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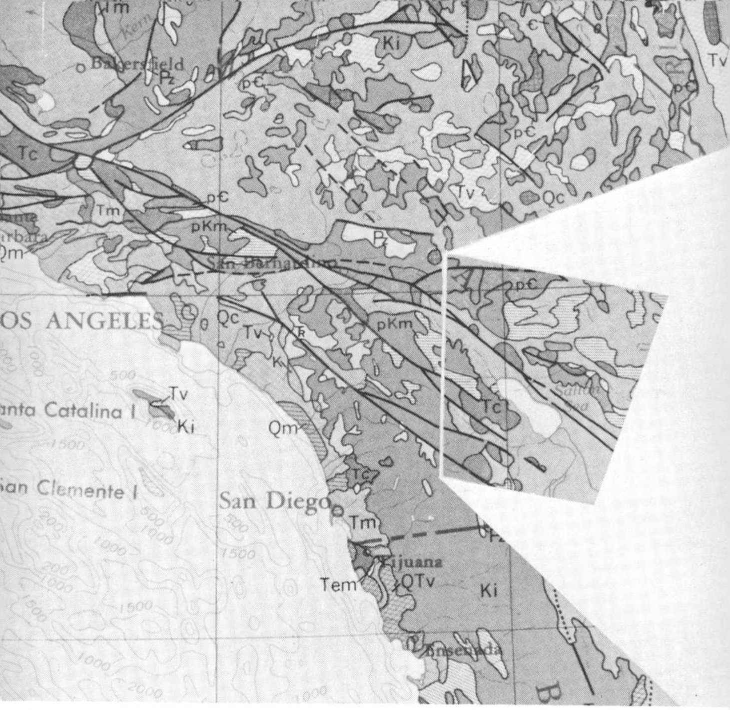
Geologic Maps:
Portraits of the Earth



Geologic Maps:
Portraits of the Earth

by Walter S. White

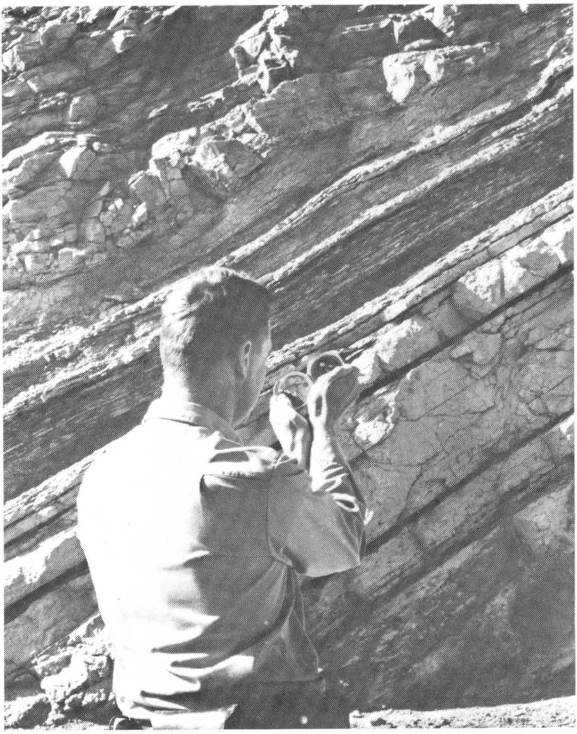
The picture above is a portrait of many square miles of the Earth's surface. The purpose of this leaflet is to explain how this portrait was made, how it can tell us about what lies beneath the surface of the ground, and other ways in which it can be useful to mankind.

A look at a person's face often reveals something about the *nature* of the person inside—elements of that individual's character seem to show through. The face of the Earth also tells us much about what lies beneath, once we know how to interpret what we see at the surface. With a large subject like the Earth, however, what we can see at any one spot would be like looking at someone's face with a microscope—we could only see a minute portion in any one view. To get a better view of the Earth, as from a distant vantage point, a geologist makes observations at many different points and plots them on a map. He

