DOCUMENT RESUME

ED 178 340 SE 029 276

AUTHOR	Freeman, Tom
TITLE	Field Guide to Layered Rocks. Earth Science Curriculum Project Pamphlet Series PS-3.
INSTITUTION	American Geological Inst., Washington, D.C.
SPONS AGENCY	National Science Foundation, Washington, D.C.
REPORT NO	ESCP-PS-3
PUB DATE	71
NOTE	50p.; For related documents, see SE 029 274-283; Not available in hard copy due to copyright restrictions; Photographs and colored charts, graphs, and drawings may not reproduce well
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Earth Science; Environment; *Field Studies; Field Trips; *Geology; Instructional Materials; Paleontology; *Science Activities; *Science Course Improvement Project; Science Education; Science Instruction; Secondary Education; Secondary School Science
IDENTIFIERS	*Earth Science Curriculum Project; National Science Foundation

ABSTRACT

Presented is the study of sequences of rock layers as the basis for historical geology. Also considered is the influence of rock layers on the appearance of the landscape. Specific relevant laws of geology are presented. Preparation for a field trip is discussed. An example field trip is discussed and field techniques and projects are reviewed. References and a glossary are provided. (Author/RE)

field guide to LAYERED ROCKS

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The sequence of rock layers, which must be deciphered by the field geologist, forms the framework on which historical geology is based. The nature and arrangement of rock layers also influence the appearance of the landscape; and most of the earth's scenic wonders are due to peculiarities in the underlying strata.

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ISBN 0-395-02617-2

FIELD GUIDE TO

Layered Rocks

Tom Freeman

Series Editor: Robert E. Boyer

EARTH SCIENCE CURRICULUM PROJECT
Sponsored by the American Geological Institute
Supported by the National Science Foundation
Endorsed by the Council on Education
in the Geological Sciences

HOUGHTON MIFFLIN COMPANY · BOSTON

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Layered Rocks

INTRODUCTION

During the vast periods of time that have elapsed since our earth was formed, its rocky surface has been continually worn away and re-formed. Wind, rain, and ice have worn down mountains. They have carved away and redeposited the resulting loose stones, sand, and mud. This loose rubble was eventually formed into layers of rock by pressure and chemical change. Rocks formed in this way are called *sedimentary* because they originate from loose sediments. Because different types of sediments form rocks of different textures and colors lying in layers one above the other, these rocks are also called *layered* or *stratified* rocks. In many places rock layers or *strata* lie flat across the earth's surface, but in most mountainous regions they have been steeply tilted by earth movements and by the folding and buckling effects that shaped the mountains (Figure 1).

Because sedimentary rock layers have accumulated one after the other in an orderly succession, they provide a method of deciphering earth history. Rock layers record geologic events, so the geologist must work out the order of rock successions.

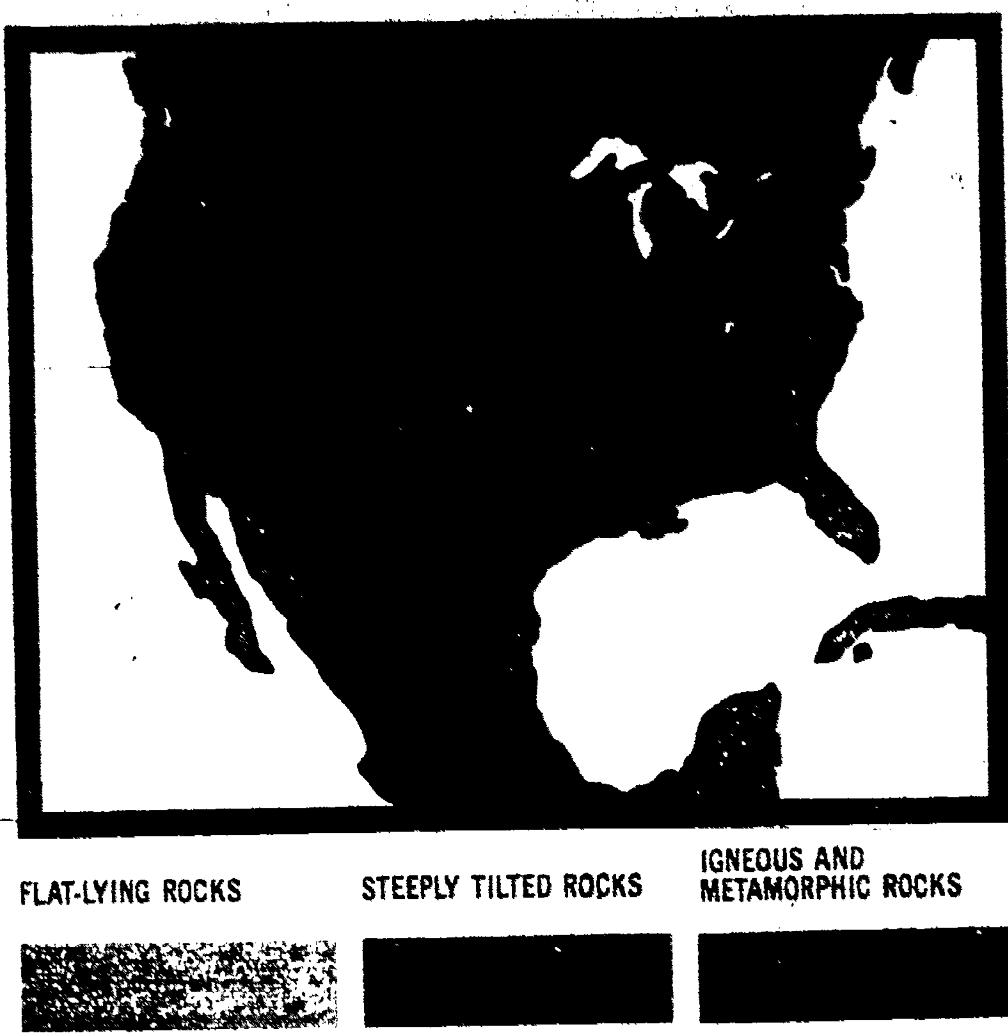


Figure 1. Map of U.S. showing distribution of flat-lying sedimentary rocks, steeply tilted sedimentary rocks, and igneous and metamorphic rocks.

and from them the sequence of those events. The size of sediments, the material from which the sediments were eroded, the thickness of layers, the fossils trapped in the rocks—all these factors are significant in interpreting geologic events. The geologist, much like a detective, carefully observes the location of sedimentary rocks and measures the size of sediments, the thickness of layers, and the surface area each layer covers. He collects rock and fossil samples to study in the laboratory. From this combination of field observation and laboratory study, he develops estimates and theories for further testing. Our geologic calendar is based upon

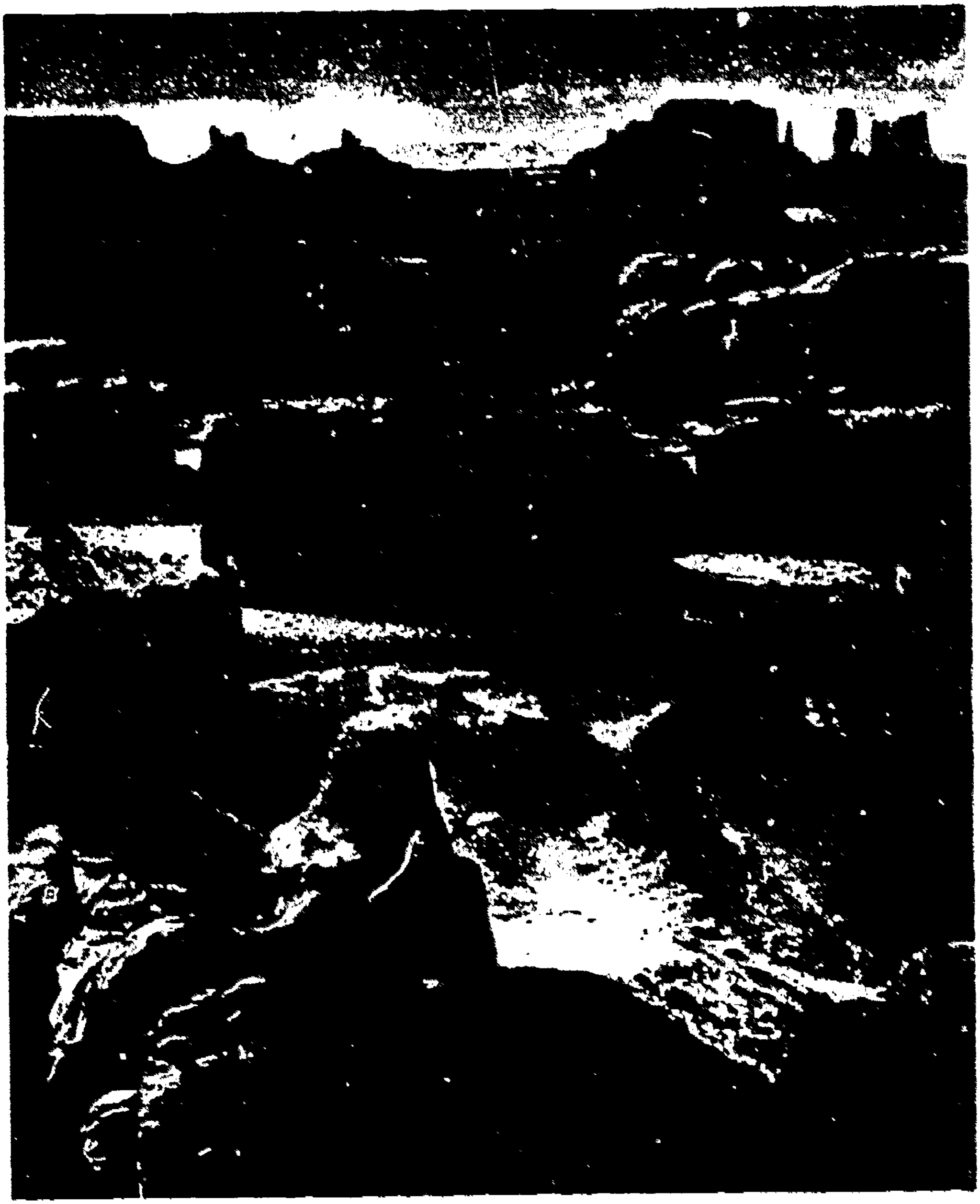


Figure 2 Buttes and mesas produced by long erosion of hard and soft layers of rocks that are nearly horizontal

a study of rock layers, and the study of strata is the base upon which other geologic studies rest.

Rock layers play an important role in shaping the landscape. Where the layers are of uniform hardness, they are worn away or *eroded* by water and wind into smooth uninterrupted slopes. Where, on the other hand, hard and soft layers alternate, erosion results in steplike landforms (Figure 2).

