. Figure 4-6 shows a Maine beach on the Atlantic Coast. Notice some of the big differences in these beaches. One is sandy with a gradual slope, whereas the other is rocky with a steep drop-off. During the winter, the rocky beach is battered by waves 10 to 15 feet in height, whereas the sandy beach seldom has waves more than 4 or 5 feet high. If you were to dig down through the sand, you would find that the sand layer is very thick. If you tried to dig under the rock beach, you'd probably bend your shovel!

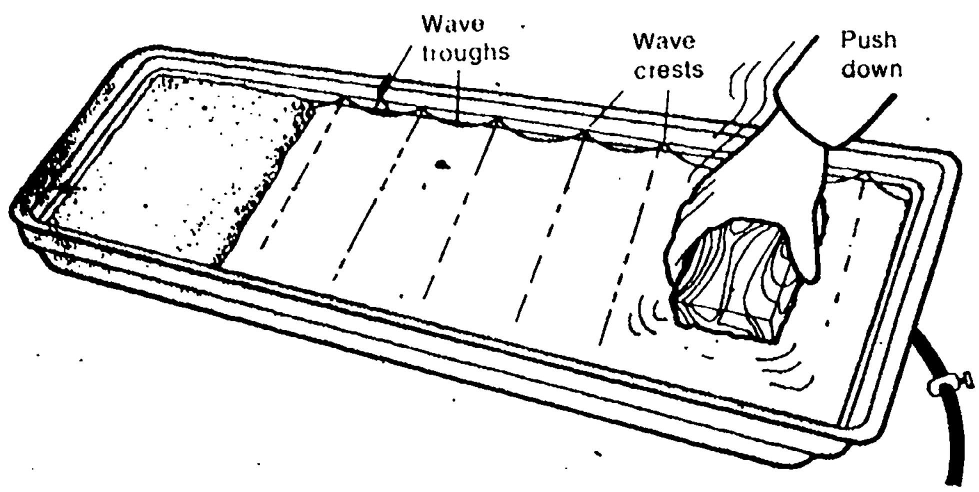
Kinetic energy from winds and storms far out at sea is transferred to the water to produce waves. The energy is carried toward this coast by waves. The waves release their energy when they reach shallow water and break. Energy can be carried to the shore like this wherever there is a big expanse of water subject to winds and storms.

You can investigate how this energy can affect beaches by simulation experiments that use the stream tables. Work with at least one partner for this activity.



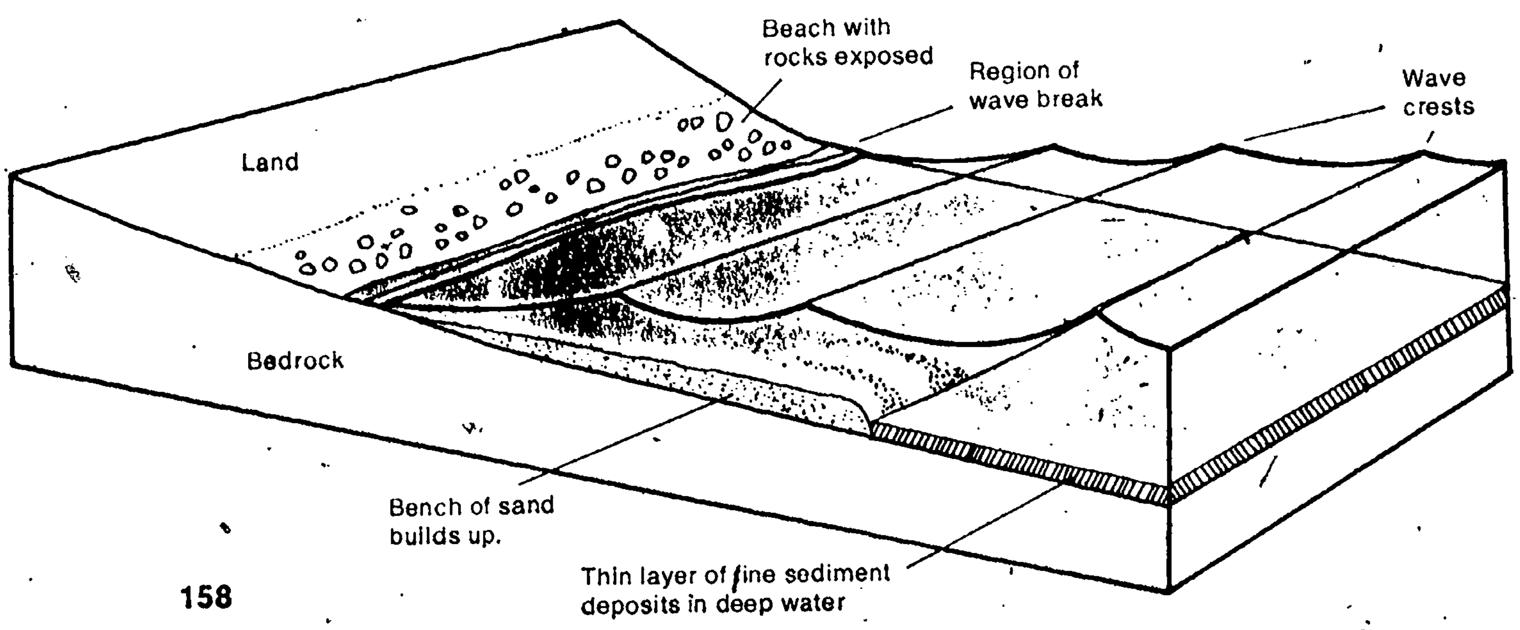

**ACTIVITY 4-1. Pile the mixture of sand and silt at one end of the stream table to make a sloping surface. Use a block to tilt the table. Then fill with water until the bottom edge of the sand is covered to a depth of about 3 cm. Put a few small pieces of gravel near the water's edge and cover them with sand. Note the relationship between the sand-silt mixture and the water line.**

ACTIVITY 4-2. Produce storm waves by pressing down firmly on a piece of wood with the palm of your hand, as shown, once every 3 seconds. Keep this up for about 5 minutes and carefully observe the sand-silt mixture. Then let the water settle for a few minutes. (Keep the stream table set up and do not alter the sand.)




During storms, high-energy waves reach the shoreline. The action of these waves on the beach is similar to the effect in your stream-table model. The effect should look something like what is shown in Figure 4-7.

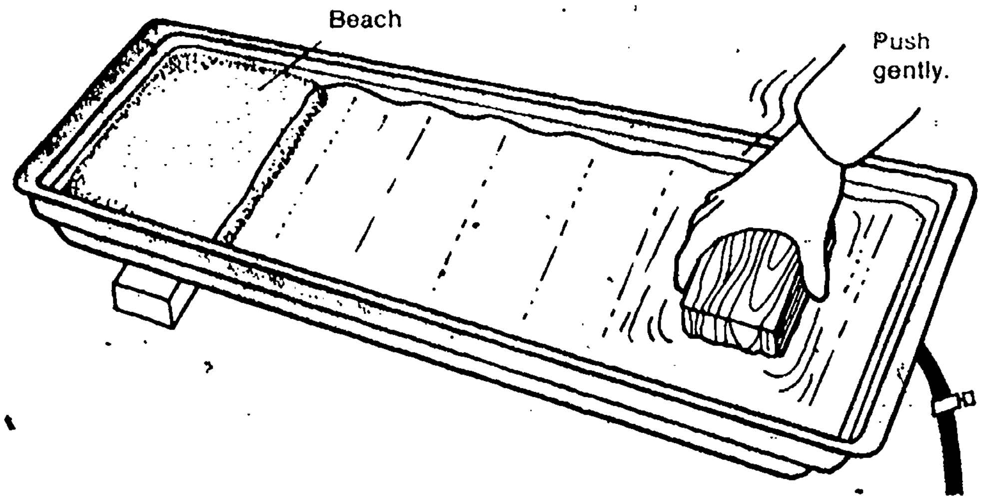
Figure 4-7



The strong waves attack the beach, shifting the sand out to sea to form a *bench*. Rocks are exposed along the shore, and most of the very fine particles are carried out into deep water, where, in calmer weather, they slowly drop to the bottom.

Some shorelines that are exposed to high-energy waves all the time may not have any sand. Only smooth pebbles are left on such shores.

**ACTIVITY 4-3. Continue your experiment, using the same stream table that was exposed to high-energy waves. Leave everything as it was. This time, however, push very *gently* so that you produce low-energy, gentle waves. Continue this for about 5 minutes, watching what happens when the waves reach shore.**




☐ **4-3.** What effect do the low-energy waves have on the beach? How is this different from the high-energy storm waves crashing into the beach?

This time, you should have observed the slow building up of the beach on shore. In fact, if you were patient enough to keep the gentle waves going for a long time, you might have covered up the gravel exposed during the storm. The waves will gradually shift the sand back from the underwater bench onto the beach.

The "Going, Going, Gone" pictures in Figures 4-2, 4-3, and 4-4 show what can happen to a beach when high-energy waves attack it. Storms increase the energy reaching the shore and help to erode beaches. Good weather reduces the energy level, and beaches will build up again. This cycle of change is always going on wherever the land meets a large body of water and where the shoreline is suitable for beaches to develop.

### Waves against a steep shoreline

Ocean waves can do a great deal of work to shape and change coastlines and beaches. You have just experimented with the effect of waves on a relatively low-lying shoreline. Figure 4-8 shows waves approaching a rocky coastline with steep cliffs.

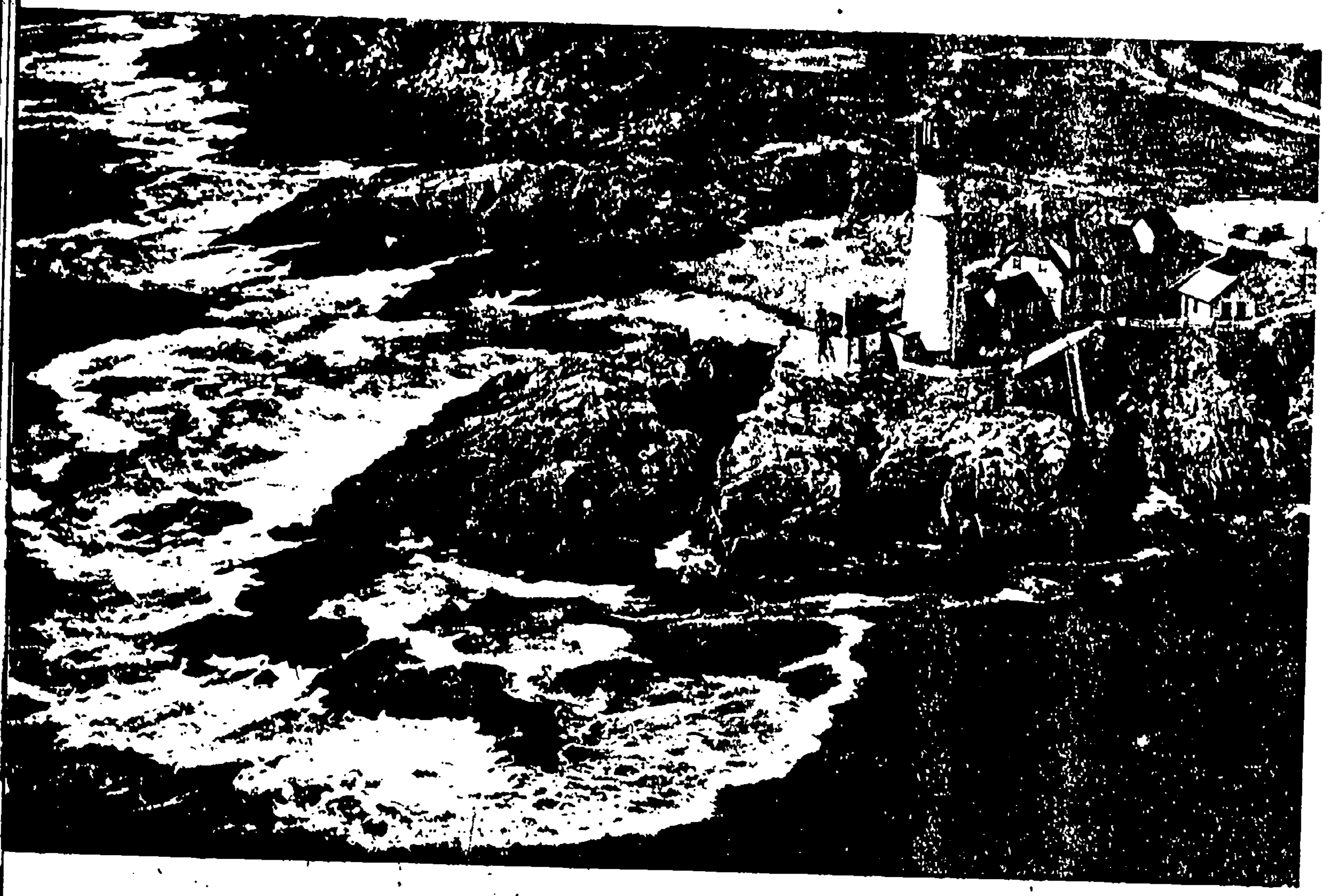


Figure 4-8

TO CLUSTER A

☐ **4-4.** What effects do waves have on a coastline like the one shown in Figure 4-8?

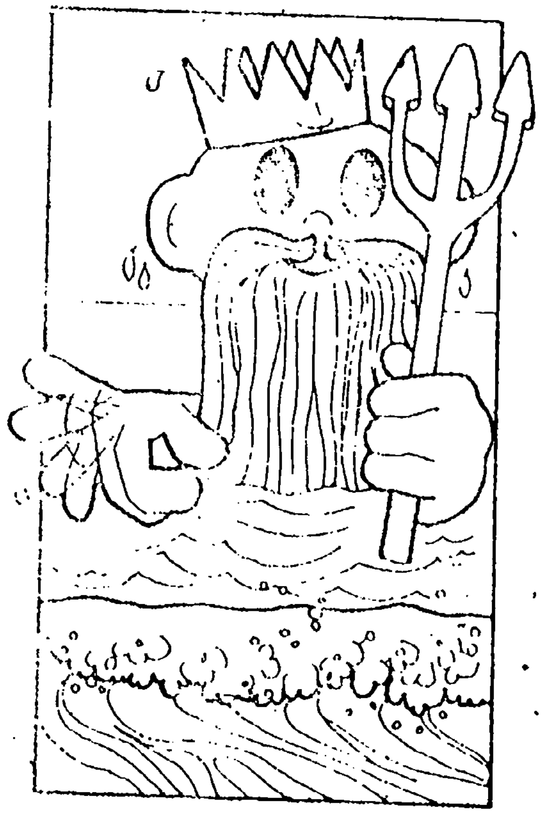
Figure 4-9

When waves crack against a steep shoreline instead of on a fairly wide and flat beach, the effects on the landscape are quite different. Figure 4-9 shows some features of a typical rocky coast.

The figure shows an outcrop with two sea caves. Look carefully near the top of the caves and you should be able to see evidence of the high-tide line. (Hint: Look for a color change.)

The top of the cave is just above high-tide level. Outside the cave, the beach is steep and curves back away from the rock outcropping in which the cave is located.

[ ]4-5. Based on your study of waves and their effect on steep shorelines, what factors do you think affect the rate at which the cave in Figure 4-9 is carved out of rock?



### Ocean waves—a better look

If you look at Figure 4-10, you will see a series of waves approaching a beach. As the waves get closer to shore, they "break" and spread onto the beach.

Figure 4-10

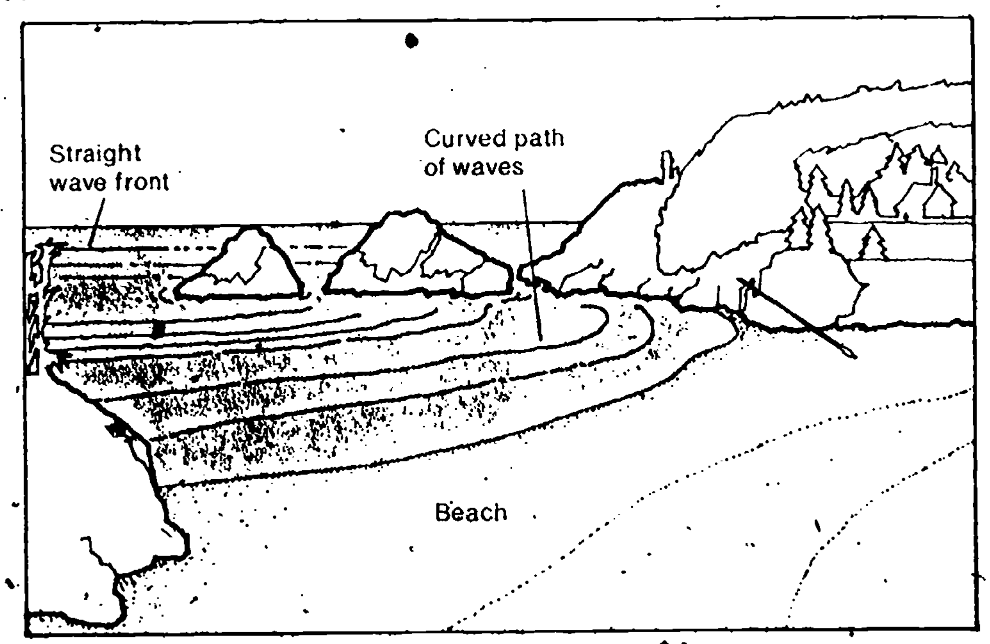
BIOCLUSTER A

[ ] 4-6. Why do the waves break as they get closer to shore?