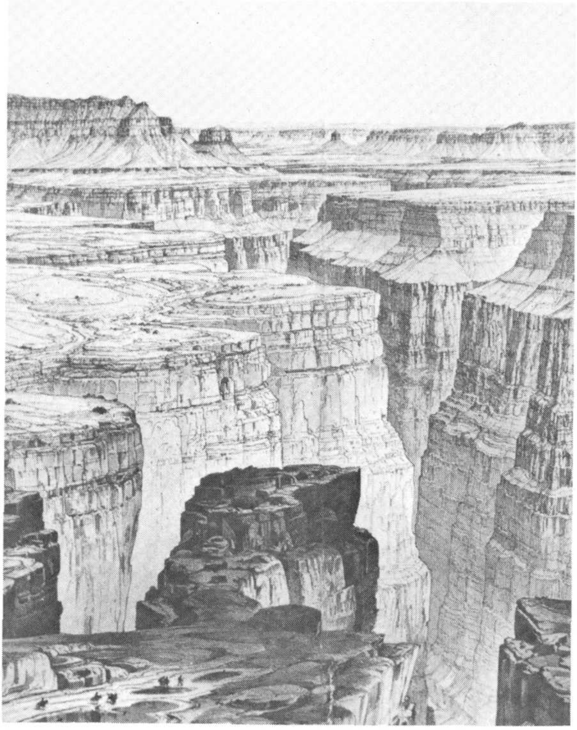
View of Salton Sea, California, from high altitude. Aerial photographs are commonly used in the preparation of geologic maps.

builds up his portrait by combining all his microscopic views. A big difference between what a geologist does and what an artist does when each makes a portrait lies in the fact that a geologist, unlike an artist, cannot see his subject whole, and doesn't know, when he starts, how the ultimate portrait will appear.

Besides giving a distant viewpoint, this portrait, a geologic map, does two other things that help the geologist look below the surface. First, it lets him see the Earth as it would appear with all the overlying materials stripped away to reveal the layers of rock just below. Some of the most scenic areas of the West owe their beauty and magnificence to the different rock layers, often highly colored, that are exposed to view, enabling us to observe directly their layering and folding or tilting. In most of the country, however, the rocks that underlie the Earth's surface are covered by trees, grass, soil, highways, and buildings, and are rarely a conspicuous part of the scenery. The geologist can actually see the underlying rocks only at widely scattered points in cliffs, ledges, streambanks, and road cuts and other excavations. But he can often find clues to the nature of the underlying rocks from the character of the topsoil and from the distribution of ridges and valleys—valleys are commonly underlain by softer or more soluble rocks than the bordering ridges and hills. When all these bits of information are put together on a map, each in its proper position, the result is not unlike an impressionist painting: the notations resemble multicolored dabs of paint when examined closely, but may form a recognizable picture when viewed from a short distance. Once the geologist has placed the bits of information on a map and has seen a clearer picture, he redraws the map to show the important features more distinctly.



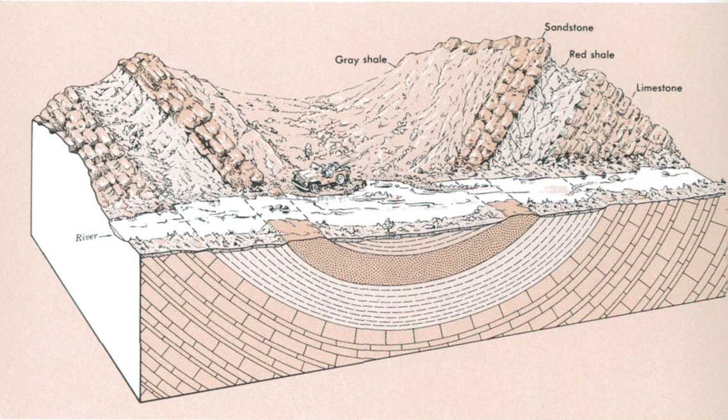
Geologist measuring the amount of tilt displayed by layers of rock in the road cut.



Individual layers of rock along the walls of the Grand Canyon are clearly shown in this drawing by W. H. Holmes.

Secondly, a geologic map lets the geologist see the differences between rock layers. Even with the soil and other materials stripped off, the differences between rock layers might be invisible from an airplane. From a distance, rocks that are quite different may have a very similar appearance. A geologist can detect the differences by examining the rocks on the ground or by studying specimens of the rocks with the aid of laboratory equipment. He can then use colors or patterns to show the differences in his portrait of the Earth.