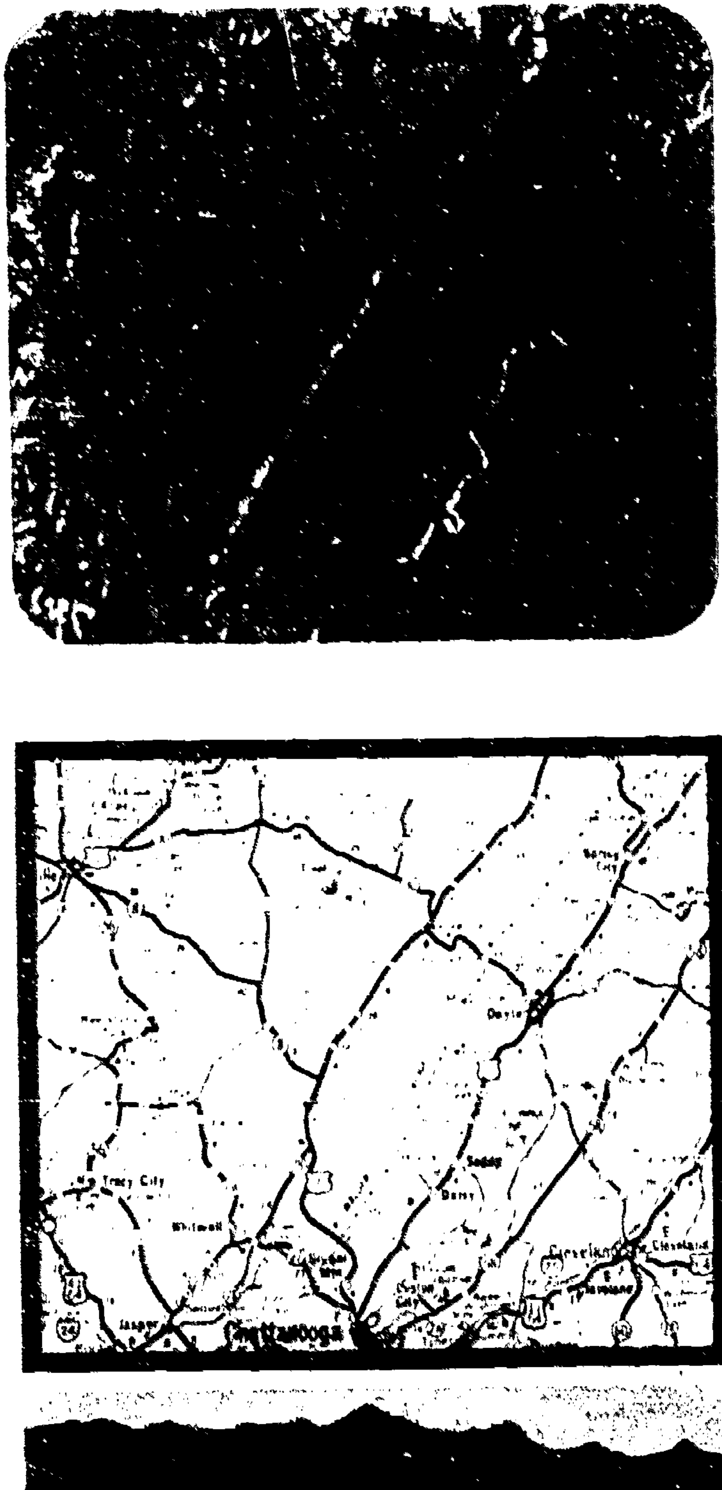


Figure 3. Relief map, road map, and cross section showing folded rock to the east, flat lying rock to the west. Paths of streams and roads show effect of this structural difference.

The more easily eroded soft layers cause the overlying hard layers to crumble away from lack of support. The spectacular Niagara Falls developed just this way (unnumbered figure, page 5).

Where alternating hard and soft layers are tilted, the hard rocks stand up as bold ridges and the soft strata erode into valleys. The paths of streams, as well as man-made roads and highways, generally follow these valleys and ridges. The two maps in Figure 3 show the landscape and highways of part of Tennessee. In the western part, which contains flat-lying strata, streams and highways are randomly distributed. To the east, however, the definite pattern in which rock layers are tilted is clearly indicated by the patterns of streams and highways.

ROCK LAYERS—THEIR ORIGIN AND FEATURES

Why are sedimentary rocks layered? Consider how the sediments from which sedimentary rocks are formed accumulate: Wind and water carry rock and mineral particles and other sediments until, for a variety of reasons, they can no longer transport them. This may happen when a stream's current slows down, or, in some streams, when the water dries up. However, deposition occurs not at a single point, but over an *area*—a surface with both length and width. As deposition continues, a layer of sediments accumulates. This particular layer grows in thickness until either the type of sediments deposited changes or deposition ceases.

How does the accumulation of snow or hail compare with that of sand or mud? A one-inch layer of snow might take an hour to accumulate, whereas an inch of hail might accumulate in a few seconds. Like snow and hail, sediments can accumulate at quite different rates. Sediments are carried and deposited most quickly by landslides.

It has been estimated that during the Madison River Canyon, Montana, landslide of 1959, sediments were moved at a speed of 60 miles an hour! This rate of sediment removal could excavate the entire Panama Canal in three minutes.

Most sediments, however, accumulate slowly, finally coming to rest after being carried along by gradually diminishing currents. Hundreds, even thousands, of years might be required to add one inch to the thickness of a layer of sediments on the deep-ocean floor.

Generally speaking, then, while a layer of sediments can spread quickly over a wide area, its thickness usually increases very slowly. This makes rock layers *tabular* in shape: Like a table top, they are large in area but relatively thin.

Law of Original Horizontality

Where do sediments most commonly accumulate? Usually they come to rest in a body of water, such as an ocean or a lake, after being carried there by streams and rivers. Have you ever thought about the degree of slope on the bottom of oceans and lakes? This slope is not so great as usually illustrated in drawings, but is actually very slight. Because the bottoms of oceans and lakes are nearly horizontal, the layers of sediments that accumulate there are also nearly horizontal. This principle is called the *Law of Original Horizontality*. Geologists apply it in assuming that most inclined layers were tilted *after* being deposited. This prompts them to search for forces that would have caused such a tilt to occur.

There are exceptions to the Law of Original Horizontality, however. Sediments might be deposited in inclined layers on the sides of hills and in channels on the bottoms of rivers, lakes, and oceans. Sediment layers in such places can have fairly steep original slopes, with angles of up to 20 or 30 degrees. Tilted layers (ones originally

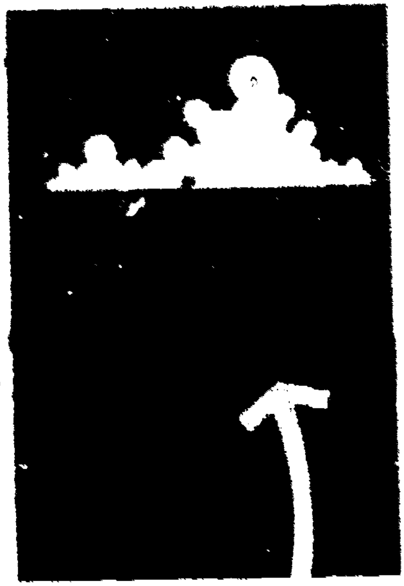


Figure 4. (A) Flanking sediments showing 30° depositional slope. (B) Sedimentary rocks tilted by structural movement.

horizontal) and layers deposited on a slope are compared in Figure 4.

When sediments are deposited on slopes or in channels, they do not accumulate in layers of uniform thickness (Figure 4A). Water currents tend to sweep sediments off high places and deposit them in lower ones so that a layer will be thicker in depressions than on mounds. Wind can drift new-fallen snow in the same manner. Snow "smooths out" irregularities on the ground because it accumulates more thickly in low places.

It is generally true that if the thickness of a rock layer changes over a short distance, the layer probably formed on an irregular surface and had some tilt when it was first deposited. On the other hand, if a layer is equally thick over a broad area, any tilt now apparent was probably produced after the sediments were deposited.

Law of Superposition

Knowing that sediments accumulate as successive "blankets," how can you tell from looking at a group of rock layers, one upon the other, which

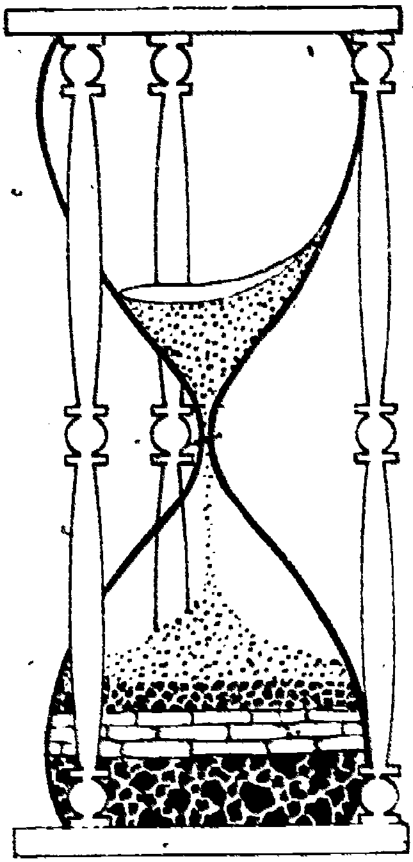
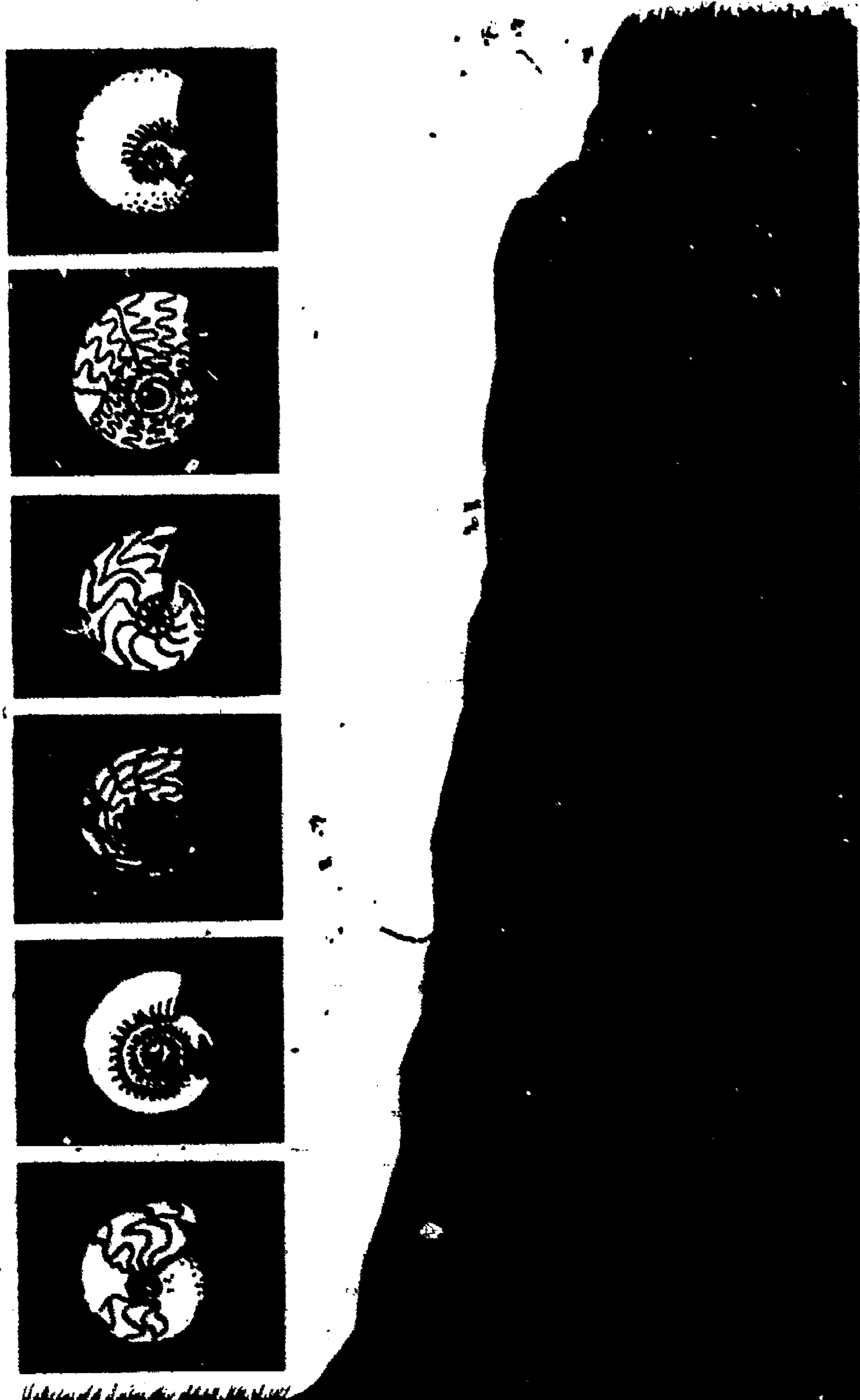