You should have found that the ocean wave breaks because the sea bottom, which slopes upward as you approach the shore, interferes with the circular motion of the wave.

Look back again at Figure 4-10. The waves approaching the shore that you see in the photograph are entering a bay. On closer inspection, you see that the wave front within the bay takes on a curved path. Figure 4-11 shows the curved fronts approaching the shore.

Figure 4-11



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Farther out to sea, the wave fronts are not curved, but are straight.

[ ]4-7. Find out why the waves bend as they enter the bay, as shown in Figure 4-11. Also, what do you predict would happen to straight waves approaching a shoreline, as shown in Figure 4-12? Make a sketch and pencil in your prediction. What would happen to waves approaching a shoreline at an angle, as shown in Figure 4-13? Make a sketch and pencil in your prediction.

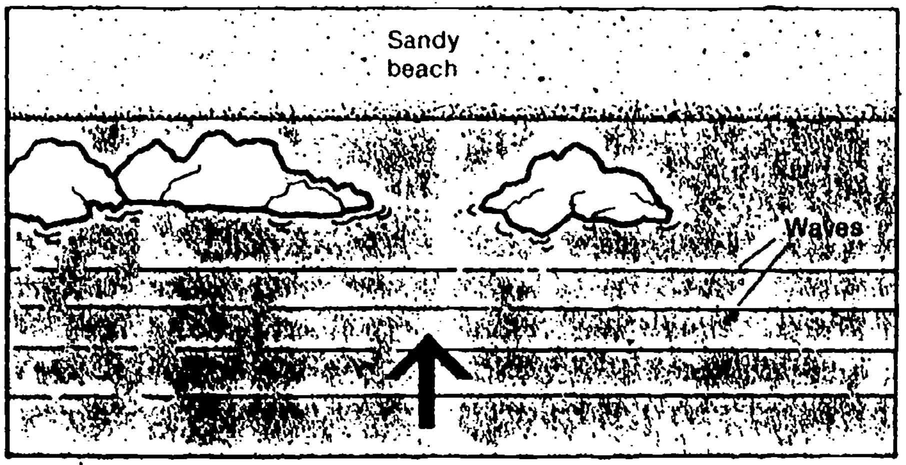



Figure 4-12

Waves moving in direction of arrow

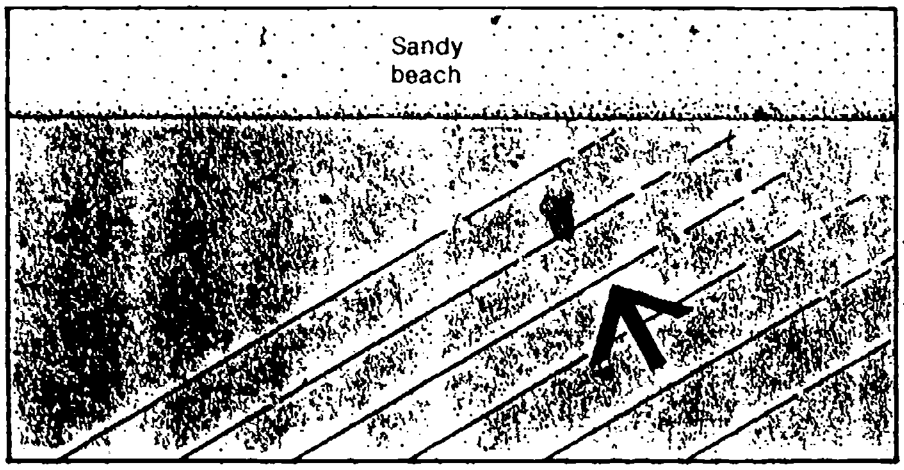



Figure 4-13

## Another ocean motion

Figure 4-14 shows two photographs of the same ship, docked at the same pier, at two different times of the same day. As you can see, the level of the water has changed drastically from one picture to the other.

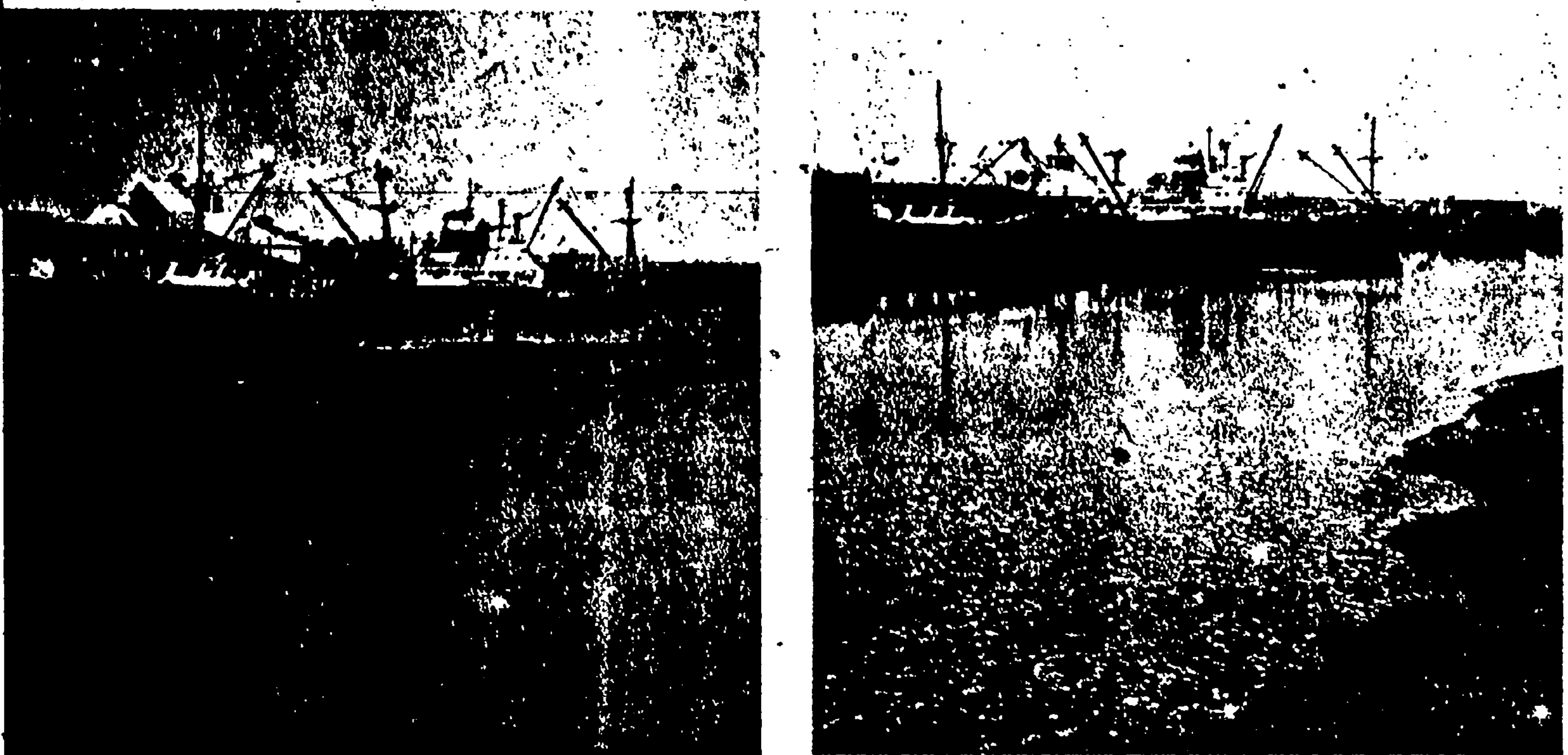


Figure 4-14

☐ 4-8. Why does the level of the sea change and what effect does a tidal change have on a coastline like that shown in Figure 4-14?

#### Interpreting a seacoast

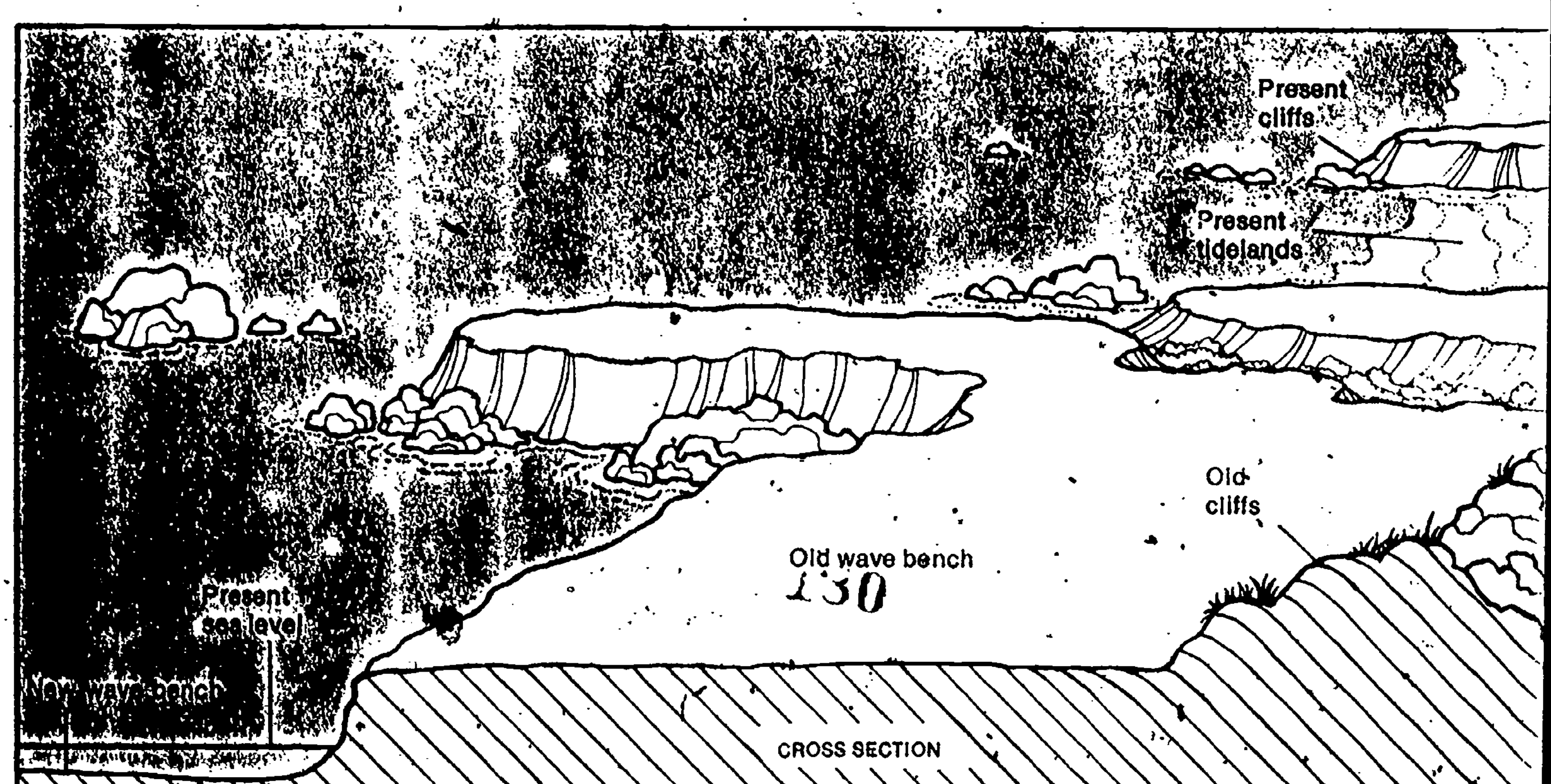
The combined effect of ocean waves and tidal changes produces a great variety of seacoast landscapes. A shore of hard, resistant igneous rock will develop a different seacoast appearance than a shore of soft sedimentary rock. Seacoasts that are subjected to many storms will be eroded more rapidly than those with few storms.

When a geologist tries to interpret a landscape, he looks for evidence of the changes that have been taking place. He tries to figure out what caused them, just as you've been doing. Figure 4-15 contains evidence of a change that took thousands of years to happen. Can you spot the evidence?

Figure 4-15

☐**4-9.** Interpret (describe and explain) how you think this coastline got to be the way it is. Here are some clues to help you. Notice the rocky outcroppings in the foreground. Do they resemble the results of erosion you've been studying? What about the flat, gently sloping area in the center of the picture? What area of Figure 4-15 does it resemble? Examine Figure 4-16, an artist's sketch of the same area.

Figure 4-16



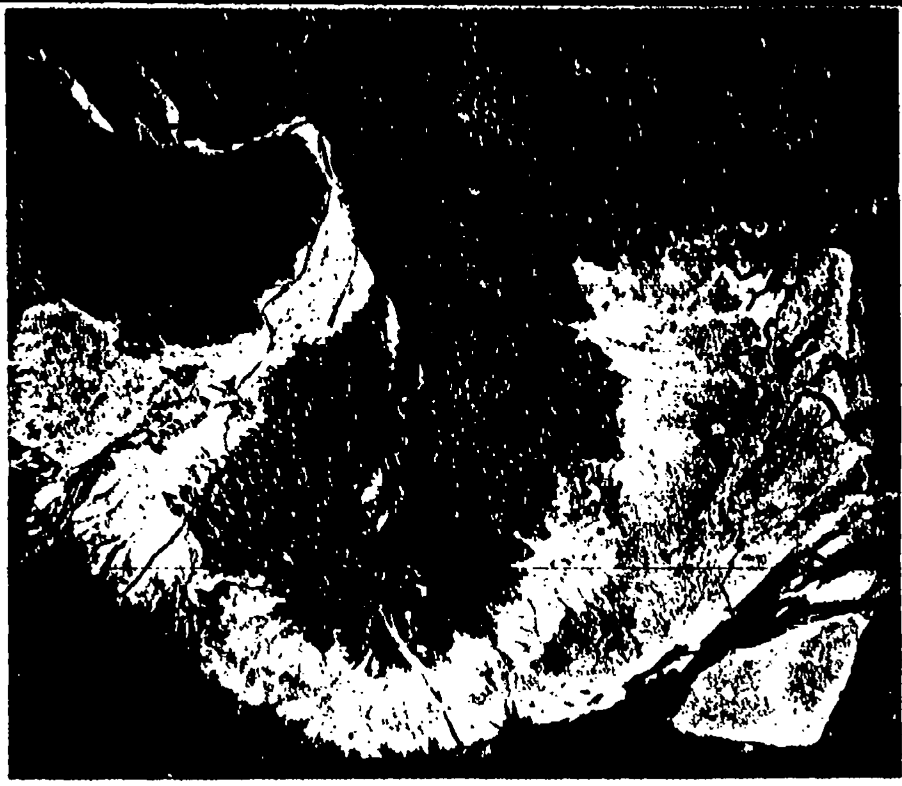
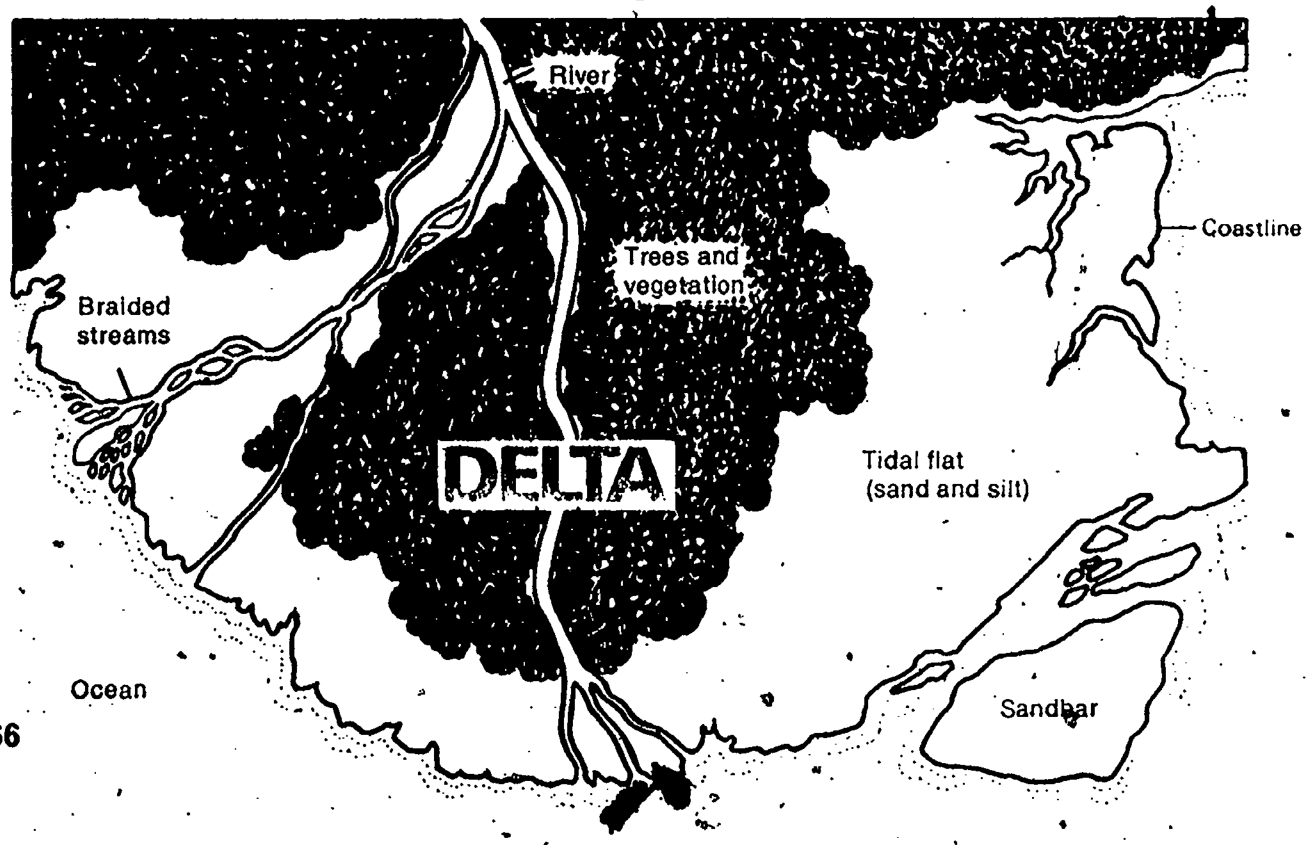


Figure 4-17

Figure 4-17 shows a view of a coastal feature that you may never have seen from this angle before. This is an aerial shot of a delta. If you were to see it from ground level, you would not be able to describe its shape unless you walked around the edges as well as across it. Figure 4-18 shows a diagram of the same region.