The first natural scientists to make meaningful predictions about what lies beneath the surface seem to have acquired their insight not from making geologic maps, but from the large panoramic views one sometimes sees in cliffs and steep mountainsides. In the turreted walls of the Grand Canyon of the Colorado River, for example, the eye can easily follow the course of individual layers of rock for



This cross-sectional view shows how the bending of rocks forms a trough.

miles and one realizes that the layers occur in the same order at other places throughout the canyon. Such individual layers of rock are grouped by geologists into units called "formations." The thickness and physical features of a formation are sufficiently distinct to allow it to be traced continuously for long distances, and it is the basic unit that is plotted on a geologic map. Geologists commonly name a formation for some geographic locality near which the unit was first identified.

When river valleys cut across ridges like those of the Appalachians, one can see arches in the strata a few hundred yards across in a single view and learn from this that rocks do not always lie horizontally, as at the Grand Canyon, but that the layers may, instead, be tipped up and folded.

In walking along such a river valley, one might notice that the layers sloping one way in one ridge resemble layers sloping in the opposite direction in the next ridge. The accompanying sketch shows two ridges and a valley between as seen from a river flowing from left to right (west to east). Both ridges and the valley extend away from us toward the north, so we are looking at the ends of the ridges and can see something of their internal structure in the sort of cross-sectional view our vantage point affords. The drawing clearly shows that the sandstone beds, with gray shale beds above and red shale and limestone beds below, bend down under the valley to make a trough. This cross-sectional view of the two ridges suggests how the rocks might look if we were able to dig a trench deep into the Earth along the course of the river and look at the rocks in the walls of the trench. It is easy to see how the rock layers must connect up beneath the valley in some way such as is suggested by the connecting lines. By drawing cross-sectional views like this, one can estimate how deep a hole would have to be drilled in the middle of the valley to reach the limestone bed beneath the red shale.

From cross-sectional views of this sort, where the vertical dimensions of things can be seen directly, the earliest geologists learned how the formations of the Earth occur in recognizable sequences of layers, and that what can be seen at the surface may, with a little imagination, be used to make intelligent estimates about what lies at depth.

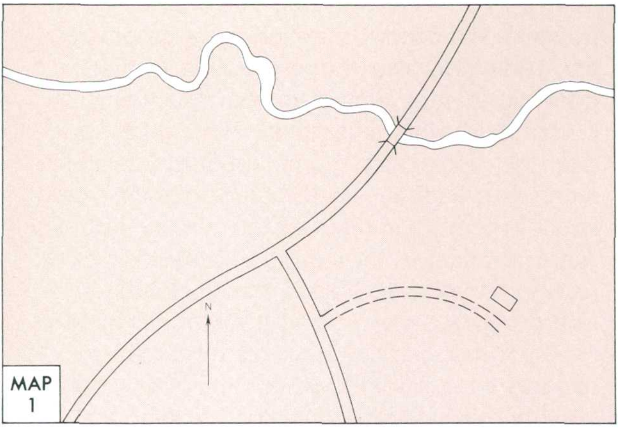
Unfortunately, the number of places where the Earth shows its internal structure as clearly as in the sketch is very small compared to the innumerable areas where the underlying structure is not at all clear. Consequently, geologists now organize their direct observations by plotting them on maps. They no longer rely on panoramic views and large vertical exposures to understand how rock layers continue beneath the surface.

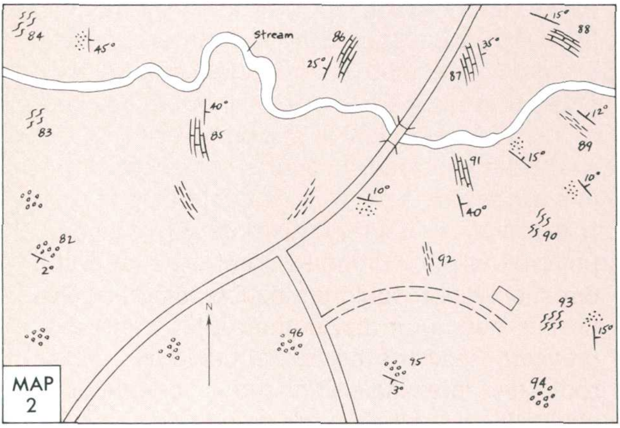
Making a geologic map, therefore, is one of the ways by which a geologist can predict the presence and position of certain rock layers beneath the Earth's surface. What does he actually do to make this geologic map? First, he makes a systematic search for places where rock appears in natural ledges or artificial exposures. Second, he records the exact location of such outcrops on a map. Third, he places symbols on his map to record the observations that appear to be most significant about each outcrop. Generally these observations are placed on a base map like