Figure 6. (Right) Relative ages of fossils determined by their superposition in strata.

Figure 5. Hour glass illustrating Law of Superposition

is the oldest and which is the youngest (Figure 5)? Because the lower layers must have been deposited first, *at any single locality* younger rocks will lie on top of older rocks. This concept is called the *Law of Superposition* and is the single most important principle in determining the relative ages of rocks. Although fossils are commonly used to date rocks, the relative ages of fossils themselves were first determined by applying the Law of Superposition (Figure 6). This law has made possible the fundamental proof of organic evolution: that is, simple forms of life can be shown to change upward into *younger* and more complex forms.

The Law of Superposition applies well enough to flat-lying rocks; but in some instances, the earth's crust has buckled and warped, completely overturning rock layers so that they are now upside



down (Figure 7). *Older rocks are then on top of younger rocks*, and the Law of Superposition cannot be applied directly. If fossils are present which are known to be younger or older tha' fossils in other layers, they can indicate whether or not the layers were overturned. Geologists also observe a variety of other features in an effort to identify the original tops of individual layers; this in turn

Figure 7 Overturned layers of rock

enables them to determine whether or not layers have been overturned.

Beds

Sedimentary layers that are visible at the earth's surface are called *beds*. Successive beds can change either abruptly or gradually into one another. Thus, there may be abrupt changes in grain size, grain shape or composition, or, like the colors in a rainbow, two beds may tend to blend into a gradational boundary. Abrupt boundaries reflect abrupt changes in the types of sediments being deposited; less obvious boundaries reflect continuous deposition during which the types of sediments gradually changed.

The boundary areas between one rock layer and the next are called *bedding planes*. They are either abrupt changes in rock type, or conspicuous surfaces along which beds tend to separate. Bedding planes are usually small in area, because the limits of a bedding plane mark the limits of the changes in deposition that produced it, and conditions of deposition tend to differ over short distances. Bedding planes can be formed in a number of ways. For example, when water currents that deposit coarser sediments in the sea temporarily subside, very fine clay previously held in suspension settles out. When the currents start to deposit coarse sediments once more, the new sediments are separated from the bed below by a thin clay film. It is along this film that the beds will tend to separate. However, even if no film of clay is deposited, other factors might still cause a bedding plane. If the lower bed hardens before the overlying bed is deposited, the two beds will probably have a bedding plane. This effect is similar to the result of pouring a "cap" of concrete on an old concrete floor. The new cap will not stick well, and will probably eventually break loose along the surface between the newer and older concrete.

One specialized type of deposit, called a *varve*, accumulates in lakes in cold climates. Each varve is a pair of thin layers of contrasting sediment types. The thicker, usually lighter-colored layer accumulates during the summer when streams bring sediments into the lake. During the winter, the sediment supply is interrupted as the lake and streams freeze; then very fine-grained sediments, held in suspension since summer, settle and form a second, usually thinner layer. This winter layer commonly contains more organic matter than does the summer layer and is therefore generally darker in color. Like a ring in a tree trunk, each varve represents one year, and, similarly, fluctuations in climate affect the thickness of the layers. Thus, like tree rings, varves can be used for matching ages, in this case the ages of different lake deposits over a wide area.

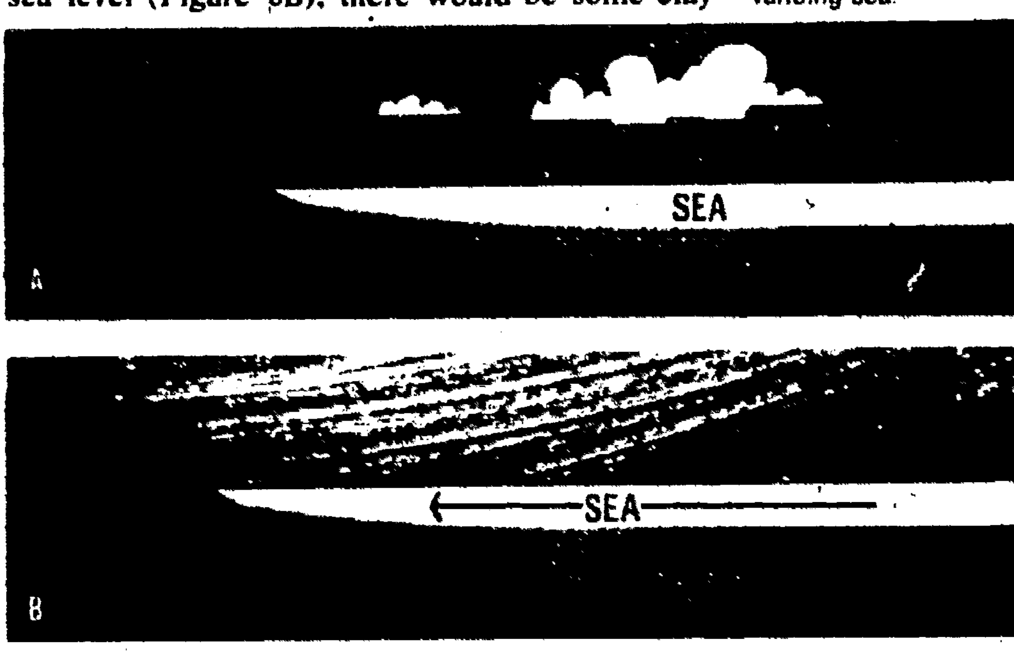
There might be noticeable changes in rock type along the length of a bed, because different kinds of sediments can accumulate in different places as parts of a single continuous layer. Similarly, hail can adjoin sleet in one county and snow in another, but all three are parts of the same blanket of ice. A bed is said to end only where its bedding planes either fade out, marking the limits of the changes that produced them, or come together, reflecting an irregularity on the depositional surface.

Formations

To a geologist, a *formation* is a body of rock that he can trace over part of the land surface and portray on a geologic map. A formation commonly consists of many individual beds and perhaps even different rock types. In fact, a formation can include as much rock and as many kinds of rocks as the geologist chooses. It is important only that a formation differs noticeably from formations below and above it, and that it can be traced in the field. A formation can end where it passes to the side into another type of rock that the geologist believes deserves a different formation name, or it can end, like some beds, where its upper and lower boundaries come together. The area of a formation is usually much greater than that of a bed. It can even be as great as that of the lal or sea in which it has accumulated. Furthermore, if a lake or sea shifts over the land, as many have done in the geologic past, the area of accumulation shifts with it. A formation might then come to occupy an even greater area than that occupied by the lake or sea at any one time.

Rivers bring to the sea a mixture of both sand and clay. As a river enters the sea, its current is slowed and coarser-grained sediments (sand) settle to the bottom first. Finer-grained sediments (clay) do not settle so quickly and are carried farther out to sea. As a result, sand usually accumulates near the shore at the same time that clay is accumulating farther out. Figure 8A is a cross-sectional view of two formations being deposited at the same time in a sea. Sand is being deposited close to the shore where currents are strong; clay is being deposited offshore where currents are weaker. If the sea were to advance because of sinking land or rising sea level (Figure 8B), there would be some clay

Figure 8 (A) Sediments settling to the sea floor, sandy sediments near shore, clayey sediments offshore. (B) Sand and clay formations being deposited in an advancing sea.