Figure 4-18



This delta is built up from sand and silt sediments. The plants on it obviously started growing after the sediments began to accumulate. Some of the larger trees are more than a hundred years old. Notice that in the right side of the photo the delta appears to have been growing faster and that a sandbar has formed.

[ ]**4-10.** Where did the sand and silt that formed this delta come from and how have the ocean tides, currents, and wave action helped shape the delta?

Ocean currents and wave action are at work along all coasts. Sometimes the currents flow parallel to the shore, and at other times they curve in or out. Usually they go in one general direction for months and months. Only occasionally do they change speed or direction. Waves, on the other hand, usually approach the shore at an angle that changes as the wind changes. (Sometimes the wind blows out to sea!)

**Figure 4-19**

The *spit* shown in Figure 4-19 has built up where the ocean currents and the wave action are working together for at least part of the year to deposit sand at the mouth of the river. Both the river and the ocean carry sediments.

TO CLUSTER C

4-11. How are wave direction and ocean currents involved in the shaping of the spit shown in Figure 4-19?

Some rivers do not form deltas or spits where they empty into the sea. Rivers like the Columbia, the Delaware, the St. John, the St. Lawrence, and the ones that empty into Chesapeake Bay have deepwater channels (called *tidal estuaries* or *fiords*, depending on where they were formed). These channels may extend for many miles from the sea inland.

Figure 4-20

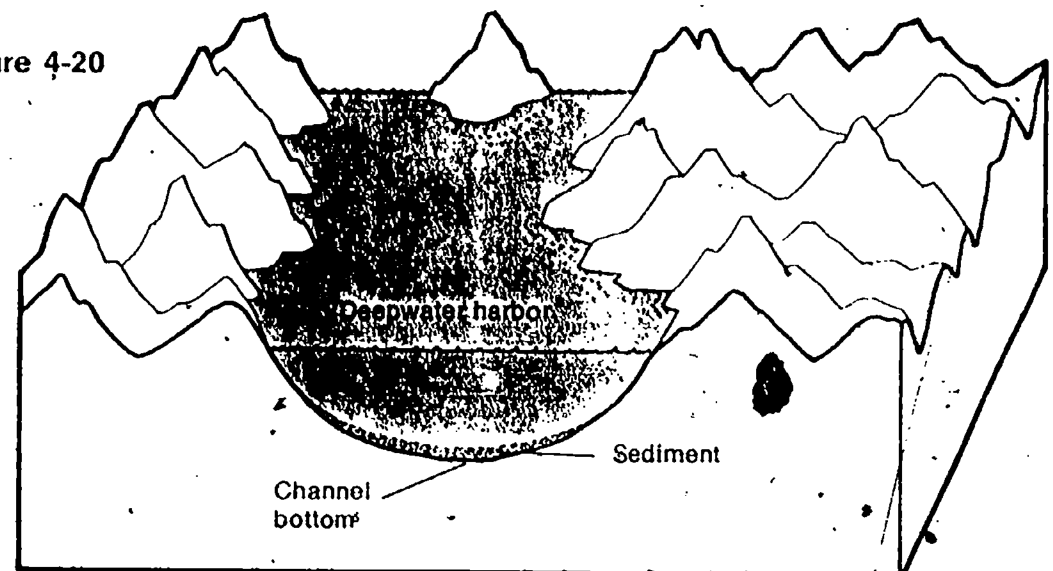
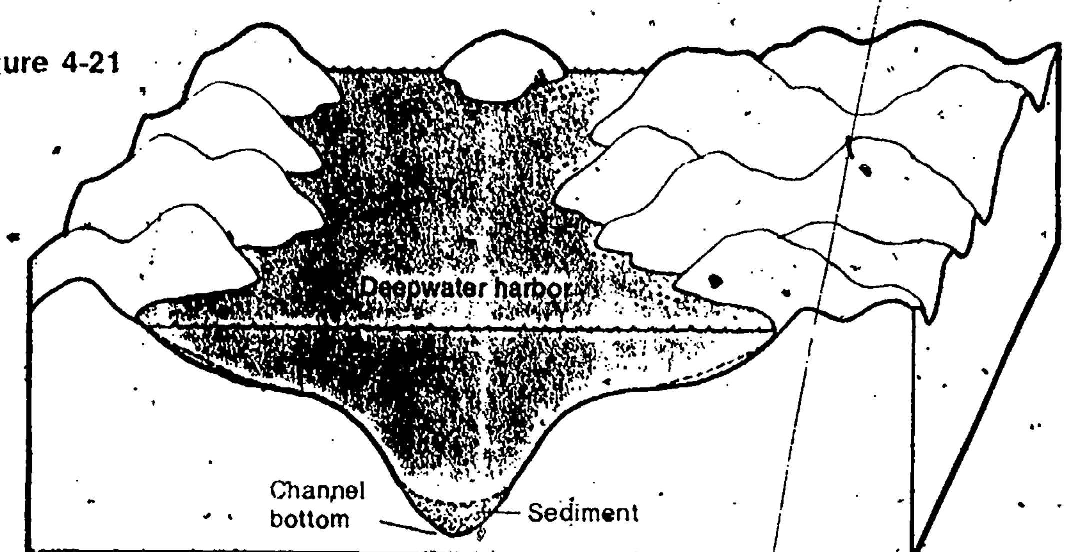



Figure 4-21



The harbors shown in Figures 4-20 and 4-21 are examples of each type. Figure 4-20 is the fiord type, and Figure 4-21 is the tidal type.

Scientists have puzzled over how these harbors were formed, but they have located some pieces of the puzzle. For one thing, the fiord type of deepwater channel is found in mountainous regions where there is much evidence of glaciation. The wide, flat channel bottom of the fiord-type harbor is typical of valleys carved by glaciers. Using depth soundings and aerial photography, scientists have discovered that the more V-shaped harbors reveal a river valley pattern and shape. The great continental glaciers that used to cover most of North America and Europe were melting and their water was running into the oceans while these harbors were developing.

[ ] **4-12.** Using this evidence, describe a model to account for the formation of the deep harbors shown in Figures 4-20 and 4-21.

**Summary**

You've seen that many different forces are involved in the shaping of the shorelands. If you've used your resources successfully, you should be able to interpret the features of the shorelands and to predict what may happen to them in the future. The stretch of shoreline shown in Figure 4-22 has many of these features. How well can you interpret this shoreline?

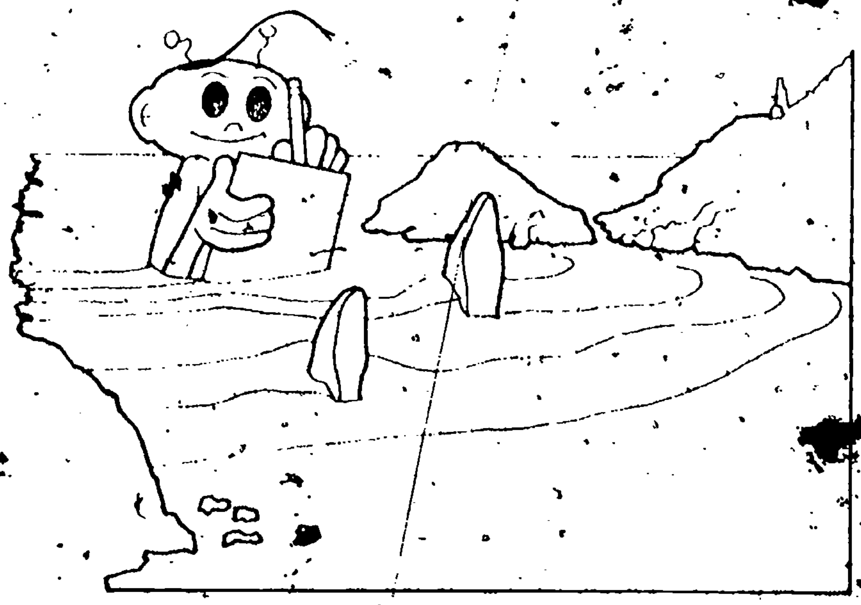


Figure 4-22

You can see that interpreting most of the landscapes of shorelands is not hard when you know the forces involved. Look over Figure 4-23. You will recognize this drawing as part of Figure 1-4 from Chapter 1. Can you identify the features of the shorelands and describe how they were formed? If you can, you should be able to visit a beach or lake near you and understand many of the processes that made them look the way they do today.

Figure 4-23


**Before going on, do Self-Evaluation 4 in your Record Book.**

# 38 Wave Action on Rocky Cliffs

CLUSTER A
(Resources 38–41)

When water crashes into rock, which is stronger, the water or the rock? Obviously, rock is stronger because it hardly changes, while the water is sent flying in all directions. Yet, over a long period of time, water can destroy cliffs, too. To simulate the process, get a notched block made of sand and plaster of paris, some mixed sand and silt, and a piece of wood, and set up a stream table as shown below. Also, scatter some gravel on the sand.

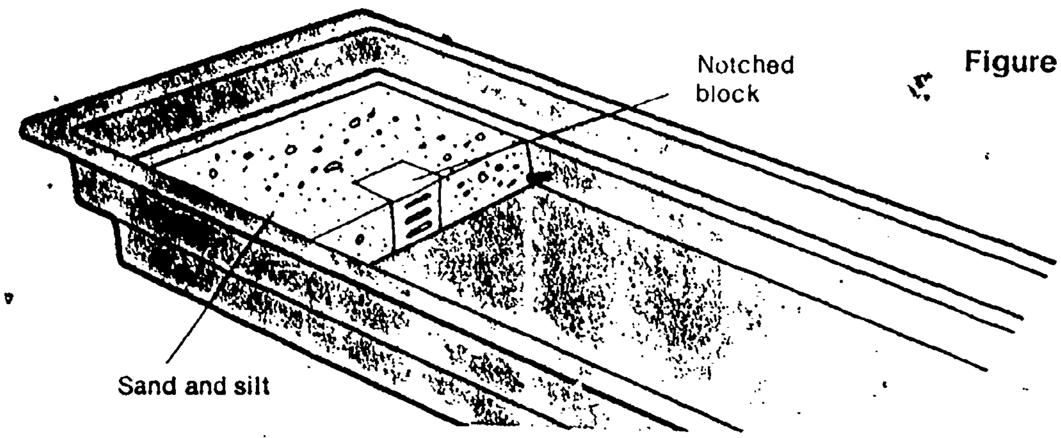
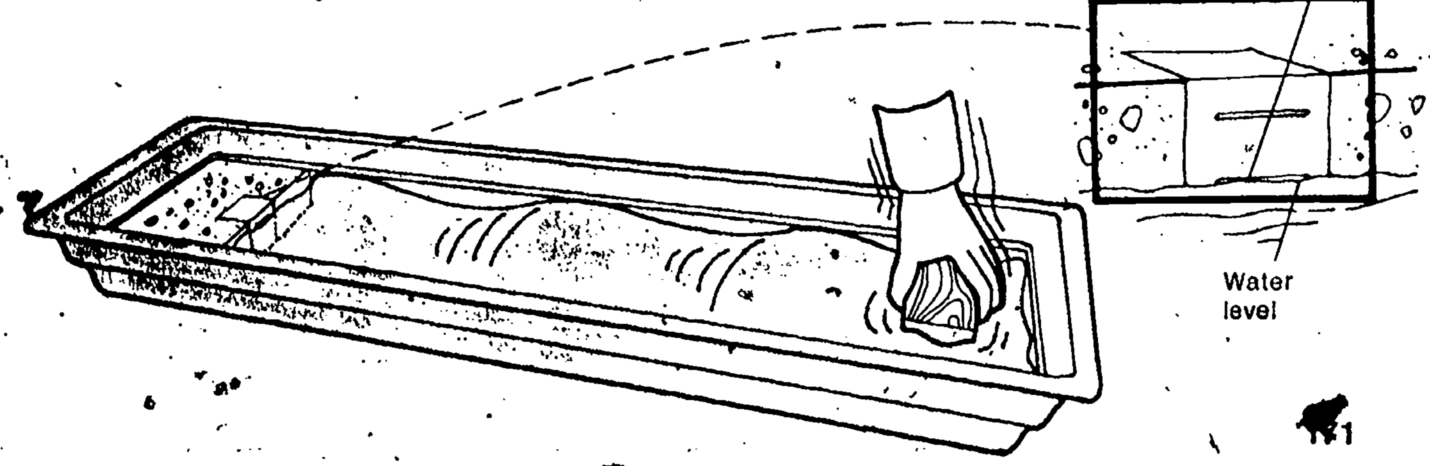



Figure 1

**ACTIVITY 1. Fill the stream table with water so that the middle notch in the block is just at water level. Now generate waves by pushing the piece of wood up and down every 5 seconds, so that the waves hit the face with the three notches. Keep the waves going for 5 to 10 minutes, carefully observing the face of the block to see which notch is most affected by the wave action.**



From these simulation experiments, you should have found out that the erosive effects of the waves occur in a narrow band just above sea level. At this level, they would produce undercutting on a cliff face. Softer rocks are more rapidly eroded than harder ones, and cracks allow the erosion to proceed faster. If you could see the waves acting against a cliff face over a period of time, you would note that the face keeps moving back, and a wave-cut bench is left.

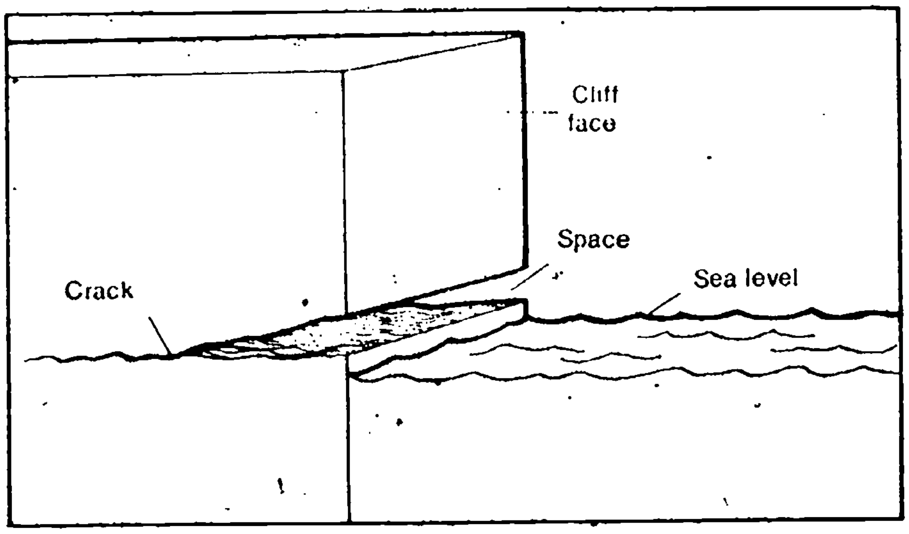



Figure 2

Let's examine the effect of cracks at sea level a little further. Figure 2 shows a crack at sea level. What does the space in the crack contain when there is no water washing into it?