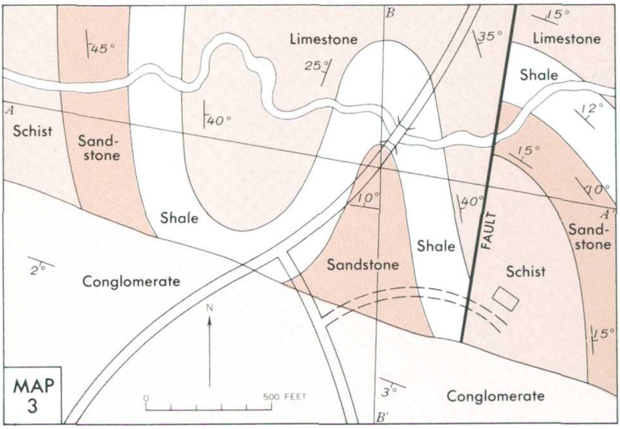
Map 1 which shows roads, streams, and houses. The base map eventually becomes covered with symbols representing the geologist's observations of the scattered outcrops that he has examined. His field map might now look something like Map 2. Each of the symbols (circles, dots, dashed lines, wavy lines, etc.) represents an outcrop that he has examined. Each symbol, plotted in its correct relationship to the stream, house, roads, and other outcrops, represents a different kind of rock. Dots, for example, are often used to represent sandstone; circles, conglomerate; straight lines, shale; wavy lines, schist or gneiss. The flat T-shaped symbols with numbers like 3^{o}, 10^{o}, 25^{o}, and 40^{o} are called *strike-and-dip* symbols and give the amount and direction of slope of the layers in the various outcrops. If this symbol were to be used to describe a sloping roof, the long line (the *strike* line) would be parallel to the ridge pole, and the short line (the *dip* line) would point directly down the slope of the roof in the direction water would drain. The number gives the inclination (or dip) of the roof in degrees measured below a horizontal plane. For a flat roof, the dip would be 0^{o}, and for a vertical wall, 90^{o}. The other numbers (82 to 96) near some of the outcrops refer to entries in the geologist's field notebook in which he records the numerous additional observations on the rocks that he cannot conveniently represent by map symbols.

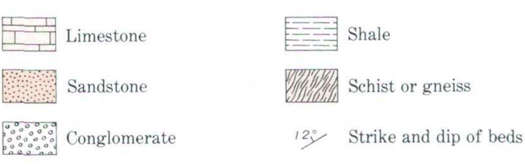
The geologist's final step is to add boundary lines between the different kinds of rock and to color in the sections to show how he thinks the area would look if the soil were completely stripped away. Map 3 has been redrawn to show the important features more distinctly and is an example of the completed geologic map.

The reliability of this map depends on the number of exposures of the rocks and their distribution. In drawing this final geologic map, the geologist first assumes that each rock type represents a layer that was once continuous over the whole area. He also assumes that

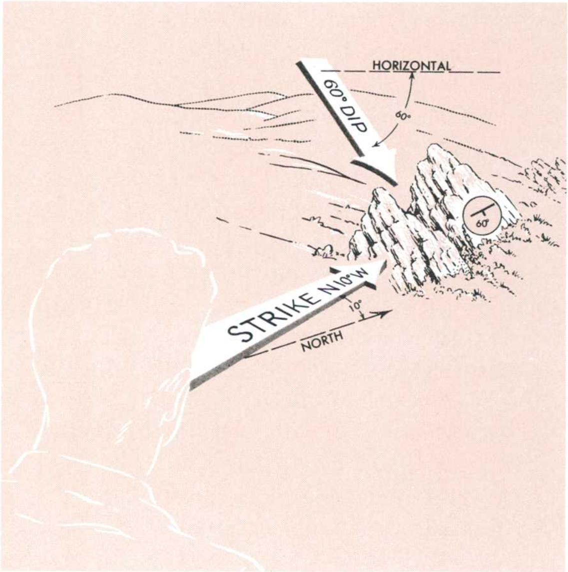

N
MAP 1


Stream
84
45°
86
25°
87
35°
15°
88
40°
85
83
12°
89
15°
91
10°
10°
40°
82
2°
90
92
N
96
93
15°
95
3°
94
MAP 2