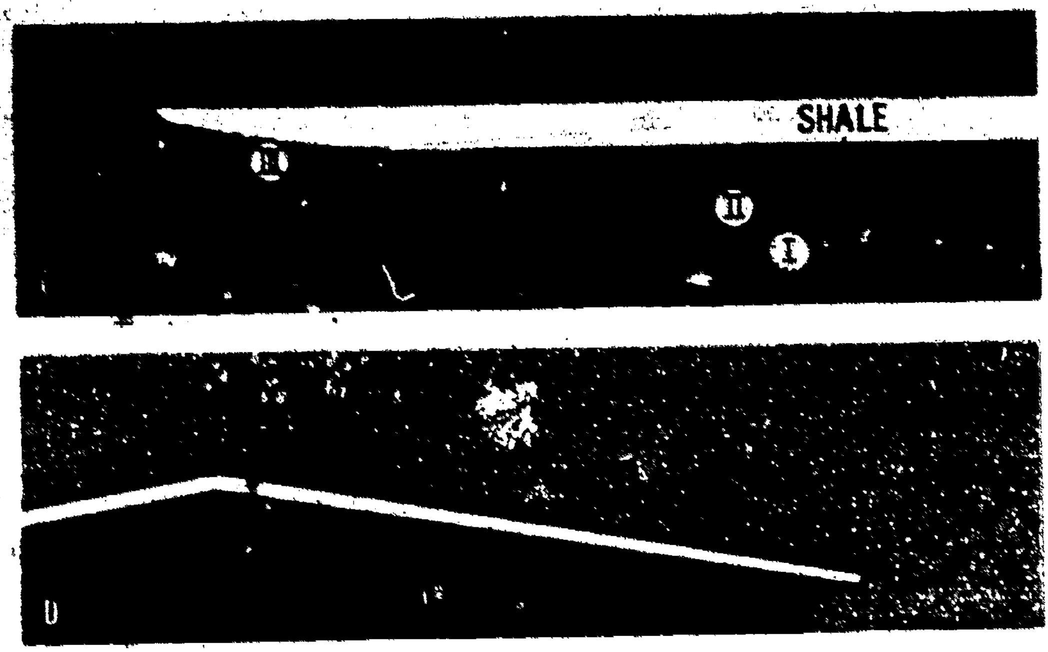


Figure 8. (C) Relating ages of parts of sandstone and shale formations produced by an advancing sea. I oldest, III youngest. (D) Shingling a roof resembles the deposition of sediment in an advancing sea.

deposited on top of sand, and a shale formation would form over a sandstone formation. Notice that the area receiving sand at any moment may be small, but the final areal extent of the sandstone is large.

Would either the sandstone formation or the shale formation be the same age throughout? From the diagram, it is clear that both the sandstone and the shale are younger in the direction in which the sea is advancing. You can think of it in terms of a roof being shingled. The man in Figure 8D has laid a continuous layer of shingles, but those along the eaves were laid long before those along the ridgepole, just as the bed of sandstone marked I in Figure 8C is older than the bed marked III. When a geologist traces and maps a formation, then, he may be mapping a body of rock that differs in age from place to place.

Does the Law of Superposition apply to *formations*, for example the sandstone and shale formations shown in Figure 8C? Shale beds are *younger* than those sandstone beds directly beneath them; II is younger than I. But these same shale beds (II) are *older* than some other sandstone beds; II is older than III.

In many instances, the original extent of beds and formations has been reduced by erosion. In fact, some layers have been completely removed, leaving no hint of their earlier existence. If layers are deposited, partially eroded away, and additional layers are deposited over them (Figure 9), the eroded surface that has been buried is called an *unconformity*. Most areas have unconformities representing missing layers, but studying a large region usually allows a fairly complete section of all the rock layers to be pieced together.

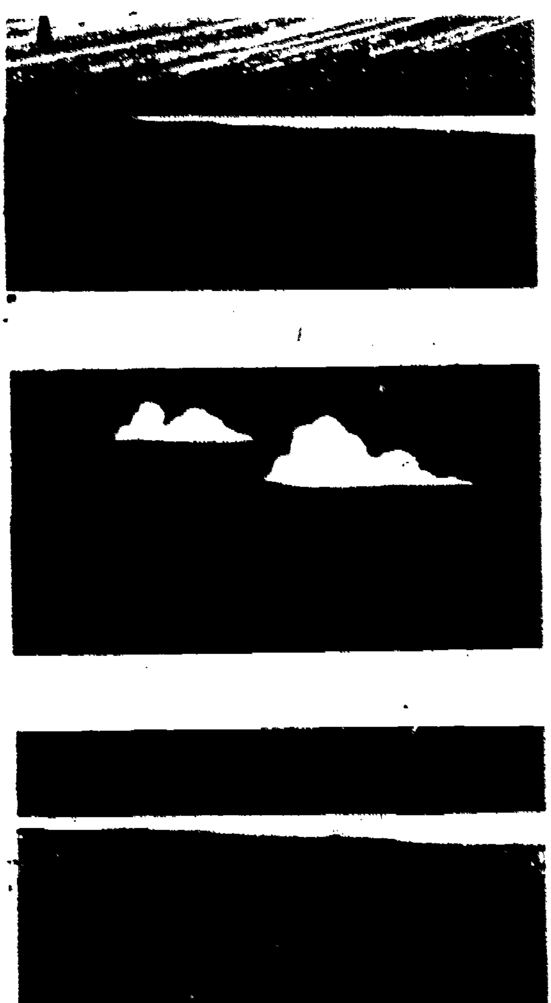
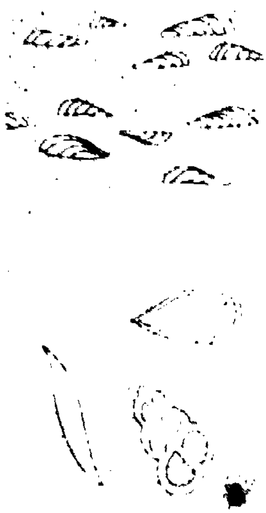


Figure 9. The development of an unconformity.

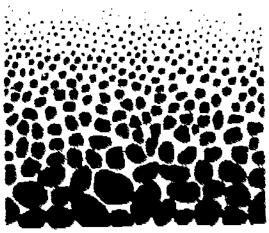
PREPARING FOR A FIELD TRIP



To make the most of your time in the field, take along all the necessary equipment. Be sure that you dress appropriately. Old clothes and comfortable walking shoes with rubber soles will add to your comfort and safety.

In the field, always be prepared to look, record, and collect. The following materials will help you do these three things:

Rock hammer (geologic pick)
Hand lens (10- or 12-power magnifying glass)
Dilute hydrochloric acid (10% solution in a 1-oz dropper bottle; available in most drug stores)
Felt pen for labeling samples
Pencils with erasers; a few colored pencils
Notebook
6-foot steel tape measure (*Note:* The English system is used throughout this pamphlet because of the standard use of English measurement for describing rocks in the United States.)
12 paper bags



FIELD TRIP TO AN OUTCROP

First, where can you find an outcrop to study? That depends on where you live. In arid regions where there is little soil or vegetation, outcrops are abundant. In humid regions, however, soil and vegetation cover the bedrock, and you should look for stream beds and roadcuts where bedrock has been exposed either by running water or by man. Do *not* work at roadcuts where the shoulder of the road is narrow and traffic is heavy. Quarries usually provide excellent exposures, but be careful of active ones, where falling rock presents a danger.

Before entering private property, always get permission from the owner. He might, in fact, be able to direct you to some excellent rock exposures. If he has done any drilling through rock, as for a well, he may be able to help you trace partially concealed rocks through the area.

Bedding and Rock Type

When you have selected a locality and arrived at the outcrop, ask yourself the following questions:

1) If the bedding is obvious, are the beds horizontal or are they tilted?
2) Are individual beds uniform, or do they differ in thickness along the outcrop?
3) Are the beds a single rock type, or is there a variety?
4) Are the beds bounded by conspicuous bedding planes that contain clay films?
5) What limits the beds along the outcrop?
6) Are there breaks, or *faults*, in the rocks, along which movement has occurred?
7) Is there soil or vegetation obscuring part of the outcrop?

Obvious bedding owes its appearance to bedding planes, but you should look to see if there are any features *within* beds that also indicate bedding. For example, look for any flat or rod-shaped mineral grains. During deposition, such grains tend to settle horizontally; therefore, they are likely to lie parallel to bedding. Do the beds contain any of the features illustrated in the unnumbered figure on page 16? If so, do they suggest that the beds are right side up or overturned?

If the beds are tilted, do the shapes of the individual beds suggest original inclination or later tilting? Look around at any neighboring hills. Judging from the angle and direction of tilt, are the same beds likely to be present in these hills? Can you see these beds from where you stand?

Check to see if any bed differs in thickness along the outcrop by measuring the bed at several points. If you measure a bed that is thinner at one end, how far beyond the outcrop would the bed extend if it continued to thin at the same rate?

Do all the beds consist of the same rock type? The following descriptions might help you in your rock identification. The References provide additional sources of help, and others are probably available in your school or town library.

Shale is formed when clay hardens. Shale can be almost any color, but it is usually gray or black in fresh exposures. The most characteristic feature of shale is its tendency to split into thin plates. It usually erodes easily and forms gentle slopes.

Sandstone is formed when sand grains such as quartz are cemented together. The grains may range in size from particles barely visible with a hand lens to those the size of match heads. Although its color varies, sandstone is usually a shade of yellow, orange, or red. Sandstone feels gritty and ranges from crumbly material to compact rock.

Conglomerate consists of rounded rock fragments ranging in size from pebbles to boulders. Both hardness and color differ, depending on the type of rock fragments and the material cementing them together. Some conglomerates can be mistaken for concrete.

Limestone consists of cemented particles of calcium carbonate. The particles can be shell fragments or fine-grained sediments precipitated from seawater, and range in size from grains too small to be seen with a hand lens to large fossil pieces. The color differs, but most limestones are shades of brown or gray. Limestone can be easily scratched with a knife. You can test for limestone by applying a few drops of dilute hydrochloric acid to a fresh rock surface. As shown by the following equation, hydrochloric acid (HCl) reacts with limestone ($CaCO_3$) to release carbon dioxide (CO_2). In the process, the limestone bubbles and foams.

$$2HCl + CaCO_3 \rightarrow CO_2\uparrow + H_2O + CaCl_2$$

2HCl	CaCO₃	CO₂	H₂O	CaCl₂
hydrochloric acid	limestone (calcium carbonate)	carbon dioxide	water	calcium chloride

Other sedimentary rocks—for example, sandstone—can be slightly "limy" and react to some degree with hydrochloric acid.

Dolomite is similar to limestone in appearance, but contains magnesium as well as calcium, as indicated by its formula $CaMg(CO_3)_2$. Like limestone, dolomite will react with hydrochloric acid, but the presence of magnesium prevents as rapid a chemical breakdown, so that it must first be scratched to make a powder. Some dolomite feels gritty like sandstone, but it has a pinpoint sparkle in sunlight that is brighter than that of sandstone. Dolomite can be shades of gray, but in old exposures it is usually rust colored. Like limestone, dolomite can be easily scratched with a knife. Look with your hand lens to see if you are actually scratching crystals (dolomite) or simply dislodging hard grains (sandstone).

Chert, sometimes called "flint," is hard, extremely fine-grained quartz most commonly found where silicon dioxide (SiO_2) has replaced limestone. It breaks with a fracture like that of glass and develops very sharp edges. For this reason the American Indians often made arrowheads from it. For the same reason, do not strike it with a hammer!

Now, can you determine the types of rocks present in your outcrop? If you find a variety of types, observe whether or not they occur in any particular order. Approximately what percentage of the outcrop do you think is made up of each rock type?

Look for fossils in the beds. If you find any, are they obscure fragments, or are they sufficiently well preserved to be identified and used in dating the rocks?