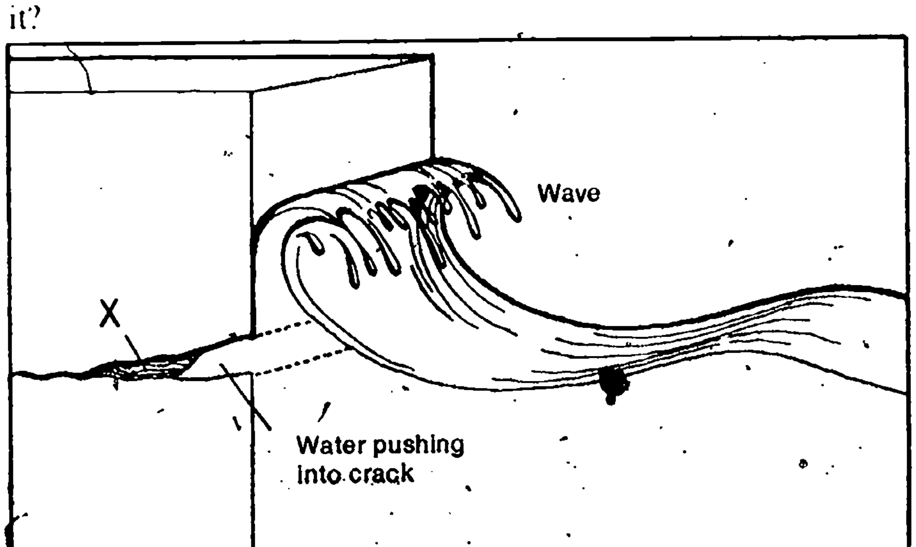



Figure 3

What happens at X in Figure 3 when a big wave washes into the crack, and what effect would this have on the crack? Imagine this process continuing in the same crack for hundreds of years. It is not difficult to see that the sudden compression of the air when the water drives into the crack will help to make the crack bigger and longer.

In your experiment, you may have seen little broken pieces of plaster tumbling down. These represent pebbles and boulders broken off in the real situation. Some of these would be small enough for the waves to pick up and throw against the cliff. What effect would this have on the cliff and on the pebbles?

In any coastline region where cliff faces are raised against the sea, the kinetic energy of waves does work. The cliff gets undercut at sea level by the abrasive action of stones and the compression of air in cracks. Arches and caves develop. Then these collapse as they are enlarged, leaving pinnacles of rock standing by themselves.

The pebbles and boulders are ground into sand, which gets transported away to be deposited elsewhere as offshore benches or as beaches and sandbars.

Now that the water in your stream table has settled down, take another good look at the model you have produced. You should find that the coarser sediment has formed a bench in front of the cliff area. The very fine material should be deposited in the deeper "offshore" water.

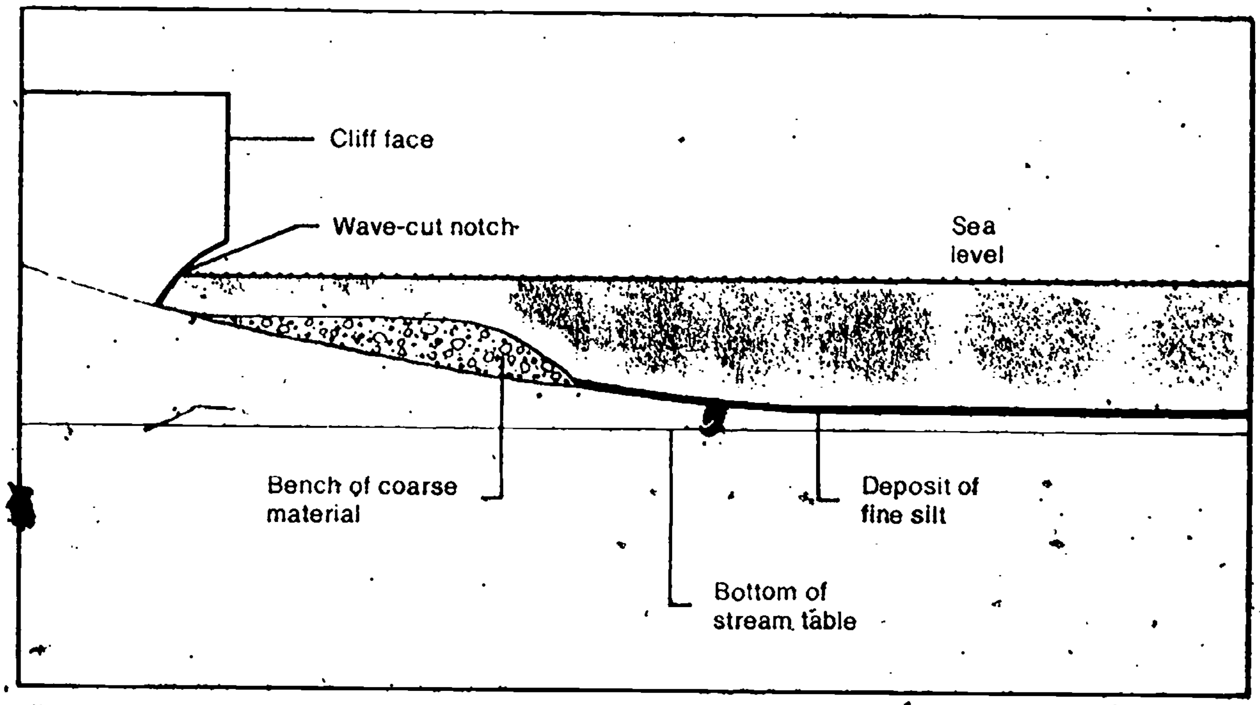



Figure 4

# 39 Kinetic Energy and Waves

Have you ever been surfing or watched surfing at the movies or on television? A surfer on a board out beyond the breaking waves just bobs up and down in almost the same spot, while a surfer in the breaking wave is pushed toward the shore, like the two people in Figure 1.

**Figure 1**

The surfers in Figure 1 have gained kinetic energy as they moved toward the shore. Why doesn't a surfer beyond the breaking wave have the same kinetic energy?

What causes the waves to break when they reach shallow water?

One model of wave action states that water particles in the upper layers are rotating because of wind action. At the high point of the wave (the crest), the particles have rotated up to their highest position. At the lowest point (the trough), the particles have rotated back down to their lowest position. A surfer is lifted and lowered by this rotational motion but is not carried to shore, as shown in Figures 2 and 3. Although the energy obtained by the wave from the wind is carried forward by the wave, the particles of water rotate in a confined area.

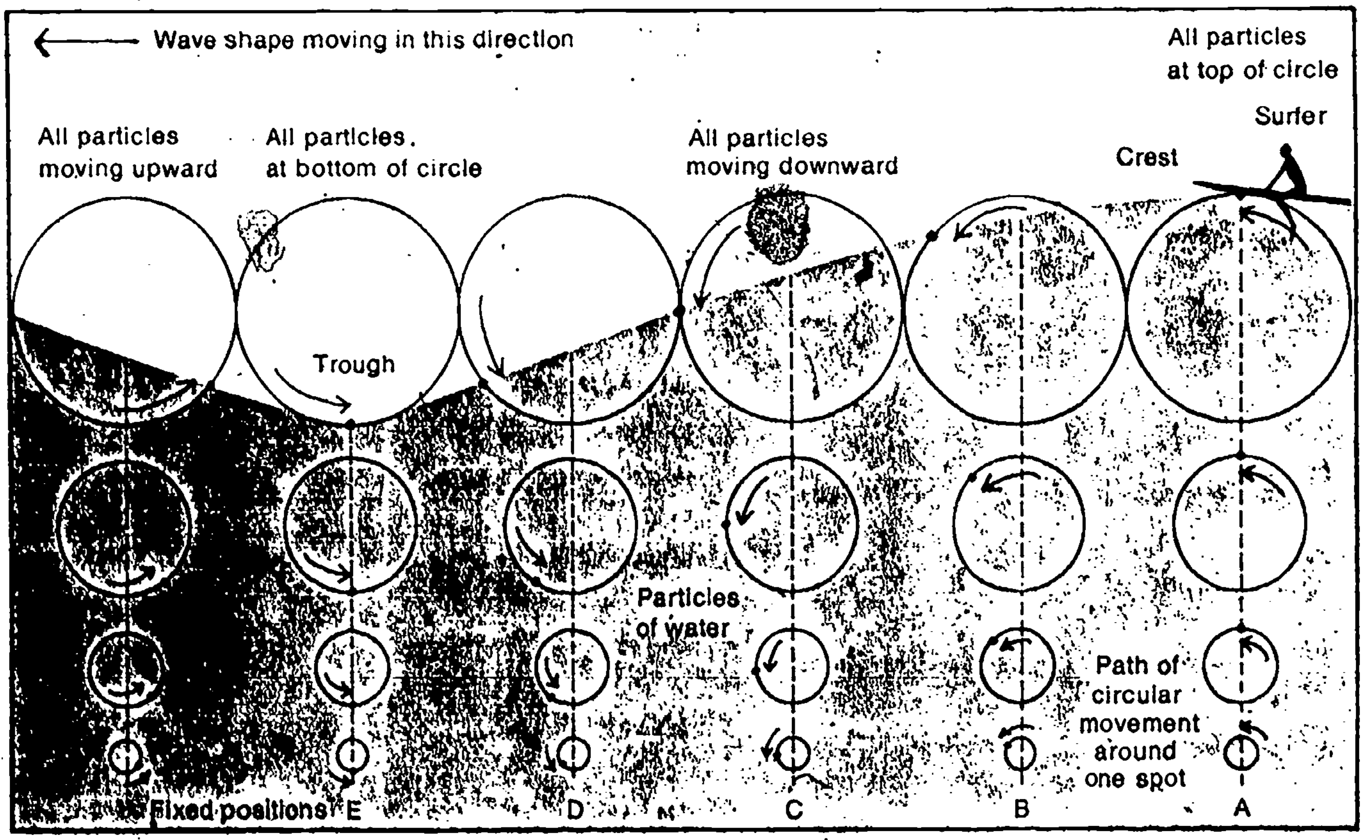



Figure 2

If the water is deep, waves can travel without interference. But imagine what happens when waves get close to shore. What causes waves to break when they reach shallow water?

When the water is shallow enough to stop the particles from rotating, the wave breaks. The circular energy of the waves is changed to forward motion of water particles, which rush up the sloping shore. The breaking wave pushes floating objects ahead of it and picks up tons of sand as it rushes toward the beach.

This model of wave action is one explanation of how water close to shore gets enough kinetic energy to form a breaking wave and thus can pick up and carry sand to the shore.

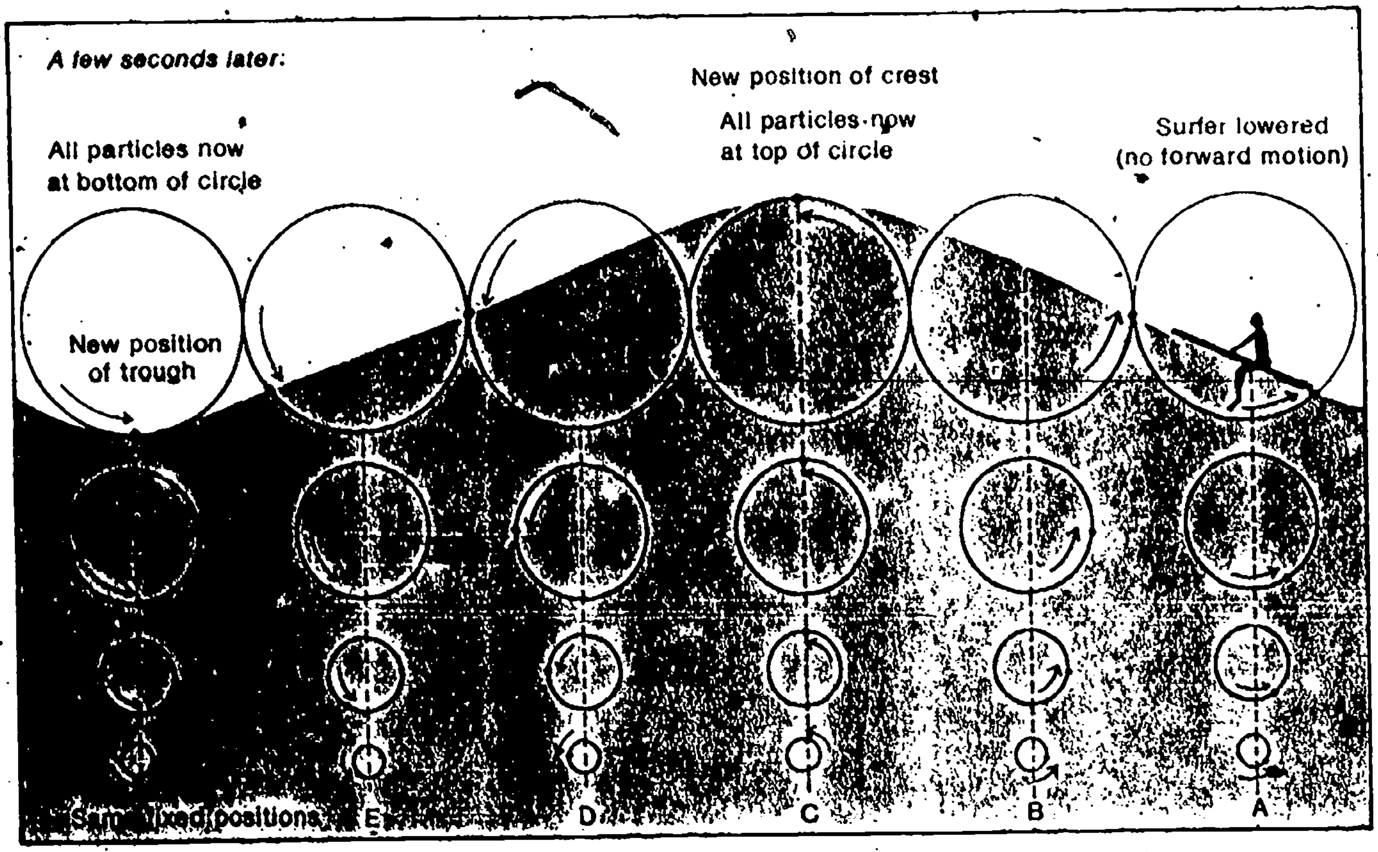



Figure 3

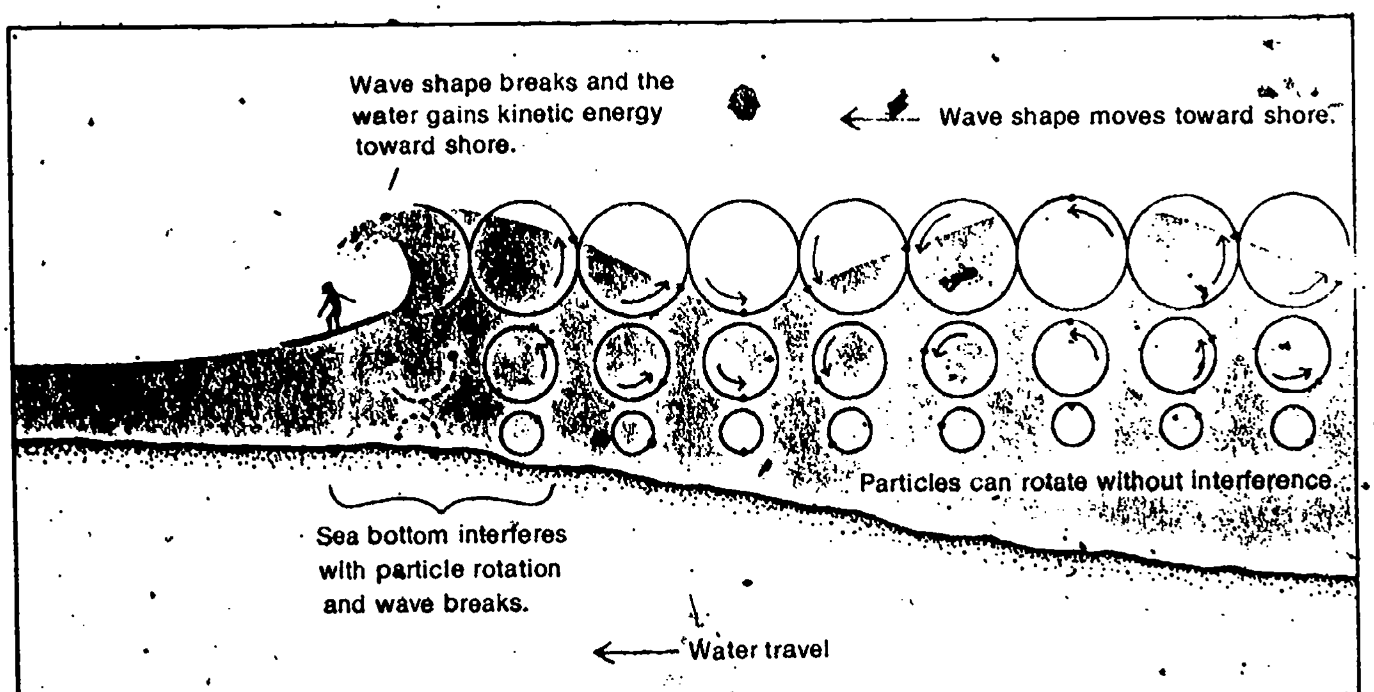





Figure 4

If the ocean is wide and a prevailing wind blows in one direction for most of the year, as along the Pacific Coast, waves continually roll shoreward. These waves (called *swells*) are usually large, reaching heights of 10, 15, and 20 feet. Some coastlines face sheltered water (like the Gulf of Mexico)—and here swells only develop after storms at sea. The total energy supplied to that coastline each year is not so great as the energy supplied to coastlines facing the Pacific or the Atlantic Ocean.