B
45°
Limestone
35°
15°
Limestone
25°
Shale
A
40°
12°
Schist
Sand-
stone
15°
10°
10°
40°
A'
Shale
Sand-
stone
FAULT
Shale
2°
Sandstone
Schist
Conglomerate
N
15°
MAP 3
0
500 FEET
3°
Conglomerate
B'


Limestone
Shale
Sandstone
Schist or gneiss
Conglomerate
12°
Strike and dip of beds

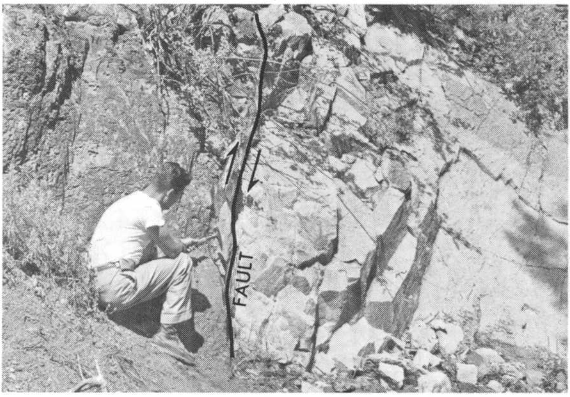
these layers occurred in the same order, from top to bottom, over the whole area. If the final geologic map is consistent with everything he knows about this and surrounding areas, and does not, for example, imply that one layer is older than another when fossils show the opposite, the map is inferred to be a correct representation of the surface distribution of rock formations. In Map 3, these tentative assumptions severely limit the number of ways in which the distribution of outcrops can reasonably be explained. Most geologists would draw about the same final map from the particular set of data given in Map 2. It is not difficult, however, to imagine situations in which the outcrops might be connected in several different ways with no one way being obviously more or less credible than the others. Such situations can readily occur where there are few exposures, less clear-cut contrasts in rock types, and more complicated geology. To find the best solution, the geologist relies on additional evidence thay may not be readily shown on the map. Such evidence might consist of particular types of fossils or of pebbles of one rock layer in another; both kinds of evidence show which layers are older and which are



younger. Or the geologist might notice, for example, that the rocks along a line running north from the house shown in Map 2 appear to be more fractured than normal, suggesting that these outcrops lie near an important break or *fault* in the rocks. Finally, he may rely heavily on what he has learned in areas of good exposure about the sequence of rock layers and about the characteristic fold or fault patterns of these particular rocks in this region.

Now the geologist has a map that shows what he could see from an airplane if all the rocks were bare and the different rock units were easily distinguishable by color or other characteristics. The strike-and-dip symbols tell whether the layers at each place are going down into the Earth at a steep or gentle angle and in what direction. The geologist can predict the subsurface geology by the strike-and-dip symbols and the distribution pattern of the rock formations, even though no cliffs or other steep cuts show the vertical dimensions and depths directly.

By drawing cross sections in different directions across the area of Map 3, we can see how it can show the subsurface geology. We can predict what might be seen in the walls of imaginary trenches 400 or 500 feet deep were they to be dug along the lines *A-A'* and *B-B'*. The top line of each cross section shown here represents the surface of the ground. Proceeding from *A* toward *A'* along this top line, the map shows schist, symbolized by wavy lines. About 250 feet from *A* the schist gives way to sandstone, symbolized by a stipple pattern. The strike-and-dip symbol just north of the stream, Map 3, indicates that this sandstone layer is inclined toward the east at an angle of 45°. Since it is known by scaling from the map (see bar scale, Map 3) how far it is from *A* to the top and bottom of the sandstone layer, and since it known that the sandstone extends downward into the Earth toward the east at an angle of 45°, we can tentatively draw it in with this inclination for at least a few hundred feet below the surface in the



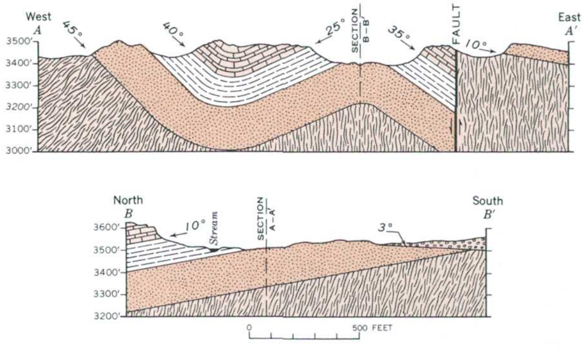
Movement along a fault has brought older rocks into contact with younger rocks.