Figure 10. (A) Wave-cut terraces that resemble strata. (B) Vertical joints that resemble bedding planes.

Bedding Planes and "False Layering"

Examine the nature of the bedding planes. Some beds may change abruptly; others may change gradually. The nature of bedding planes may be related to certain types of rock. Inspect a bedding surface closely to see if it is coated with a film of clay that indicates a change in the type of sediment deposited.

Watch for "false layering." Look for evidence to suggest that the layers you observe are true beds. Erosional terraces and rocks divided by fractures or color bands can be easily mistaken for beds, for example. If you have ever visited the ocean or a large lake, you may have seen some steplike "layers" along the shore (Figure 10A). These "layers," however, are surface features and do not extend underground. They are steps, or *terraces*, that were fashioned by the waves when the water level was higher than it is now. In fact, terraces indicate how often the water level has since fallen (once for each terrace); and if you look closely, you might even observe a new terrace being formed at the water's edge today. Driftwood, beach sand, sand dunes, and other features above and along the present shorelines of some of the Great Lakes identify much older beaches.

Different kinds of fractures or breaks occurring in rocks can be mistaken for bedding planes. Some fractures, called *joints*, commonly occur as a series of more or less parallel breaks from a few inches to a few feet apart. They can occur in any direction, but because they are parallel to one another, joints can resemble bedding planes (Figure 10B). Usually, bedding is obvious due to differences in rock types, but where the beds are similar in composition, it may be difficult to tell bedding planes from joints. When trying to identify bedding planes, look for changes in rock type, no matter how slight. These changes will be separated by bedding planes —not by joints. Look for flat or rod-shaped grains, which normally come to rest with their long dimension parallel to bedding.

Figure 10. (C) Scaly (false) layers produced by alteration and fracturing of rock (D) Color banding produced by mineral-bearing waters

The action of water and air on fresh rock can cause it to scale off in crude layers. Unlike fractures, these weathering scales cannot occur in just any direction; they are always parallel to the surface of the outcrop (Figure 10C). Scales can be confused with bedding unless evidence for true bedding is discovered.

Water moving through rocks can deposit iron oxide in vivid red or orange bands. These bands are usually irregularly shaped and have little or no relation to the true bedding (Figure 10D). They are most common in sandstone because water moves through it more easily than through shale or limestone.

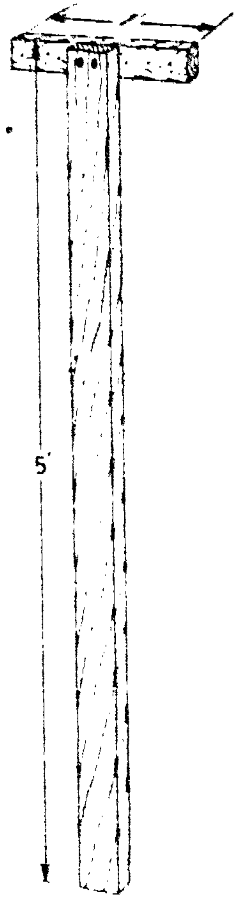
Limits of Beds

Glance along the outcrop and consider the limits of the beds. Do they merely terminate at the land surface or are some beds limited by an unconformity? If beds terminate at a fault, try to match them within the outcrop across the fault. Observe whether bedding planes fade out or come together within the limits of the outcrop.

Sketching the Outcrop

Make a detailed sketch of the outcrop with the vertical scale large enough so that the thinnest bed will be drawn at least ¼ inch thick. Number each bed on your sketch and enter a brief description of each in your notebook (Figure 11). Include the following features:

1) Any thinning of the beds.
2) Abrupt changes between beds; indicate with solid lines.
3) Gradual changes between beds; indicate with dotted lines.
4) Unconformities; indicate with wavy lines.
5) Any faults.
6) Any joints or other false layering.



SOME FIELD PROJECTS

Measuring a Section

Geologists construct a three-dimensional picture of the rock framework of an area by analyzing several small portions, called *measured sections*. To measure a section, the geologist illustrates each rock type, its thickness, the sequence of rock types, and, in addition, writes a brief description of each.

You will find some outcrops steep enough so that the boundaries of their vertical beds can be measured with a tape measure. For less steep outcrops, rock thicknesses can be measured with a homemade device called a *Jacob's staff* (unnumbered figure, page 23). With the 5-foot staff resting on the ground, sight along the 1-foot board in a line parallel to a bedding plane, as in Figure 12A. The rock between the point sighted and the point at the base of the Jacob's staff is 5 feet thick, regardless of the distance between you and the rock. When beds are tilted, in order to sight parallel to the