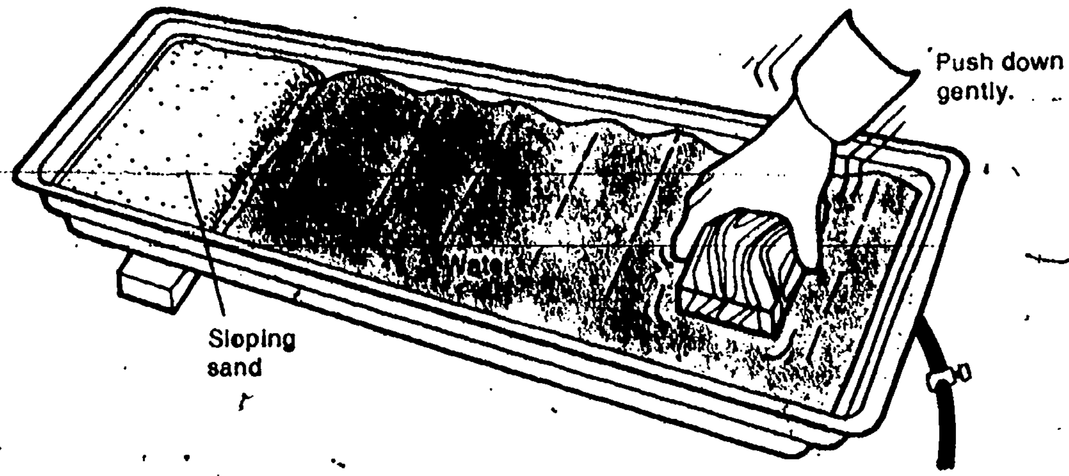
# 40 Beaches and the Curving of Waves


Figure 1

When you stand on a beach, do the waves always come at you head on, 90° to the beach waterline? Are all waves formed the same way? Take a careful look at Figure 1, which shows an aerial view of a coastline, with waves washing past an offshore jetty. Notice the pattern formed by the waves.

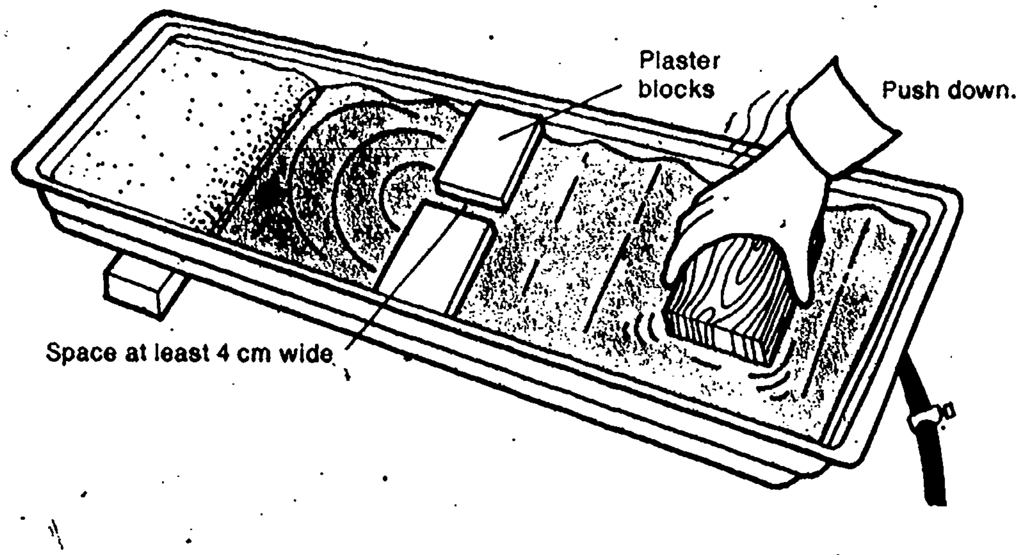
You can understand this pattern and the effect it might have on a shoreline by doing a stream-table activity. You will need a partner, one stream-table set, two plaster blocks, and one wooden block.

**ACTIVITY 1.** Set up the stream table with a sloping sand beach at one end, with the water about 2 cm deep where it meets the beach. Generate waves by gently pushing the wooden block up and down rhythmically every 3 seconds. Notice the pattern produced by the waves and the effect of the waves on the beach.




**ACTIVITY 2.** Now put two plaster blocks into the water as shown. The blocks should have a space of at least 4 cm between them and should appear above water level.

Generate waves in the same way that you did in Activity 1. Note the pattern this time and the effect on the shore.




Where a prevailing wind is blowing toward land at right angles to a straight coastline, the wave pattern is like the one you found in your first simulation experiment. The crests approach the coastline parallel to each other and to the coast.

Almost all energy is concentrated on the coast, causing steady erosion all along the coast. Figure 2 shows the typical wave pattern for these conditions.

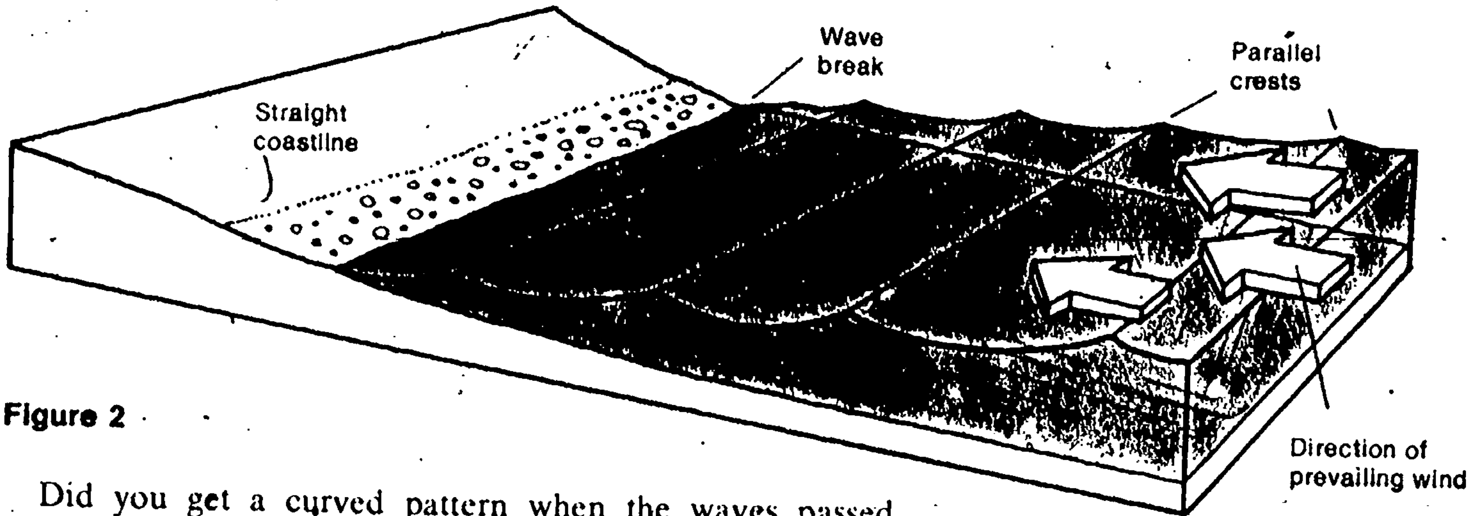



**Figure 2**

Did you get a curved pattern when the waves passed through the gap in your second experiment? When parallel waves pass the edge of an obstacle, or between obstacles, the crests curve. This is called *diffraction*. Your second experiment should have produced a pattern like that in Figure 3. Compare this with Figure 1.

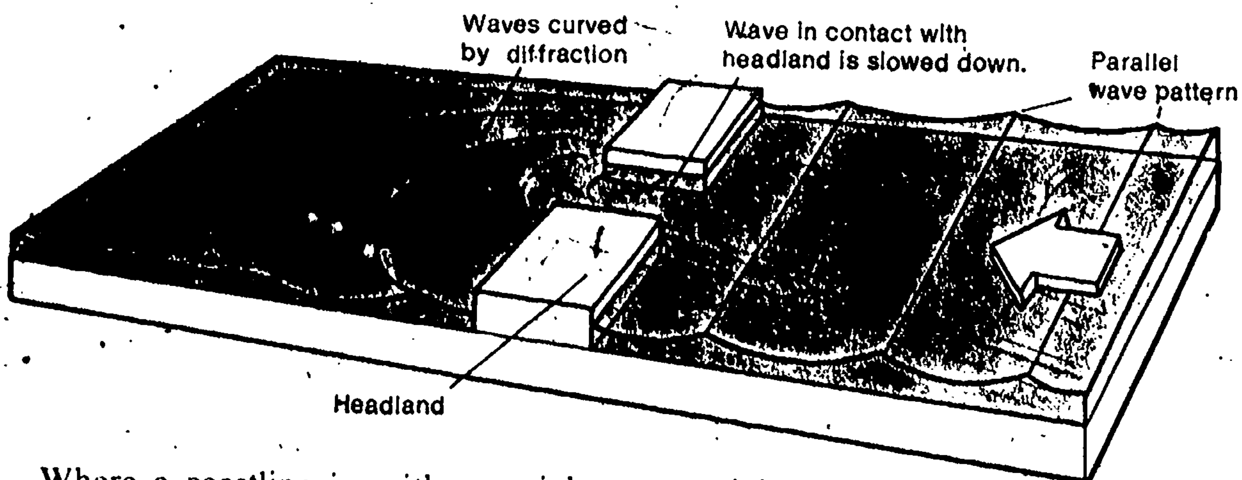
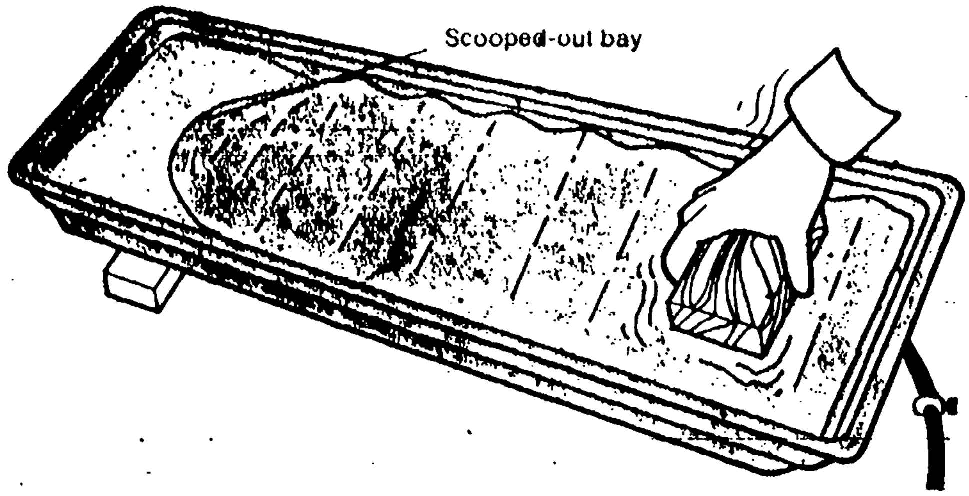



**Figure 3**

Where a coastline is neither straight nor at right angles to the prevailing wind, some parts of the wave line reach land before others. The parts that reach land first are slowed down, whereas the other parts continue at the same speed. The wave line bends, and this is called *refraction*. Predict what wave pattern you would get with waves entering a wide, curved bay.

**ACTIVITY 3. Pile your sand mixture at one end to make a deeply curved, scooped-out bay, and generate more waves.**

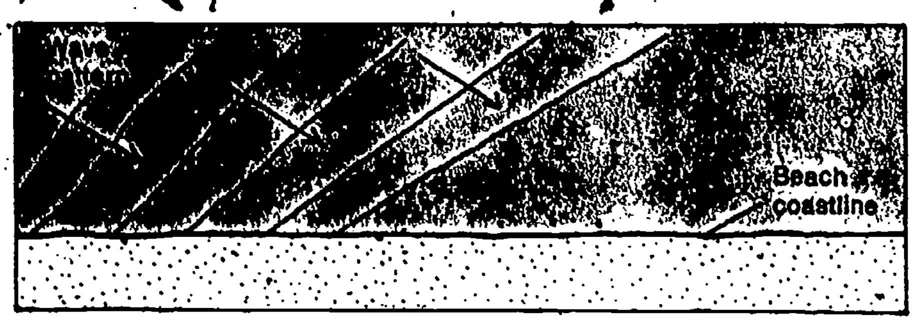



Did you predict correctly? Where is the most beach-forming activity when waves are curved by refraction entering a bay? This experiment should help you understand how wave refraction helps to form beaches at the heads of curved bays as well as pocket beaches between headlands.

# 41 Waves at an Angle and Movement of Sand

What happens to a coastline when the wave pattern reaches the shore at an angle most of the time? Imagine a consistent wave pattern approaching a beach coastline as shown in Figure 1.

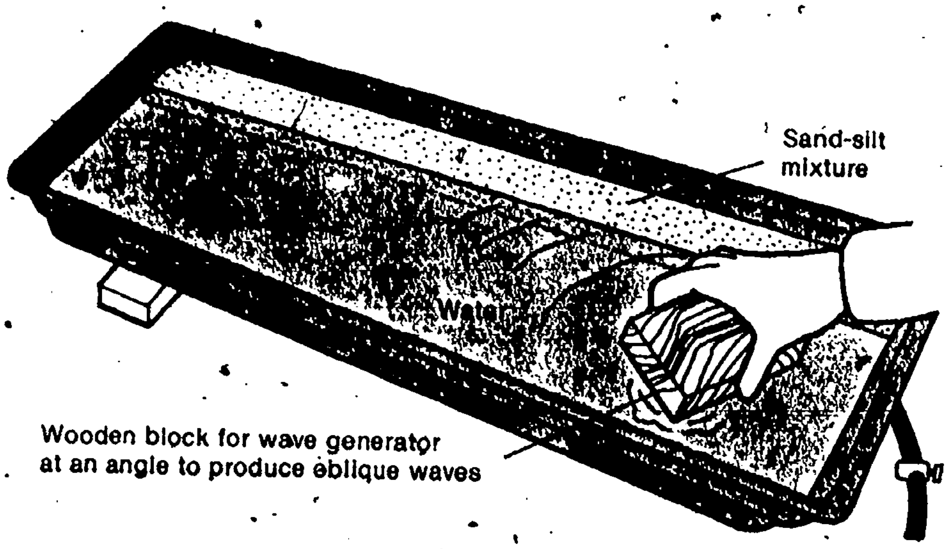
**Figure 1**



Predict what will happen to the shape of the wave pattern when the waves reach the shore. Make a diagram to illustrate your prediction.

Now get a partner, a complete stream-table setup, a piece of wood, and two plaster blocks. You can conduct a simulation experiment to see if your prediction is correct and to observe the effect of this type of wave action on a beach.