cross section. Proceeding eastward in the same way, we can fill out the near-surface part of the section all the way from *A* to *A'*. (The heavy line labeled "FAULT" on the map represents a break in the Earth's crust. The strike-and-dip symbols don't tell us what the fault's attitude is, but let us assume for purposes of this illustration that it is vertical.) If the boundary lines of the various rock units are extended downward parallel to their dips, and the patterns filled in, we can easily see how rock formations in the western two-thirds of the section probably join below the surface in a trough-shaped structure. Familiarity with similar folded structures elsewhere leads the geologist to round off the bottom as is shown in the cross-sectional drawing. Though different geologists might round the trough off in slightly different ways, the differences would normally be too small to have much effect on the predicted depth to the sandstone in the center of the trough.

Eastward, the east side of the trough (or *syncline*) is the west side of an upwarp (or *anticline*) and everything down to the top of the sandstone can be drawn without any serious stretch of imagination. From the cross section alone, the thickness of the sandstone is not known. However, if the geologist knows how thick the sandstone is in other places where it comes to the surface within and outside the map area, he may be able to predict its thickness in the anticline fairly closely and complete this part of the cross section with some confidence. Otherwise he might use the thickness of the sandstone layer he found in the western part of the section and dash the base of the section to show his uncertainty. The upper surface of the schist is the floor on which the sandstone was deposited. The attitude of the schist layers suggested by wavy lines need not conform to the dip of the layers in the sandstone and overlying rocks.

The fault is a break or dislocation in the rock layers, and each rock layer ends against it on the west side and starts anew between the fault and point *A'*. If the layers almost join across the fault, the displacement is small, but if the fit is poor, as it is here, we know that the displacement is large. Good estimates of the actual vertical displacement can be made by measuring how far the rocks on one side of the fault must be shifted to bring the base of the sandstone to the same level. Cross sections can be drawn in other directions and places to determine what lies below the surface in all parts of the area. In section *B-B'*, drawn nearly north-south, the dip of 10° measured in sandstone gives the same thickness for the shale that was obtained from the construction of section *A-A'*. Such a check for internal consistency between geologic maps and sections makes both the map and the cross section more credible.

The conglomerate formation (open circle pattern) in the southern part of the area is



Cross sections *A-A'* and *B-B'*.

shown as a thin sheet inclined gently south as the 3° dip of the bedding suggests. Map 3 shows there is a discontinuity between the conglomerate and the rocks to the north—the northward limit of the conglomerate is a straight line that cuts across other formation boundaries. This suggests a fault, but the map does not indicate that a fault is necessarily present. If the conglomerate were known from included fossils to be younger than the other rocks, or if it contained pebbles of rock units to the north, it would be possible to interpret the conglomerate as a broad gravel bank that lies on top of the other rocks; under these circumstances, no fault need be present. This latter interpretation is shown in cross section *B-B'*. The existence of these two possible interpretations illustrates how a geologic map may correctly represent the distribution of rocks at the surface and still be ambiguous.

The preceding paragraphs are concerned wholly with understanding the spatial relationships of the different rock formations—their geologic structure. The analysis of the geology of the area is not complete, however, without consideration of time. Geologic history attempts to put all the geologic events of an area into the proper time sequence.

A basic premise of geology, amply supported by many kinds of evidence, is that most rock layers were originally laid down as horizontal or near-horizontal sheets, either in the bottom of a sea or lake, or on land in a valley or plain. Cross section *A-A'*, therefore, shows first that the layers have been folded and broken since they were originally laid down, and second, that the present surface of the land cuts across the various layers just as though a giant planer had been run across the area after the rocks were deformed. Something like this has indeed occurred, and the processes that have accomplished this planing effect are collectively called erosion. Most people are familiar with this term as it is applied to the spectacular gullies formed when soil is eroded on hillslopes, but the geologist sees the results of erosion in a broader sense whenever she looks at a geologic map or cross section, or at a landscape. Were it not for the combined effects of deformation and erosion, the most ancient rocks of the Earth would be the most deeply buried, and we would never see them at the surface. But, because the crust of the Earth has been periodically buckled and broken and then planed off by erosion, its layering and structure are exposed to view just as a knife cut reveals the inner structure of an onion.