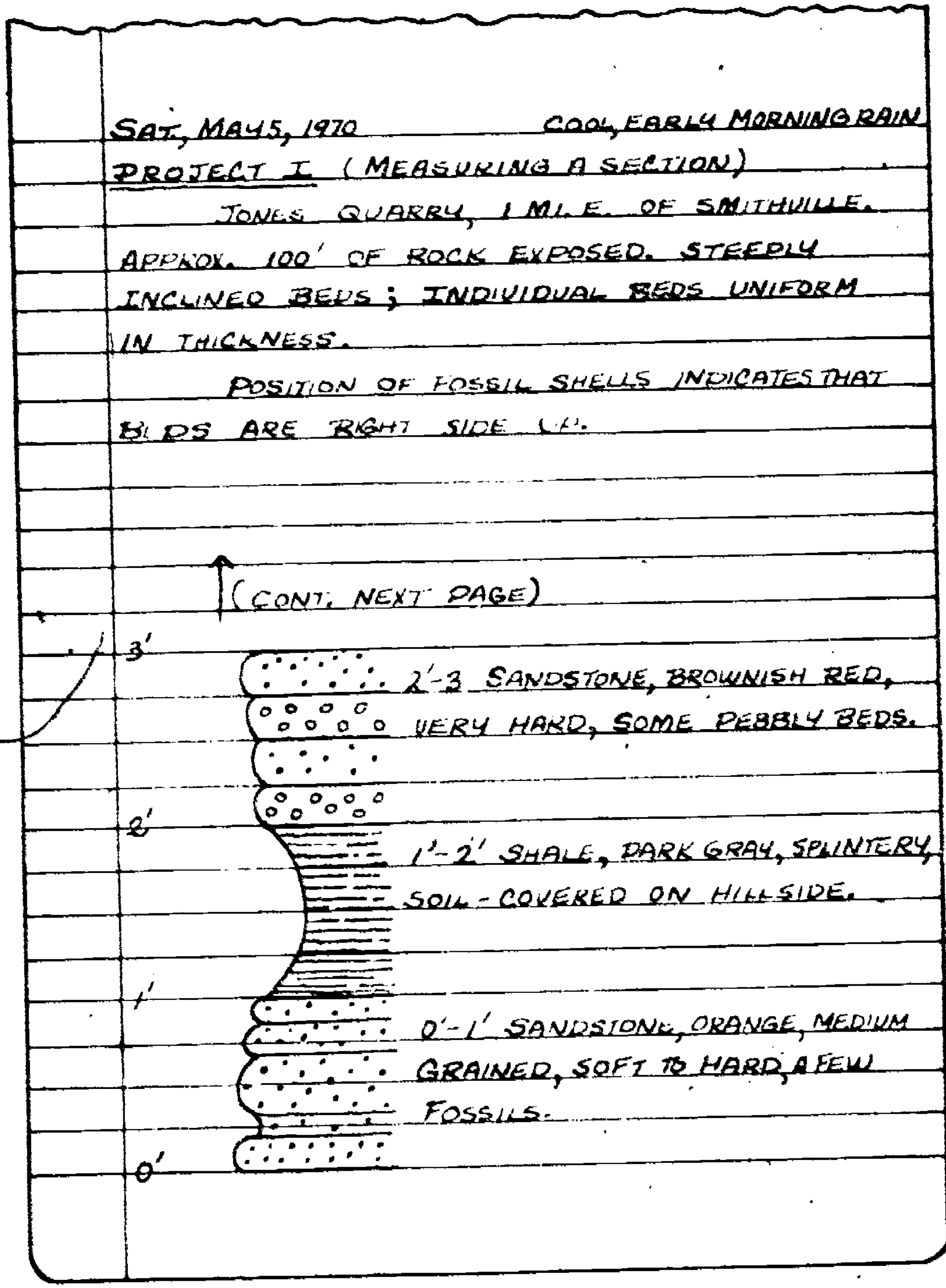


Figure 11 Photo of typical field notebook page

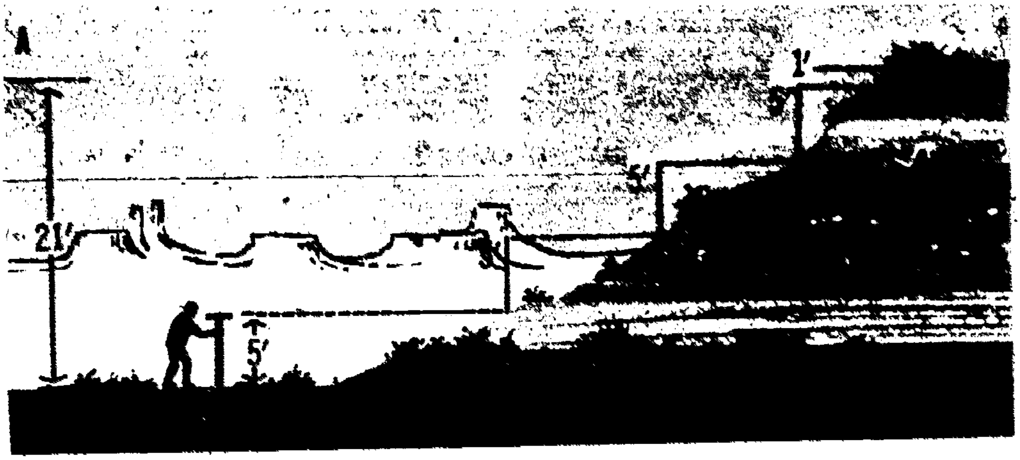
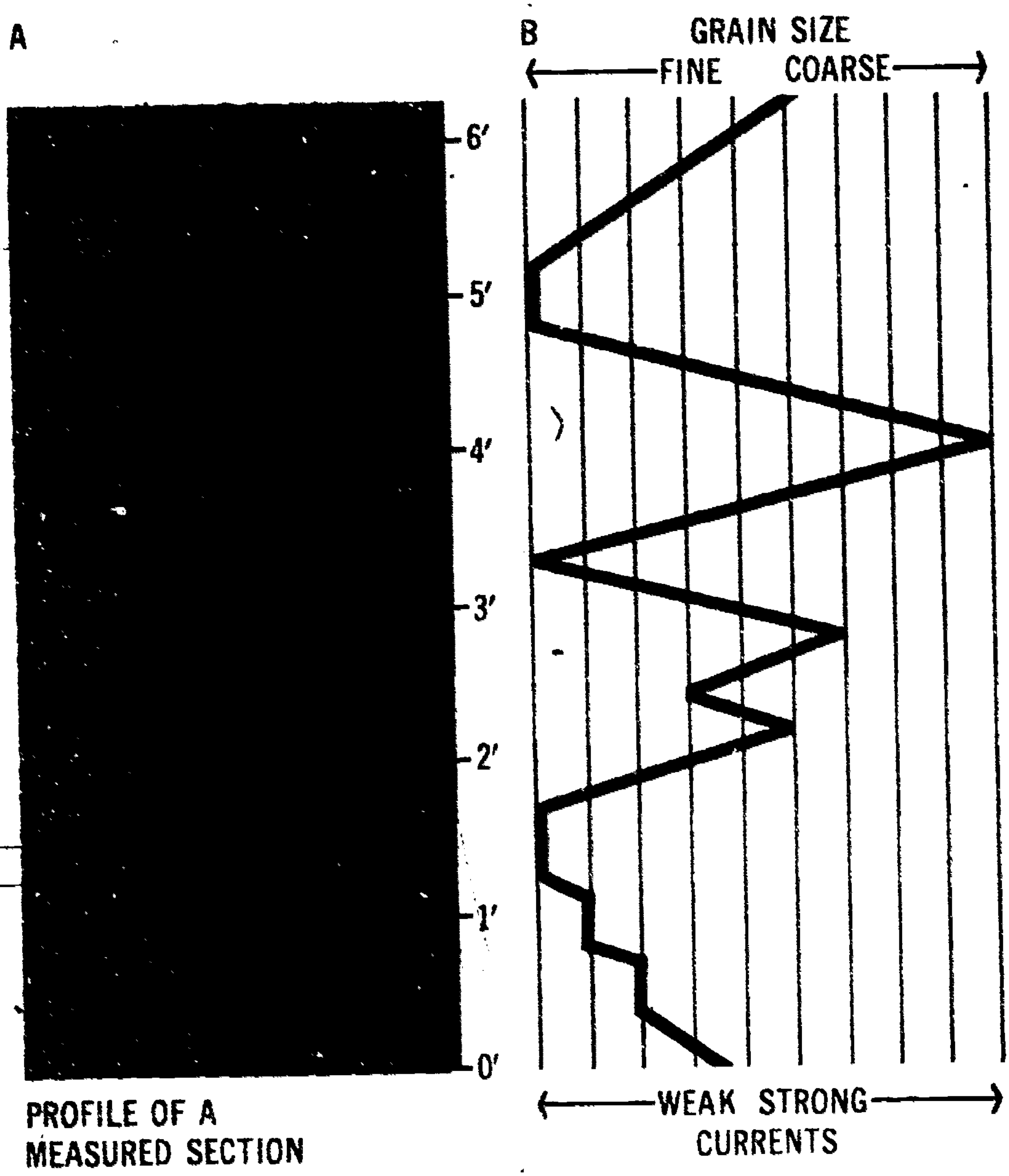


Figure 12. Use of Jacob's Staff to measure thickness of (A) horizontal layers and (B) tilted layers. (Note angle of inclination.)

bedding plane the staff must also be tilted (Figure 12B). The rock thickness from the point of sight to the base of the staff is again 5 feet. Because the Jacob's staff is a fixed height, the line of sight usually cannot be aligned with a bedding plane; it will fall within a bed instead. Use the bedding planes above and below as a guide in estimating where the line of sight should fall within a bed. When describing the rocks, estimate the footage of a bed boundary that falls between 5-foot levels.

Select an outcrop with a good exposure of rocks to measure. As you measure, describe all features of the beds and sketch a profile, or side view, of



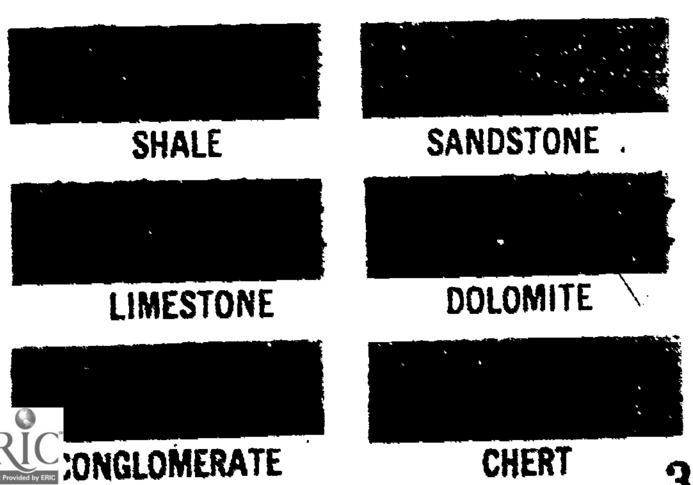


Figure 13. (A) Profile of measured section and geologic symbols. (B) Graph showing the relative strengths of currents that deposited rocks in (A). (Original grain sizes of dolomites are difficult to determine.)

the rocks (Figure 13A). Indicate the rock types of individual beds with symbols like those shown. Instead of labeling each bed and entering descriptions under corresponding numbers, identify parts of the profile by intervals. For example, in Figure 13A you might want to include the lowest five beds of sandstone under one description labeled 0'-1', the shale under the label 1'-2', and so on. See if there are beds that might be grouped together as a formation. These beds should be sufficiently distinct from other beds below and above them.

Collect any fossils that you see, put them in separate paper bags marked with their position in feet and inches above the base of the section, and take them back to the laboratory for identification. It may be necessary to clean the rock material away from fossils before they can be identified. You can clean fossils in the laboratory with a tack hammer and small cold chisels, or with small inexpensive vibrating tools. Hobby shops generally carry a line of such equipment. Try to identify and date the fossils using reference books and any other available resources. Also try to find if they were freshwater, saltwater, or land animals. The origin of fossils will indicate the type of environment in which the beds were deposited.

Relating Grain Size and Currents

For this project, collect a small sample from each bed in the section previously measured. If a bed is more than several inches thick, you might collect samples from different levels within that bed. Collect about ten samples, place each in a separate paper bag marked with its position in feet and inches above the base of the section, and take them back to the laboratory. If it is practical, label each rock directly to eliminate the possibility of confusing samples later.

In the laboratory, use a binocular microscope or hand lens to arrange the samples by grain size, for the moment ignoring the labels. Some samples, such as shale, may appear to have identical grain sizes. When this is the case, group two or more samples together.

Next, tape a piece of finely ruled paper with the lines running vertically to the side of your measured section profile. The number of lines on the paper should correspond to the number of grain-size categories into which you have divided your samples. Now, across from its position in the section, plot each sample on a line according to its grain size. Do this for every sample and then connect all the points with one zigzag line. The line graphically illustrates the fluctuations in strength of currents that deposited the rocks in your section (Figure 13B). Large, coarse sediments can be carried only by a strong current; finer sediments can be carried by a slower current. Generally speaking, the coarser the grains of sediment, the stronger the current that deposited them. However, currents can vary with time because of winds, tides, sea-level changes, or changes in the shape of the sea floor. In addition, factors such as the distance the sediment is transported from a source and the kind of rock material being transported may affect the nature of the sediments being deposited.

Tracing Rock Beds and Formations

To *trace* rocks is to match isolated parts of what was originally a single continuous bed. These parts may have been isolated for a number of reasons. A rock layer can be disrupted by erosion or faulting, or the edge of a layer can be covered in places by soil and vegetation so that it disappears, reappears, and disappears again.

To trace a layer of rock across the countryside, you must be able to recognize isolated parts of that layer. The most reliable way to match rocks is simply to "walk" beds—trace a continuously exposed bed—from one locality to the next. This can be done most easily along river bluffs, sea coasts, lake shores, and in arid regions where soil and vegetation are scarce. However, it is impossible, for example, to "walk" a bed through a corn field.

Where you cannot "walk" rocks between outcrops, the most important guide to matching is *rock type*. If you are tracing a layer of sandstone, you should of course look for sandstone—not shale or limestone. Although a single bed can change in rock type, usually the rock type of a bed is continuous. Even where rocks are covered, you can sometimes get an idea of the underlying rock type by studying the soil and vegetation. The breakdown of sandstone produces a sandy soil, but the breakdown of shale and limestone produces a clay soil. These soils support different kinds of vegetation. For example, pine trees grow well in a sandy soil but poorly in a clay soil. Therefore, where there are many pine trees, you can suppose that the soil was formed from sandstone.

You might be surprised at the variety of ways rocks affect the land and its use by man. German settlers, the first to extensively farm the land in parts of the southwestern United States, chose the fertile soil that develops on certain formations in that area, and you can now trace these formations by locating German churches and old German farms. You might even be able to trace a limestone formation by the presence of land snails, which need calcium in the soil to build their shells. Can you think of any other possible indicators of bedrock type?

In Fayette County, Texas, there is an obvious difference in the number of roads on the two sides of County Road 609 (Figure 14). Northwest of 609, surface rocks are rich in particular volcanic materials, such as bentonite and pumice, that produce very poor soil which supports only scrubby cedar and post oak trees. Southeast of 609, however, surface rocks consist of sandstones rich in minerals derived from older rocks. The result is rich black soil that not only supports a lush growth of live oak trees, but has created an important agricultural area

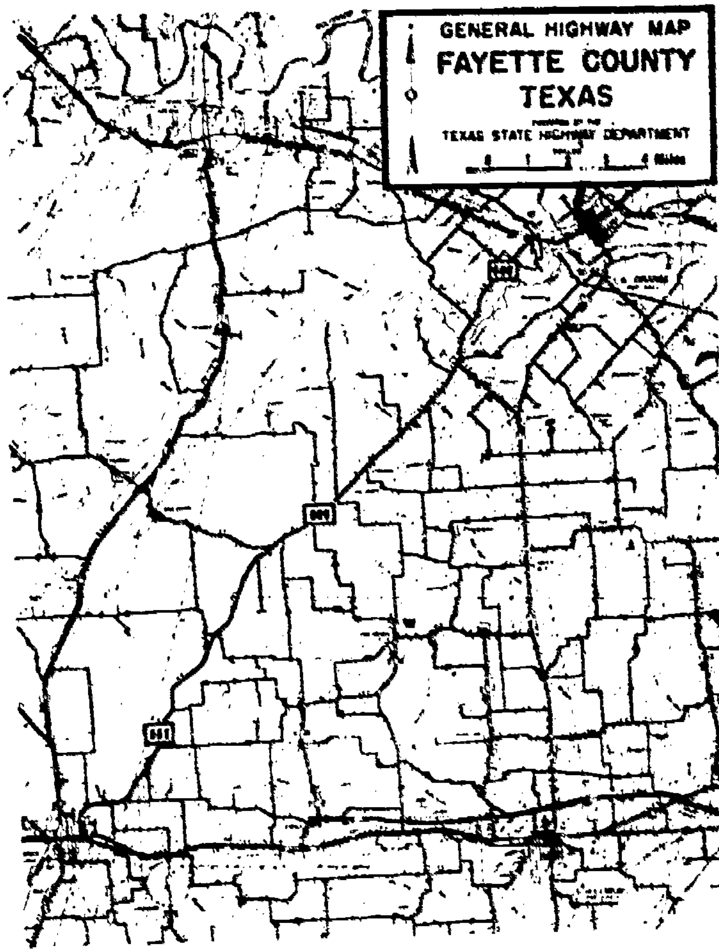


Figure 14. Fayette County, Texas, highway map.

as well. Because the good soil found southeast of County Road 609 makes many farms profitable, more roads are needed there than to the northwest.