**ACTIVITY 1. Pile the sand-silt mixture along one side of the stream table and put water into the table to a depth of about 3 cm. Place the piece of wood you are using as a wave generator at an angle, as shown. Push down on it every three seconds or so to produce a pattern of waves at an angle to the shore. Watch the wave pattern and the erosion effect carefully.**

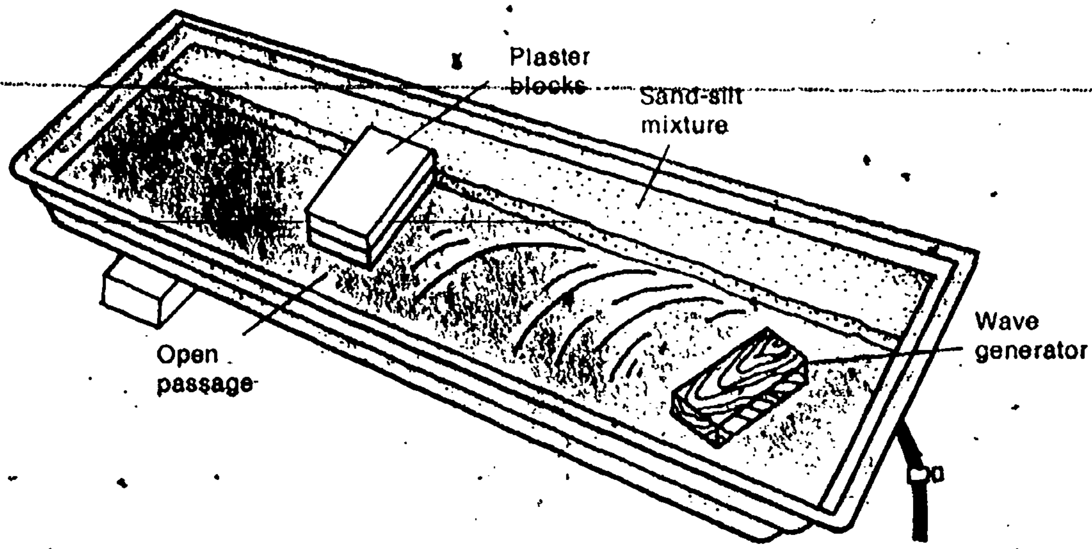



Did you predict the wave pattern correctly? What happened to the beach?

In your simulation, the wave pattern curves into the beach, and the sand is shifted steadily along the shore in a process that is called *longshore drift.*

Because man uses beaches for recreation and builds homes on the seashore, he often builds structures to reduce beach erosion. Let's see what these structures do.

**ACTIVITY 2. Get the plaster blocks and set them at right angles to your simulated beach, one on top of the other. The topmost block must be above water. Make waves at an angle as you did before and observe what happens as the blocks obstruct the longshore drift.**




The diagram in Figure 2 shows how the waves are bent (refracted) as they reach the shore area. As long as the waves follow this pattern, the sand builds up beside the obstruction. Boat ramps, sea walls, or jetties can interfere with longshore drifts of sand along a beach and in much the same way cause a change in the shape of the coast. A jetty at Panama City, Florida, is shown in Figure 3.

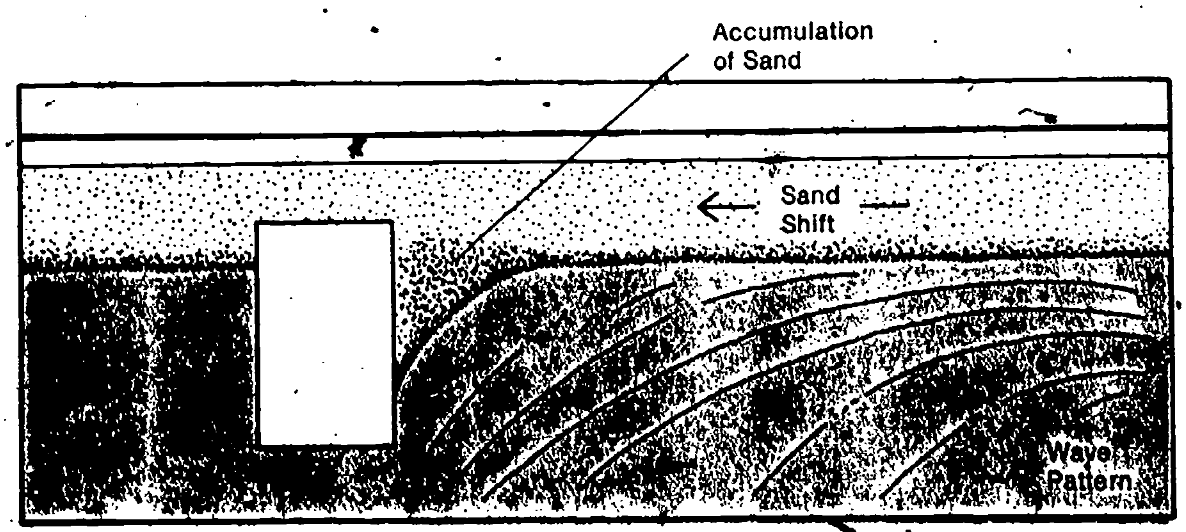


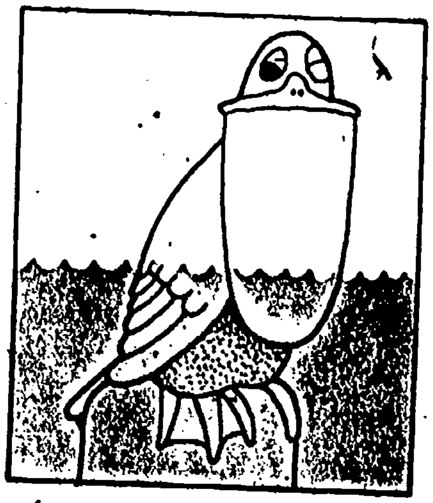



**Figure 2**

Figure 8

# 42 Measuring Sea Level

CLUSTER B
(Resources 42–44)

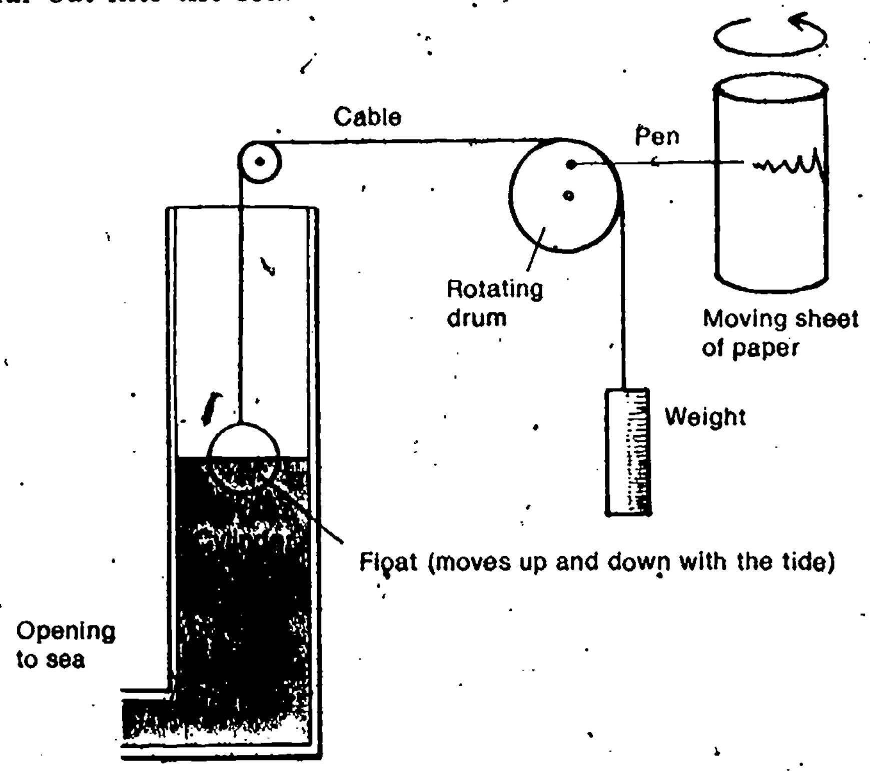


Many times in the chapters in *Crusty Problems* there are references to *sea level.* The elevation of mountains and places along river systems is related to sea level. Along the coast, major landscape changes are related to sea level. It is all very well to talk about sea level, but how can it be measured?

If you have observed boats tied to a wharf, piles standing out of the water, or beaches and shore rocks over a period of days, weeks, or months, you will realize that sea level just isn't level! Waves can cause a minute-to-minute change. Tides can cause a day-to-day, week-to-week, and month-to-month variation. You even get a slightly different view of sea level if you are in a boat looking at the land.

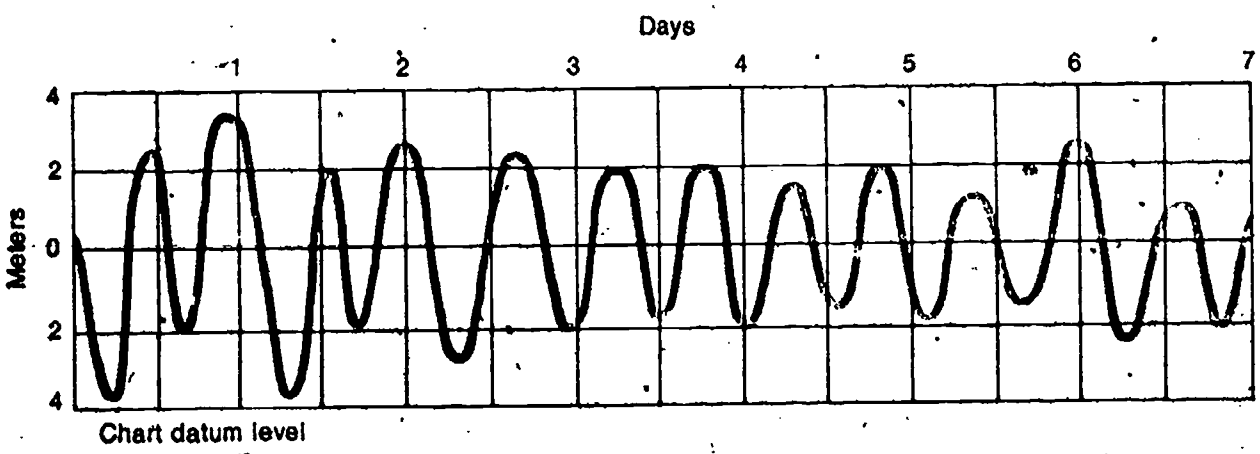
What can you do to get an operational definition for *sea level* when it is changing all the time? The measurement of sea level is no easy task. Usually the problem of making such a measurement is solved by installing a measuring instrument called a *tide gauge* at the end of a pier that stretches far out into the sea.

Figure 1




A tide gauge has a cylinder with a small opening that allows water to enter and fill the cylinder to the levels reached by the tide. One common form has a float in the cylinder. As the float moves up and down with the tide, a cable turns a drum, and a pen draws a line on a moving sheet of paper.

Figure 2



The pen traces out records like that on the chart shown in Figure 2. The graph, developed over a period of time, shows the highest level reached by the tide, the lowest level, and all levels between.

From continuous readings like these, taken over a long time, a value for mean sea level can be calculated. Mean sea level is an average value between high water and low water. Which value on this chart would be about the level of mean sea level?

The United States Coast and Geodetic Survey classifies tide stations as primary, or first class, only if they have been in continuous operation for more than nineteen years. There are about 40 places in the United States that are first-class stations.

Charts from all these stations are used to calculate the mean sea level, to which all surveying measurements are related.

Careful measurement has shown that the sea level is not the same at all places (see Figure 3). For example, if the sea level at St. Augustine, Florida, is taken as zero, then the sea level at Portland, Maine, is about 38 cm higher; at San Diego, California, it is about 58 cm higher; and on the Oregon coast it is about 86 cm higher.

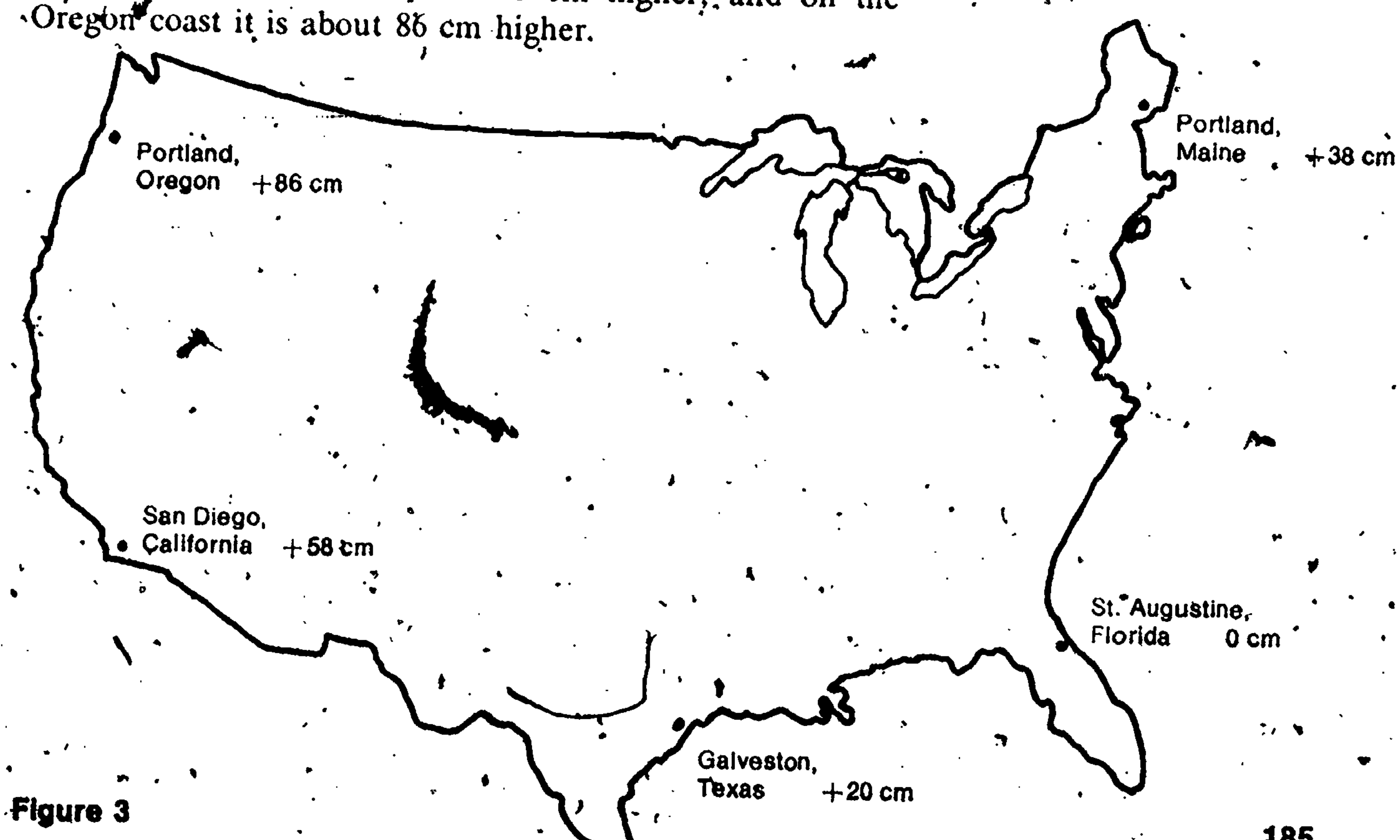
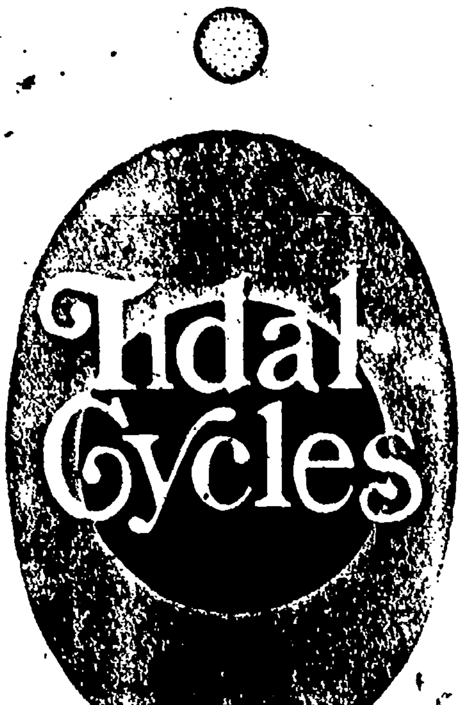



Figure 3

Scientists are not certain why there is a difference in sea level, but they think it is related to such variables as barometric pressure and water temperature.

# 43 Tidal Effects on Shorelines




One of the most noticeable cyclic events (events occurring at regular periods) that affects the shoreline is the daily rise and fall of the tides. The difference between high tide and low tide in the United States can be as much as three meters (10 ft), and in some parts of the world it can be more than nine or ten meters (33 ft). Only the larger lakes have measurable tides; Lake Erie has a tidal range of only eight centimeters (3 in).

Men have noticed how tidal cycles follow the daily cycles of the earth, moon, and sun. The present theory of tides explains them in terms of the gravitational attraction of the moon and sun, which causes the water on the earth's surface to bulge out. The moon, though smaller than the sun, has a greater effect (over twice as great) because it is so much closer to the earth.