With these principles in mind, one can gain an insight into the geologic history of an area by studying the cross section. Here the sandstone was originally laid down as a sheet on a relatively flat surface that cuts across the layering in the schist. This indicates that, still earlier, the schist must have been deformed, and that erosion had then carved a level surface on this rock before the sandstone was deposited. Layers of shale were then deposited on the sandstone and this shale was overlain in turn by limestone. Detailed study of these formations would probably reveal whether they were laid down on the sea floor, in lakes, or on land, because each kind of rock has physical or chemical characteristics that reflect its environment of deposition.

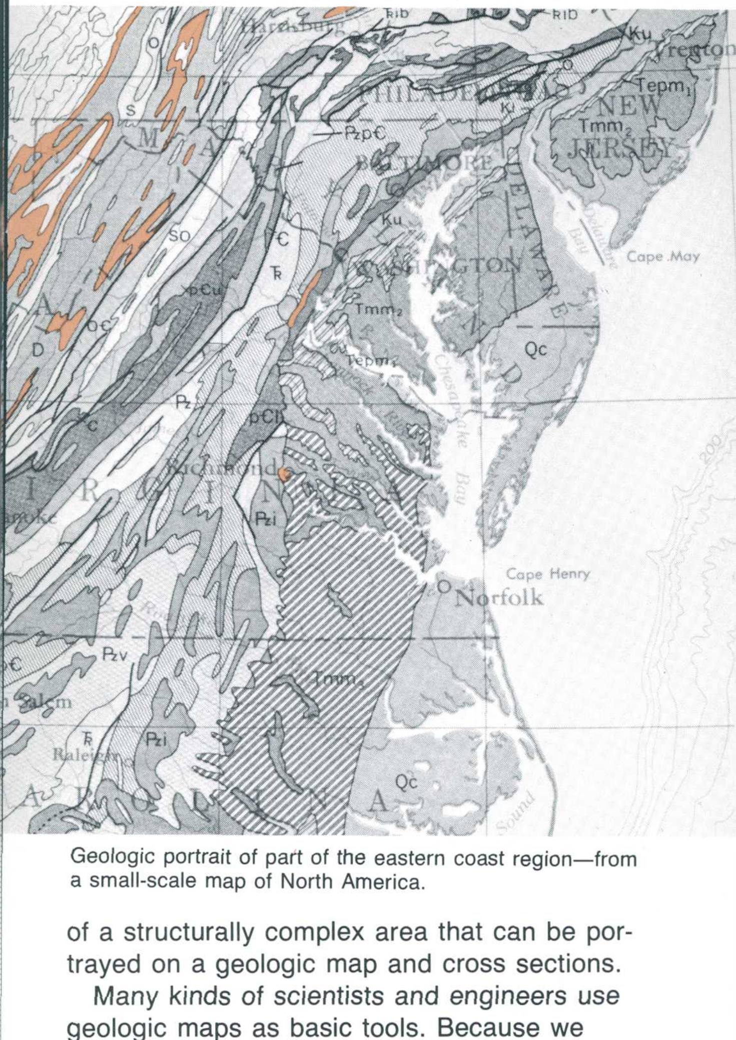
Fossils are records of the progressive development of life on Earth.

Fossils in the rock provide information about both the environment and the time of deposition.

After the limestone was deposited, the area was crumpled and broken as shown by the folds and faults. Again the area was subjected to erosion and a relatively flat surface was cut across all the rocks. The conglomerate was deposited on this surface. The area was then tilted slightly toward the south to give the conglomerate its present low dip in that direction. The latest event that produced the present land surface was the erosion which is still going on.

In this brief account of how a geologist makes and uses a map to organize her field observations for study and analysis, it has been convenient to describe what she does as a series of steps taken in a regular sequence, with each completed before the next is begun. Actually, because a geologic map represents an interpretation, it is used as a diagram to test hypotheses. It may be drawn and redrawn many times before a version satisfies all pertinent facts. If more than one version survives these tests, additional field or laboratory observations may be needed to decide among them.