Of course, other factors besides mineral composition control vegetation. How easily water flows through soil is important. Some rocks produce fertile soil but are eroded into such steep slopes that the soil washes away as fast as it forms, and plants cannot take root.

Different rocks occupy different areas in Fayette County because the rock beds have been tilted toward the southeast and then smoothed by erosion so that the land is nearly horizontal. From this information, can you tell whether the beds southeast of County Road 609 are younger or older than those to the northwest?

Do you ever identify a particular day, such as Sunday, by its position between Saturday and Monday? Sometimes rock beds can be recognized in the same manner—by looking at the beds below and above. The same is true of formations. If at a particular place a bed is underlain by shale and overlain by limestone, identifying the bed elsewhere is more reliable if there too it is underlain by shale and overlain by limestone. Where the bed has changed in rock type, its relative position might be your only guide in recognizing it.

The changes rocks undergo when exposed to air and water accentuate rock differences, so that individual beds stand out more clearly in natural exposures than in recent exposures made by man. If individual beds or formations are particularly noticeable, rocks can sometimes be traced across valleys at a glance. If you have ever gazed at isolated hills and mentally "connected" layers from one hill to another, you have already traced rocks in just this way.

Fossils may also be useful in tracing rocks. Certain fossils may occur only in one specific formation or, less commonly, in only one bed. Under these conditions rocks can be matched by a careful examination of their fossils. You do not have to know fossil names, but simply to match them by sight. Care should be taken, however, because fossils originally buried in one formation may sometimes be found in younger formations. It is possible, for example, that part of a formation containing fossils can be eroded and the resulting pebbles and fossil fragments redeposited in a younger formation. Geologists have been fooled by this more than once. How might you recognize "redeposited" fossils?

Similar fossils might also have been originally in different formations if, for example, two formations were being deposited at the same time side by side. (Look again at Figure 8B.)

Whether rock layers are horizontal or tilted and how the land surface is shaped both direct the search for parts of a bed or formation. In areas where layers are horizontal, the same layer commonly occurs at the same level on different hills or in different valleys, unless layers have been shifted unevenly by faulting.

In areas of tilted layers, eroded edges of beds usually parallel the ridges and valleys. Therefore, a layer occurs at the same level along the *length* of these land forms. If you were to walk *perpendicular* to these features, you would be going higher or lower in the rock succession instead of staying with the same rock layer.

Locate another exposure of the same rocks that you used for your measured section. You might do

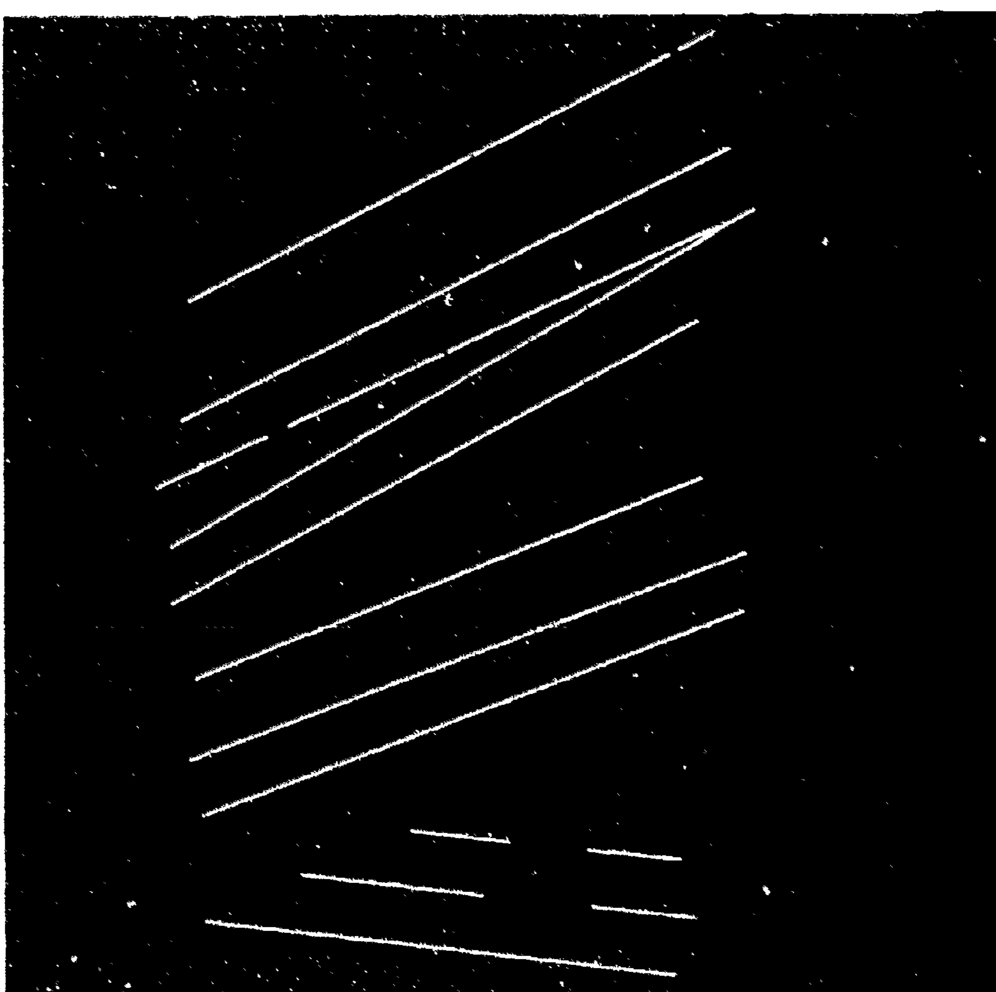


Figure 15 Matched profile sections showing similarities and differences

this by "walking the beds" a hundred yards or so along the outcrop. If heavy soil and vegetation prevent this type of tracing, you will have to search out an isolated outcrop and match the two sections by other methods. After you are satisfied that you are in the same rock interval, construct a second measured section. Mount the two profiles on a sheet of paper and draw lines connecting matching bedding planes (Figure 15). Depending on how continuous the beds are in the area, you may be able to connect them all, or you may not be able to connect any, even though you are in the correct interval of rocks.

Next, answer the following questions:

1) What does the continuation, or lack of continuation, of beds suggest about the conditions of deposition?
2) Do any beds that can be matched between sections change in rock type? If so, why?
3) On what basis did you first match the two sections?
4) On what basis did you match individual beds?
5) Can you see any reason for mining geologists to carefully trace beds containing gold or other valuable mineral deposits?

Illustrating the Thickness of a Bed

Select a bed or group of beds in your area that might be quarried for some purpose, such as limestone for cement, sandstone for glass sand, coal for fuel, or any hard rock for road material. Try to select a rock type or types for which you can locate at least five or six accessible exposures. These exposures should be distributed over several square miles, far enough apart to occur as scattered points on either a city or a county map.

Measure the thickness of the selected beds at each exposure and record each thickness at its position on the map. In the laboratory, draw a line through a thickness measurement, and extend it so as to separate numbers greater than this value from

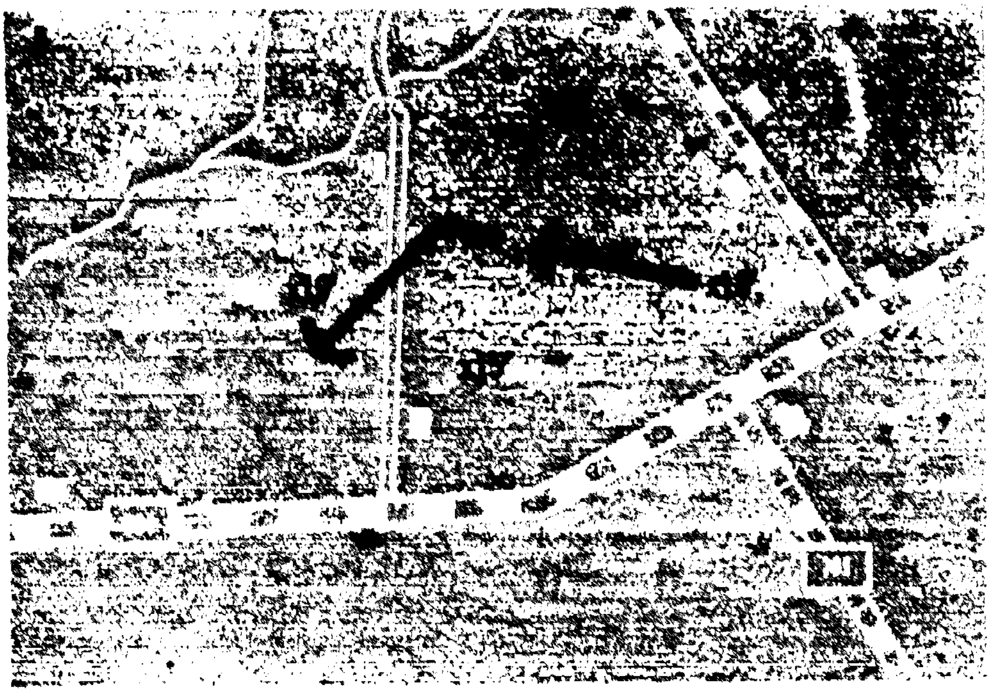
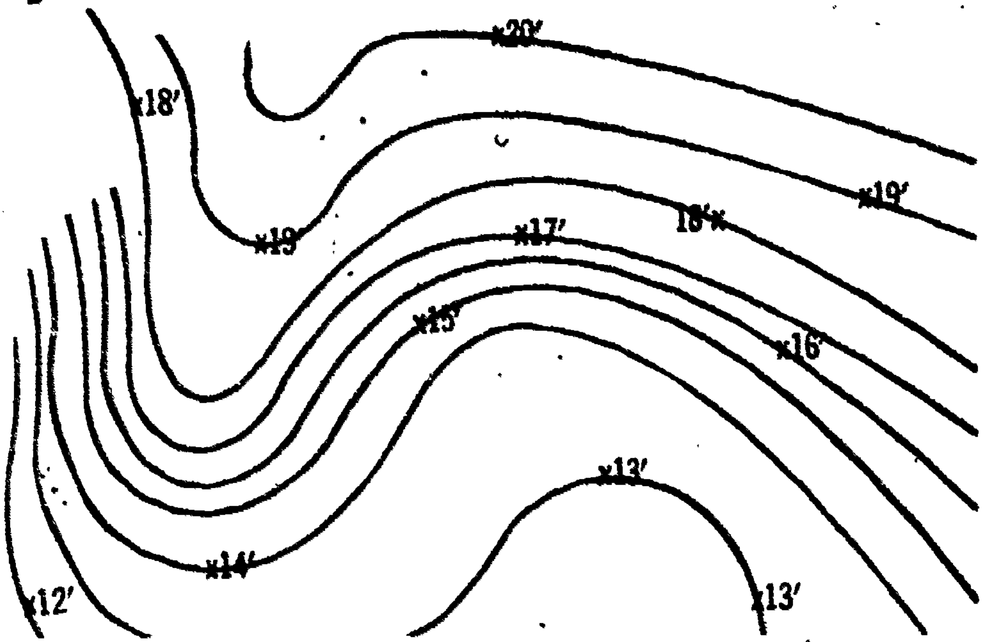