In Figure 2 of the previous resource, there is a chart showing a daily tide record. Notice that the recordings in the early part of the chart show a big difference between high-tide level and low-tide level (almost four meters on the sixth day) while a week later the difference is only about one meter. When the moon and the sun are in a straight line with the earth so that their gravitational attractions are pulling together, big tides are caused. When they are at right angles, their attractions work against one another, and the differences are small. This causes a cycle of big tidal differences at certain times of the month and small differences at other times.

On a gently sloping shore like the one pictured in Figure 1, the period of big tides causes wave action on the upper part of the beach for the first time since the last big tides. You can imagine the tremendous effects a combination of a storm and one of these very high tides has on the upper part of the beach and the dunes.

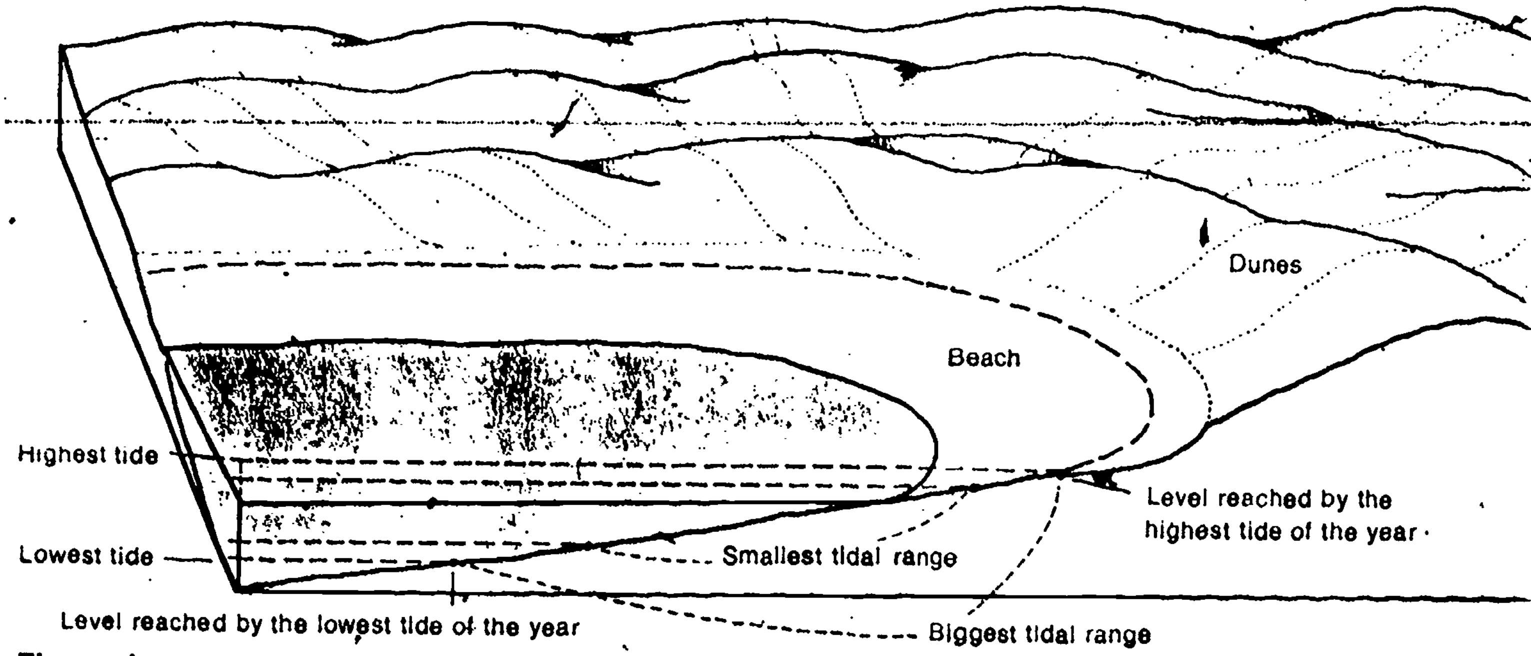
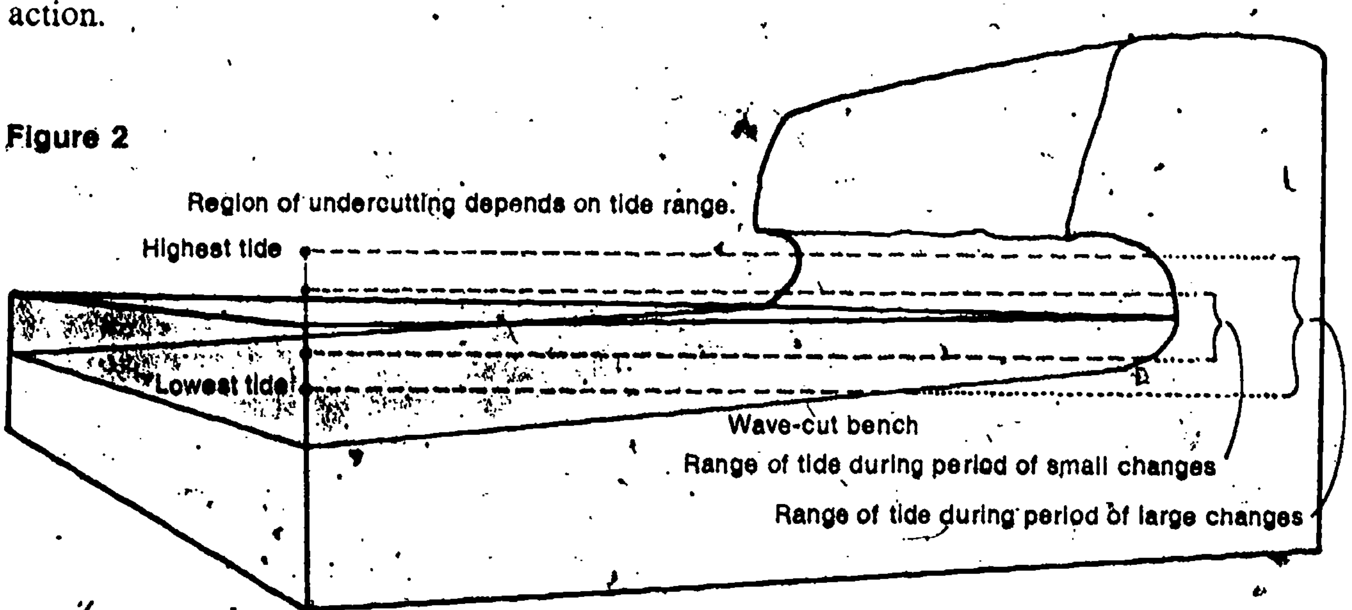



**Figure 1**

On a cliff or steep shore, the tide cycle affects the part of the shore that gets undercut by wave action. In Resource 38, you saw that most of the erosion takes place at sea level. If the rise and fall of the tide is small, only a narrow strip is exposed to wave action. If the change is large, a much wider strip is exposed. The range of the rise and fall of the tide controls how much of the cliff face is affected by wave action.

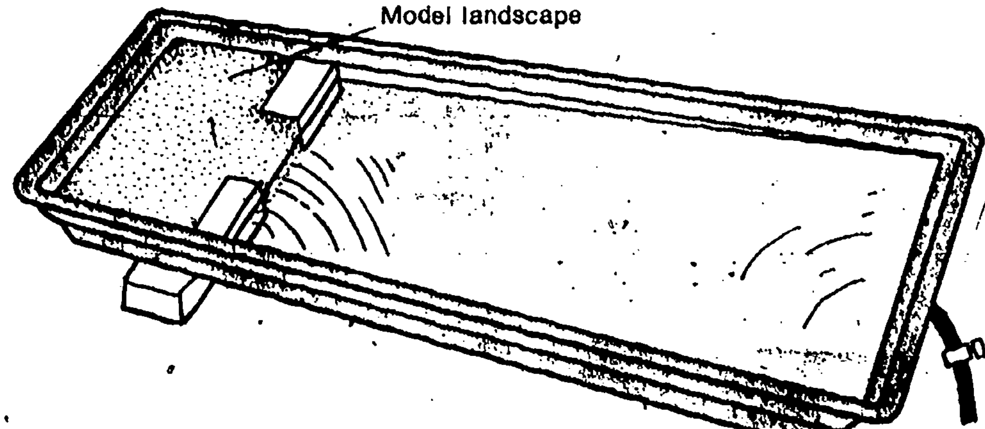
**Figure 2**



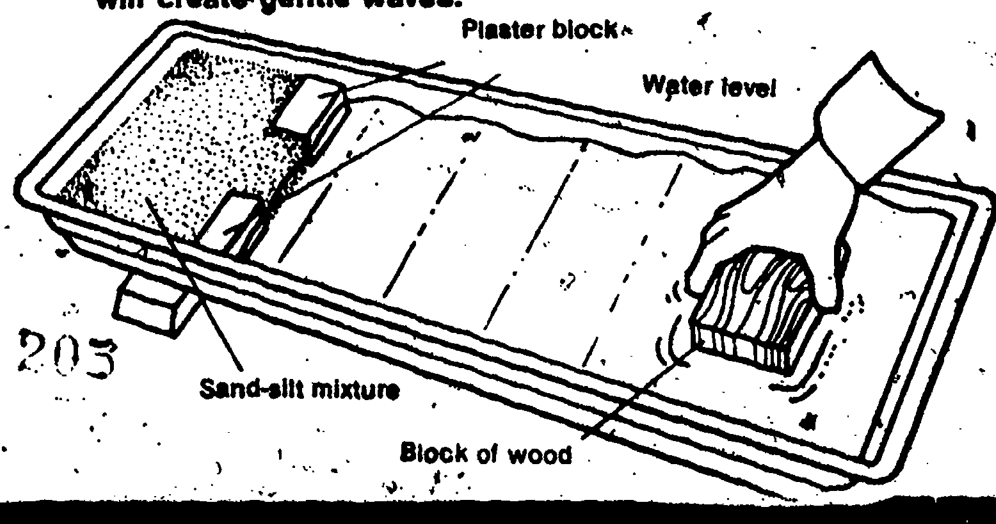
# 44 Changing Sea Level and Erosion

This resource will help you find out what effect a change in sea level can have on a cliff-type coastal landscape. To get started, obtain two plaster blocks (one larger than the other), some of the sand-silt mixture, a piece of wood, and a stream table. You will use the sand-silt mixture and plaster blocks to build your own landscape.

**ACTIVITY 1. Pack your sand-silt mixture at one end of the stream table as shown, embedding the two plaster blocks along the front edge. Raise this landscape end of your stream table with a block of wood or other support. Then fill the other end with water until it just covers the smaller of the two plaster blocks.**




**ACTIVITY 2. Place the piece of wood in the stream table at the opposite end from your model landscape. Push down gently on the wood with the palm of your hand and then quickly lift your hand. Do this every 5 seconds or so, and you will create gentle waves.**



Keep making waves this way for about 5 minutes. Notice where the erosion at this sea level takes place. Now let the water out through the drainage hole until only the lower half of the smaller plaster block is covered with water. Then repeat the wave action to see how a change in sea level can affect the landscape.

Wave erosion takes place at sea level and cuts a bench (Figure 1), the cliff being steadily cut back. If the sea level drops, erosion cannot take place at this level any more, and a flat wave-cut bench is left. The old cliffs are left behind, but they often lose their distinctive features because of slides and erosion. Old wave-cut benches can be recognized on many coastlines and are evidence of changes in sea level.

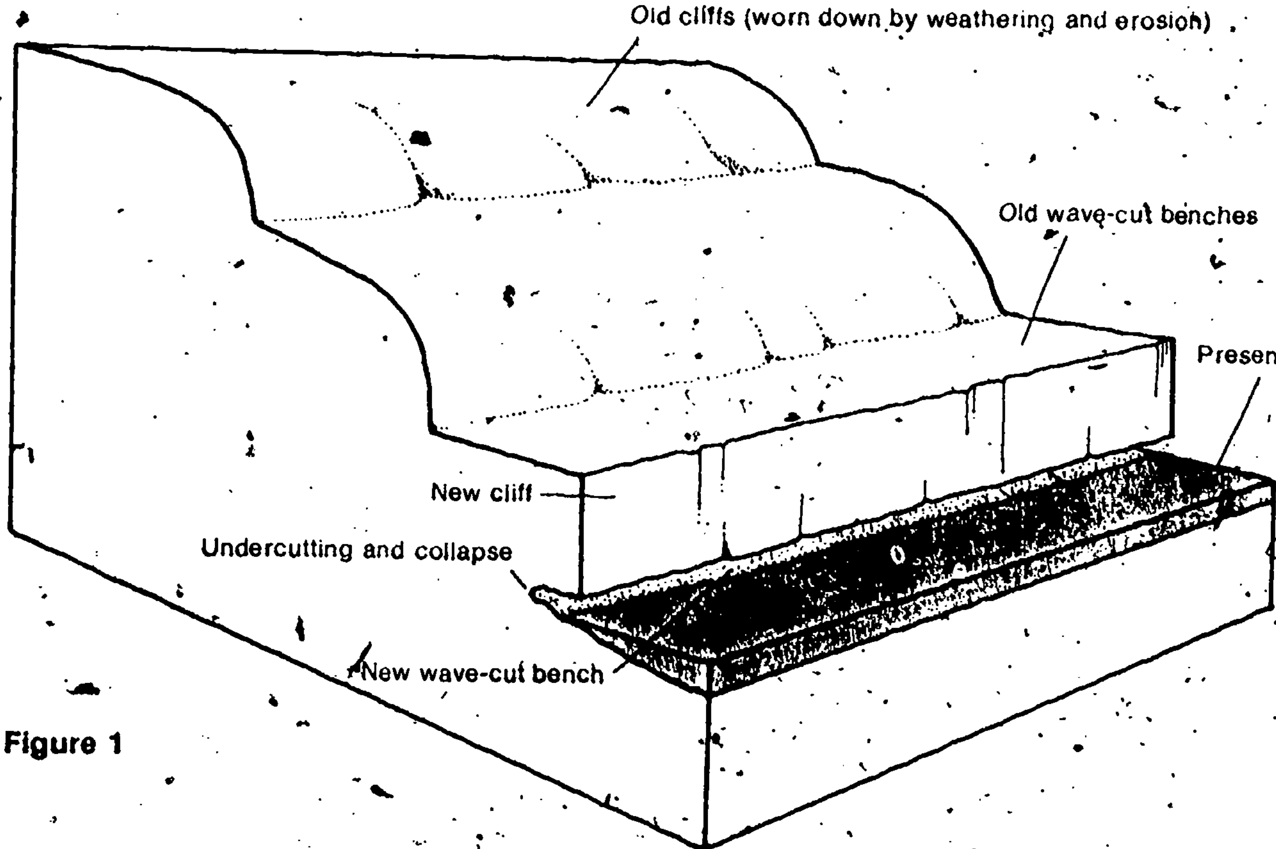
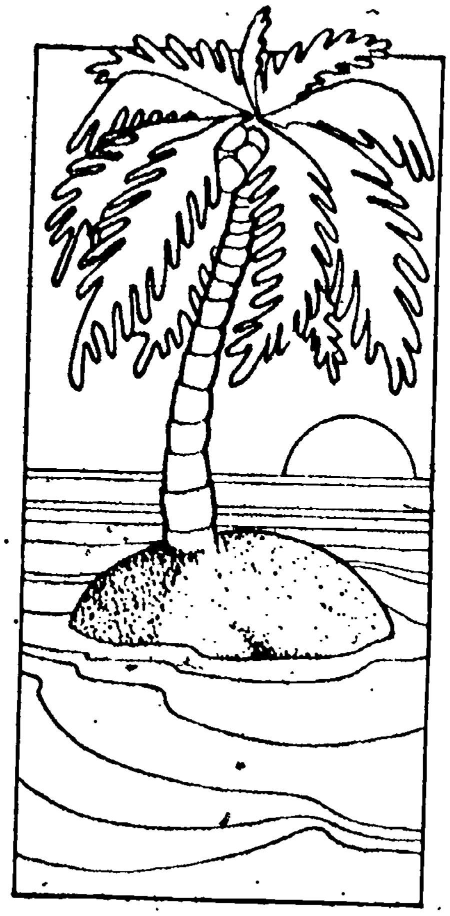



Figure 1

CLUSTER C
(Resources 45–47)



# 45 Where Does Beach Sand Come From?

The moviemakers' concept of an island paradise is a white sand beach with waving palms, but white beaches in the tropics and in southern regions of the United States are not all that common.

In Hawaii, some of the beaches are black. In Florida, some of the beaches are tawny, some are buff-colored, and there are long stretches of eggshell-white beach. On the West Coast of the United States, beaches are more often brownish-gray. All these beaches have sand. How can the sand be so different from beach to beach?

*Sand* is simply a name given to rock material ground to a certain size by the action of water or wind. Beach sand is formed by the grinding action of rocks on each other and on bedrock when vigorously rolled by moving water of high kinetic energy.