A geologic map, therefore, really plays three distinct roles. First, it is a convenient means of recording observations about rocks in a way that preserves their spatial relationship to each other. Second, along with the cross sections that can be drawn from it, it is a device for study and analysis of many kinds of geologic features such as sequence and thickness of formations, their geologic structure, and their history. Trial versions of the map suggest conditions that a satisfactory hypothesis of the local geology must meet, and these lead the geologist to critical localities where alternative hypotheses can be tested. Finally, when the geologist has deciphered the significant geologic relationships of an area, her map is the most compact way to illustrate many of these relationships so they can be readily grasped and used by others. It would take volumes of text to describe the features

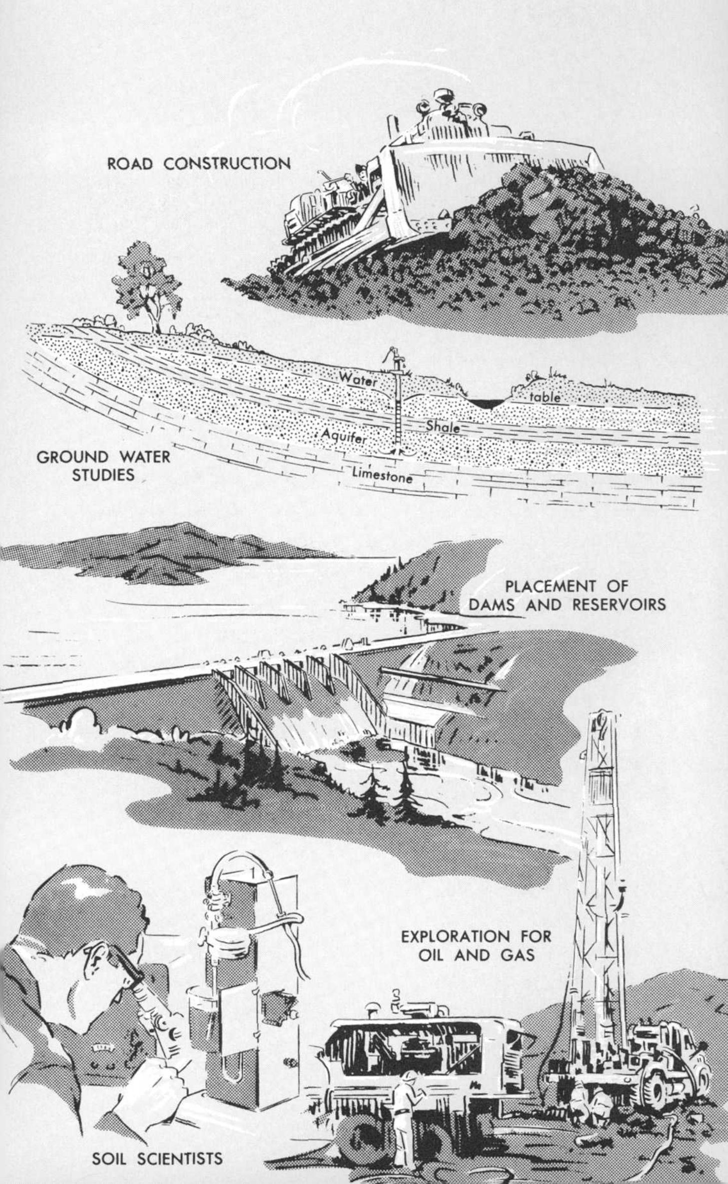


Geologic portrait of part of the eastern coast region—from a small-scale map of North America.

of a structurally complex area that can be portrayed on a geologic map and cross sections.

Many kinds of scientists and engineers use geologic maps as basic tools. Because we know, for example, that certain kinds of rock or geologic structures are associated with certain kinds of mineral deposits, geologic maps can help the exploration geologist find new places where favorable conditions exist. The highway or construction engineer can use geologic maps to locate sources of construction materials and to predict foundation and excavation conditions. Hydrologists use geologic maps to locate sources or movement paths of underground water. And because soil is commonly a product of the disintegration of the bedrock beneath, geologic maps are helpful to soil scientists in classifying soils for agricultural purposes.

Geologic maps can be used for these and other purposes whether or not the geologist who made them had such purposes in mind. Even though the map is interpretive, it is primarily a method of recording and presenting data in compact and systematic form. A map originally made as part of a program of petroleum exploration may turn out, ultimately, to have far greater value in a search for uranium or potash. One prepared solely to solve a geologic problem may later help an engineering geologist choose between potential construction sites.



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