Figure 16 (A) Constructing a thickness map. (B) A completed thickness map

numbers smaller than this value (Figure 16A). Do this for every value, being careful *not* to cross lines (Figure 16B). At every place along any one line, the thickness of rocks being studied is portrayed as approximately the same as at the place where this thickness was first measured. The purpose of this thickness map is to show where maximum thicknesses of the rock interval occur. But bear in mind that you have represented this interval of rock as an uninterrupted body. Because erosion has removed the rock in places, a geologic map must be used along with the thickness map, or a field check must be made of prospective sites. Using a geologic map and a thickness map, a geologist can calculate the volume of certain rock within a given area. Also, where the percentage of minerals, petroleum, or water that occurs in these rocks is known, the geologist can calculate the total amounts of these resources as well.

B



Now consider the following questions:

1) Would the map be more reliable if the locations where the rocks were measured were more numerous and closer together? Why or why not?
2) The map does not show the thickness of overlying rocks. Would the thickness of overlying rocks be a factor in the economics of a quarry operation?

Compiling the Regional Section

Before a geologist can interpret the history of deposition in a region, he must first establish the order of deposition of the different formations. This order, called the *stratigraphic succession*, can also prove important in determining rock movement

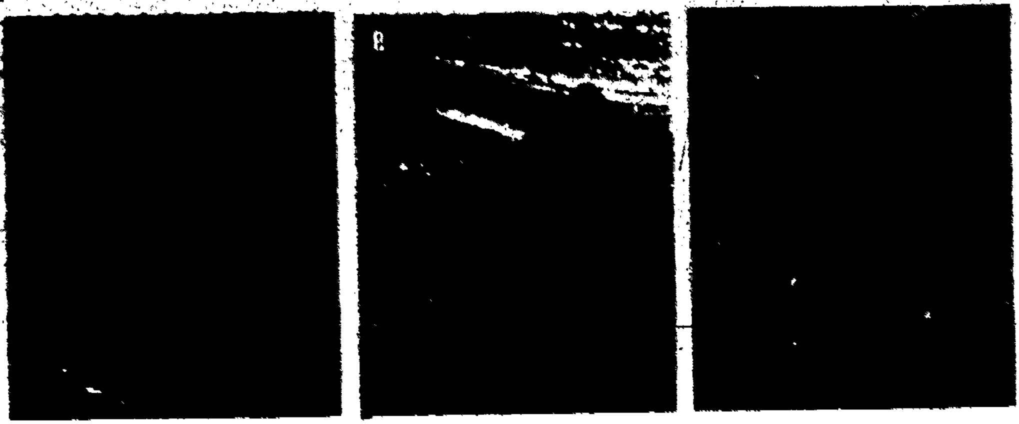


Figure 17. (A) Stratigraphic succession diagram. Stratigraphic succession used (B) to determine direction of fault block movement; (C) to recognize overturned rocks.

Fig 18. Working upward in the stratigraphic succession (left) by following a flat surface in the direction of bed tilt. (right) by climbing a hill of flat-lying rocks.

across a fault (Figure 17B) and in recognizing overturned strata (Figure 17C).

In ideal situations, the stratigraphic succession can be determined by proceeding from the lowest exposed formation to the highest point (Figure 18). More often, however, changes in tilt of beds, local soil and vegetation cover, or the shape of the land itself will require matching one local part of the succession with another; the eventual result is a composite section (Figure 19).

The purpose of this project is to determine the stratigraphic succession in your area and to divide that succession into formations. The size of the

area studied will in large measure be determined by its geology. For example, in a plains area of flat-lying rocks, you might have to travel several miles before moving up or down significantly in the succession. On the other hand, in a region of mountains or steeply tilted rocks, you might cross hundreds of feet of different strata in less than a mile. An area of five to ten square miles, which can be covered on foot or on a bicycle, will usually suffice, however.

Where should you begin? Having chosen the area, start with the lowest rock layer and proceed upward in the succession. The lowest layer will

probably lie in a direction opposite the direction of any tilt of the beds, and in a low spot such as a stream valley. After you locate the lowest layer, begin measuring and recording the rock types you encounter. The amount of detail in your descriptions should depend on the total thickness of the rocks you intend to measure. While you may not know their exact thickness, you should be able to make a rough estimate. If hundreds of feet of rock are exposed in your area, time will not permit a detailed bed-by-bed description. Pace yourself accordingly.

Measure until you run out of exposure. This may be at the edge of soil and vegetation or at the top of a hill. Then, look in the direction of bed tilt (if any) or to a higher hill for the next higher part of

Figure 19. Compiling a composite section. Formations A, B, C, and D are exposed on one hill and D, E, and F on another. Matching the two parts of D ties the rocks together in a composite section.

the succession. Match the two parts and continue upward.

Building a composite section piece by piece requires both a "feel" for the geology of the area and a keen understanding of techniques of tracing rocks.

When you have finished compiling the stratigraphic succession, divide it into as many formations as you think appropriate.

Now it will be interesting to compare your subdivisions with those of a professional geologist. Obtain a geologic map of your area from a source such as the state geological survey or the geology department of a nearby college or university. Using the map, which will probably include a short composite section, compare subdivisions and consider the following questions:

1) How does the total thickness of your section compare with the corresponding part on the geologist's map? What might account for any differences?
2) In what ways do the subdivisions of the professional differ from yours? In what ways are they similar?
3) Did you both recognize the same unconformities? If not, you may want to return to parts of the section and re-examine them in light of the new information.

QUESTIONS AFTER THE FIELD TRIPS

1) Do you know of any earth materials in your area that are produced from layered rocks? If so, are they quarried at the surface or are they produced from underground?
2) Do the streams and highways in your region have any pattern that might suggest that their position is controlled by valleys and ridges? If your highway map does indicate ridges,

sketch them in. Observe the streams and highways and see how they relate to the landforms.

3) Are agricultural activities centered in certain regions in your state? If so, are they tied to a certain formation or group of formations? What is there about these formations that produced good farmland?
4) Would you expect different formations to support different kinds of trees? Compare a forest map and a geologic map.
5) Are there any landforms in your neighborhood, such as a waterfall, that owe their development to the layering of rocks? Are there any particularly rugged areas in your region? If there are, what role does the nature of the bedrock play in their development? Are the rocks soft or hard?
6) Shale is the most common sedimentary rock, but you will probably see more sandstone and limestone. Why? How does climate affect the amount of shale we actually see?
7) Sedimentary rocks constitute only a small part of the earth's crust, but we see them almost everywhere. Why? Would you expect to find sedimentary rocks on other planets? What factors are essential for the development of sedimentary rocks?
8) The rates of radioactive decay of certain elements are now being used to determine the ages in years of sedimentary rocks. Why can't the Law of Superposition be used for making such determinations?
9) Exploiting mineral-bearing layers is easier in areas over which deposition was uniform. Why is this so? What are some *post-depositional* events that can complicate exploration for minerals?
10) Do you think it would be possible to make a chart matching all the sedimentary rocks over North America and placing these rocks in a sequence from youngest to oldest? What problems would you encounter in doing this?

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Glossary

bed—an observable, separate, single layer of rock. A bed is set apart from rocks below and above it by differences in rock type, planes of separation (called *bedding planes*), or both.

bedding plane—the boundary between one rock bed or layer and the bed above or below it. A bedding plane is either an abrupt change in rock type or a conspicuous surface along which beds tend to separate.

erosion—the natural breaking down and wearing away of rock—either into particles of sediment or into materials in solution—by water, wind, or ice. The basic cause of erosion is gravity.

fault—a rock fracture or break along which there has been obvious movement of the rocks. The result is a dislocation of rock layers and any mineral veins that existed before the fault.

formation—a subdivision of the rock record, delineated by the field geologist and used as a basic map unit. It must differ noticeably in rock type from formations below and above it, and it must be traceable in the field.

joint—a rock fracture or break along which there has been no obvious movement or dislocation parallel to the fracture surface. Joints are produced by gentle rock movements caused by heating, unloading through erosion, chemical reactions, and perhaps moon-induced earth tides.

outcrop—a place where a rock body can be seen at the earth's surface. Also called *exposures*, outcrops occur where rocks are not hidden by soil, water, or man-made structures.

section—a term used to refer both to a local exposure of rock (like the *measured section* analyzed by a geologist as part of his analysis of the rocks in an area) and to the general stratigraphic succession of rocks in a region. In its broader meaning, it is commonly recorded as a part of the legend on geologic maps.

sedimentary rock—rock formed through the deposition and cementation of sediment particles (sandstone, shale, etc.), the precipitation of "chemical" sediments from water (rock salt, gypsum, etc.), and the accumulation and cementation of shell or fossil material (limestone).

strata—layered rocks. Such rocks, which are broad in area but relatively thin, are called *tabular.*

stratigraphic succession—the order of deposition of different formations in a region, used to interpret the geologic history of that region. It can also help establish rock movement across a fault and help identify overturned beds.

unconformity—a buried surface of erosion created when rock layers are partially eroded and additional layers deposited over them. Unconformities are important because, unlike some formational boundaries, they clearly separate rocks in time.

varve—a double layer of sediments deposited yearly in lakes in cold climates. A thicker, usually light-colored layer results from summer accumulation; a thinner, darker-colored layer is produced in the winter. Varves, like tree rings, can be used for dating and determining fluctuations in the climate of the area in which they occur.

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