This process can happen in the fast-flowing section of a river. Because the sand particles are small, they are carried far beyond the rocky region where they were formed. And if the kinetic energy of the stream is sufficiently high, the particles can eventually be washed out to sea. Many particles get no farther than the river mouth, where they build up as sandbars. Others, however, are swept along by sea currents and wave action, finally becoming part of a beach.

Sand particles break off from rocks when waves batter the rocks against each other or against the cliffs. This sand can be deposited on pocket beaches in the bays between rocky headlands or carried away by wave action and washed up on a beach elsewhere.

The color and kind of sand formed depend on the kind of rock that was ground down. In general, rocks made of hard minerals break down to sand. White sand like that along the southeast coast usually comes from quartz. Darker sands are often formed by the breakdown of dark-colored igneous or metamorphic rock. The black sands of Hawaii are composed of tiny grains broken from dark-colored lava rock. In some localities, the color of the beach may be altered by wastes, organic matter, or mixtures of clay with the sand.

Figure 1

Some of the sand on the Oregon beach in Figure 1 below could have come from the grinding down of the rocky headland in the distance. There are no rocky headlands within hundreds of miles of the Florida beach pictured in Figure 2. Part of this sand comes from broken shells and coral, though some may have been brought a long way by ocean currents.

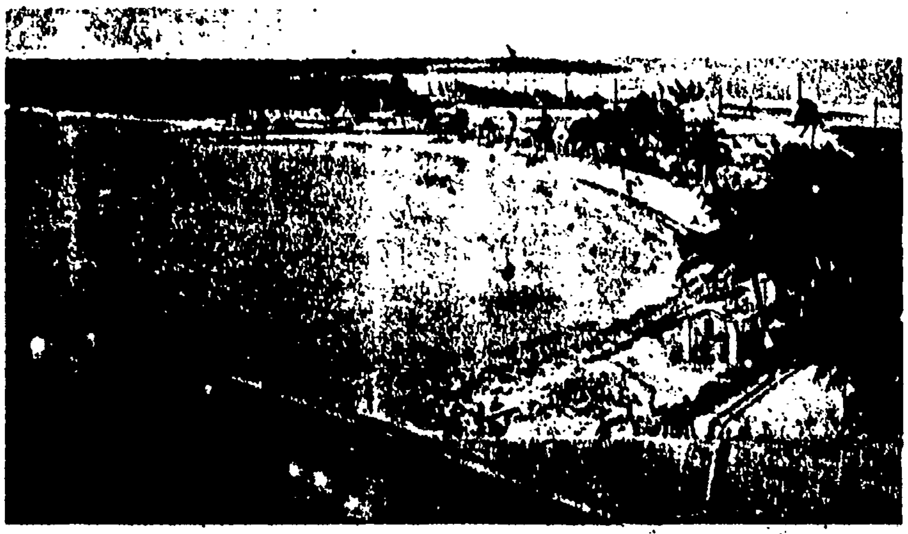


Figure 2

# 46 Spits and Sandbars


Where rivers enter the sea, the river mouths are often partly blocked by deposits of sand called *sandbars*. Long, curved sandbars called *spits* also form at the tip of headlands that project into the sea.

One way that spits form can be demonstrated in a stream table. Imagine a long coastline with angled waves drifting along a shallow shore. Can you predict what kind of beach will form where the coastline changes direction?



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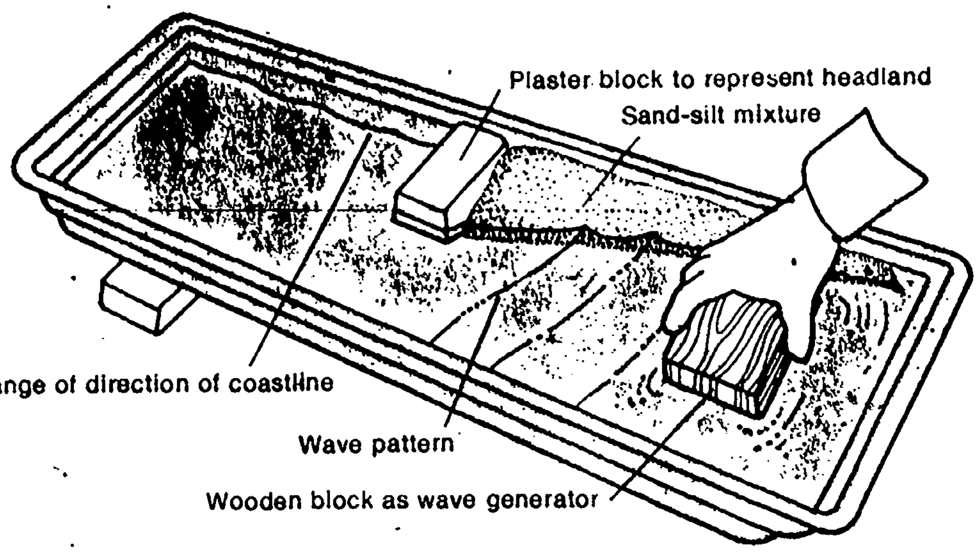
**ACTIVITY 1. Pile up the sand-silt mixture to make a beach from one corner of the stream table to about the middle, as shown. Then put in a plaster block to represent a rock headland. Pour in water to a depth of about 3 cm. Generate angling waves by pushing down every 3 seconds on a wooden block. Do this for about 5 to 10 minutes.**




Your simulation should have produced a landform like that shown in Figure 1. Longshore drift shifts the sand along the coast to the headland. The energy of the waves is reduced as they swing around the headland, and the sand is deposited as a curved sandbar, or spit.

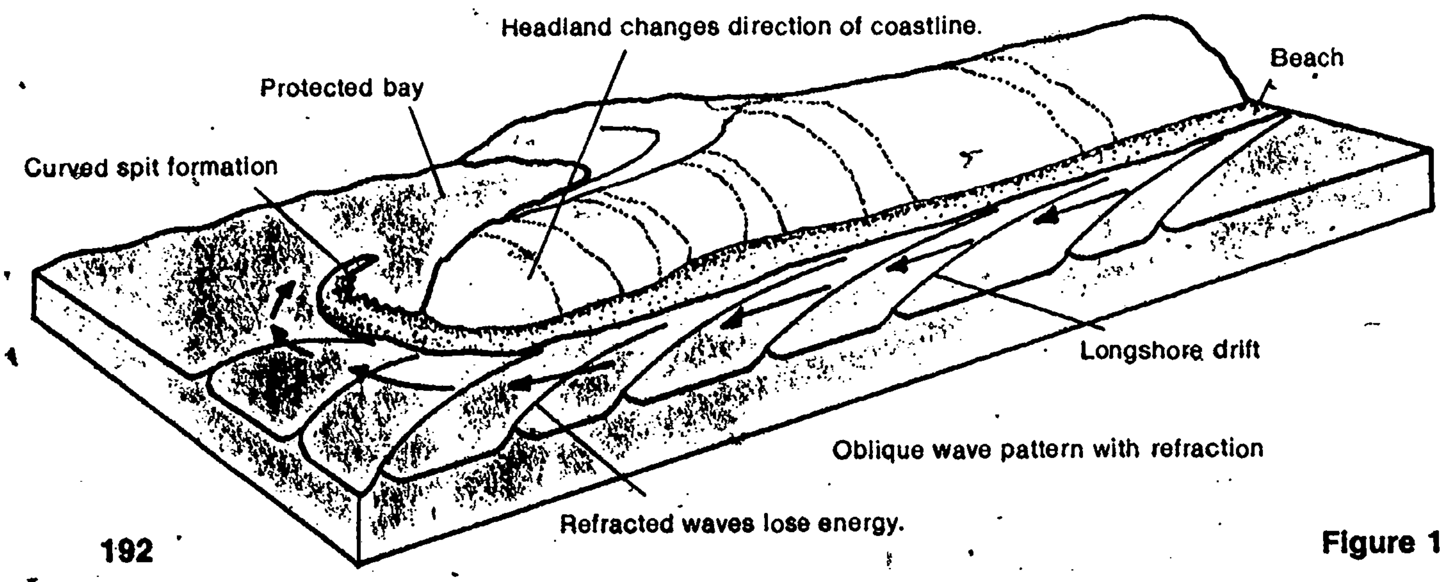



Figure 1

Sandbars can also be deposited off the mouths of rivers or in shallow water off a beach when currents carrying a load of sand are slowed down and lose energy.

## 47. Rise in Sea Level Floods Valleys

Figure 1

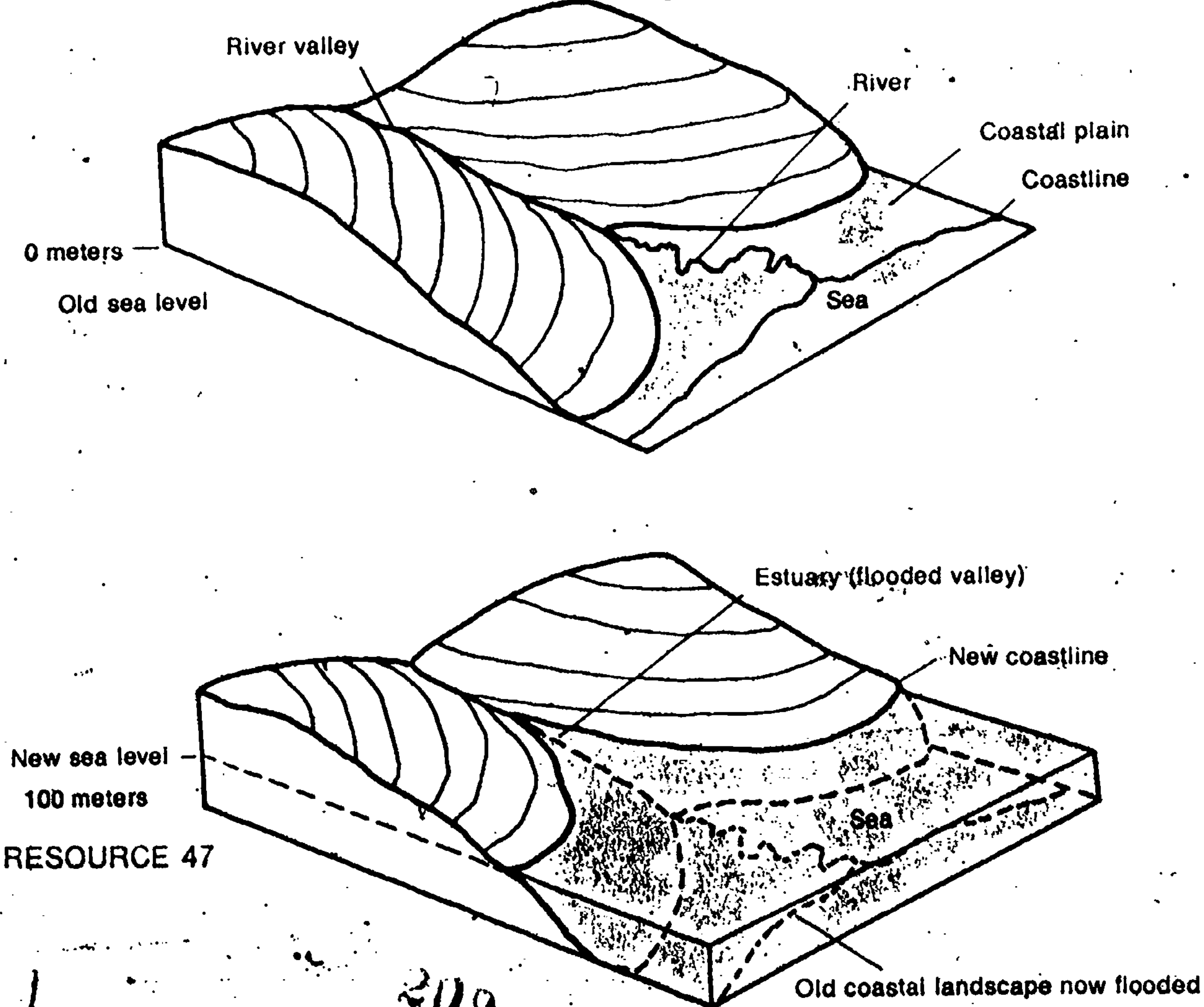
The large body of water in the mountain scene of Figure 1 is *not* a lake system; it's a system of valleys flooded by the sea. The scene is in Alaska where Tracy Arm (in the foreground) empties into Holkam Bay. The bay, in turn, connects with the Pacific Ocean.

Since you have already done the mountain chapter, you will recognize features which indicate that the landscape was glacially carved. There is evidence that during the ice-age period, when these mountains were being carved to their present shape, great ice sheets covered much of the Northern Hemisphere. With so much of the earth's water trapped in the form of glacial ice, the sea level would have been much lower then than now.

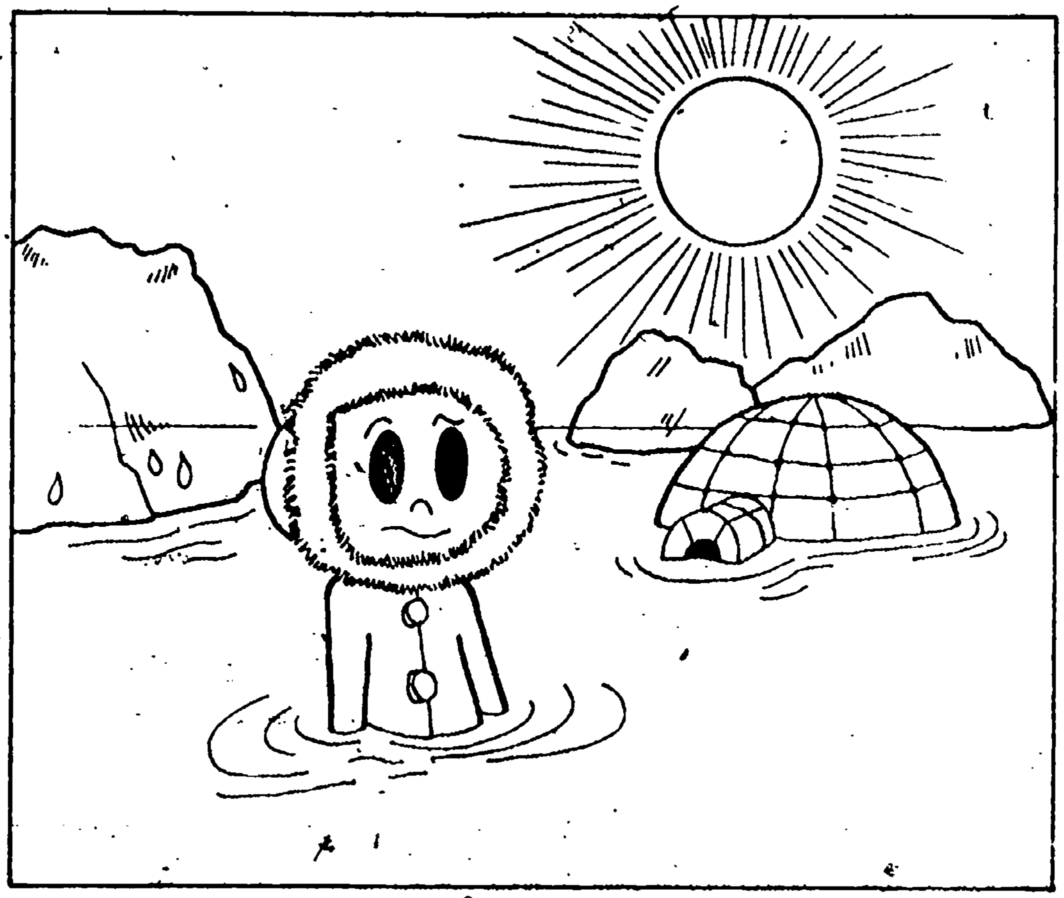
One theory suggests that as the climate changed to a warmer one, the ice sheets melted back to their present positions over the North and South Poles. The water released by the melting ice raised the sea level—one estimate is by about 100 meters. A rise as big as this caused the flooding of many valleys near the coast.

Flooded, ice-carved valleys like Tracy Arm are sometimes called *fiords*, while flooded river-carved valleys are called *estuaries*. Many of the world's best harbors occupy flooded valleys. Some deep harbors in North America that have formed because of the flooding of river valleys include the Hudson River, Chesapeake Bay, Delaware Bay, San Francisco Bay, and the straits and harbors between British Columbia and the state of Washington. Oslo, Norway, is at the far end of a 90-mile fiord.

**Figure 2**



Flooding due to a rise in sea level caused by melting ice is not the only possible way of forming an estuary or a fiord. The same result would occur if earth movements caused the land to sink beneath the sea. The diagram in Figure 2 shows how a river valley could become an estuary if the sea level rose, or the land sank, or a combination of both effects resulted in a relative rise in sea level.



**PICTURE CREDITS**

*T*–Top
*B*–Bottom
*L*–Left
*R*–Right

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