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ABSTRACT

Presented is a suggested instructional lesson based on important clues that lead to a better understanding of the kinds of materials that lie under and within the earth's crust. Comparing density of earth rocks to density of the whole earth, and accounting for the discrepancy, leads to awareness of the difference of materials of the earth's interior and its surface. Studying earthquake waves is a clue-finding effort providing information about the earth's interior. Clues leading to a better understanding of the earth's crust are provided by a simple pendulum bob, as well as heat flow, volcanic rock, and earthquake waves. (EB)

NATIONAL SCIENCE TEACHERS ASSOCIATION

how to...

TELL WHAT'S UNDERGROUND

Rolland B. Bartholomew, *Assistant Professor of Geology and Science Education/The University of Texas at Austin*

The story of the Mexican farmer who was startled by a volcanic eruption in the midst of the field he was plowing is now a familiar one. Volcanologists who have talked with this man confirm the story. Furthermore, they report that the frightened farmer fled from his work to tell his friends and neighbors what had happened. Fortunately for science, the eruption (see Figure 1) continued for several months, ultimately forming a mountain of volcanic material over 1,000 feet high replacing the farmer's field and extending its lava flows over several miles of previously farmed land.

What does this story have to do with telling us "what's underground"? Volcanic eruptions are one of the best sources of evidence for determining the kind of material that lies under and within the solid material that we call the earth's outer surface–the crust. Such eruptions, along with other sources of evidence, provide geologists with clues as to what's underground. Some clues are better than others, and our purpose here is to help you understand and pass on to your students those that are most reliable.

WHAT'S FAR DEEP UNDERGROUND?

The least reliable clues are those that provide the geologist with ideas about the center of the earth. Density is such a clue, so let us take a look at two variations of density as applied to the earth.

1. Consider the density of the rocks found on or near the surface–possibly rocks that students bring to class and want to have identified. The density of these rocks can be determined by measuring the mass and volume of each and applying the density formula – Density = Mass/Volume. The density range will be from about 2.5 g/cm^3 to 3.5 g/cm^3 with only a few rocks falling outside of that range.

2. Calculate the density of the whole earth by using the formula, Density = Mass/Volume. The density of the earth will be about 5.5 g/cm^3*.

*$D = \frac{M}{V}$; $M = 5.98 \times 10^{27}$ g. $V = 1.08 \times 10^{27}$ cm^3

$$D = \frac{5.98 \times 10^{27}\ g}{1.08 \times 10^{27}\ cm^3} = 5.5\ g/cm^3$$

Figure 1 — Paricutin spews gases and smoke as it encroaches on a Mexican farmer's corn field. Courtesy of Fred Bullard, University of Texas, Austin.

What accounts for this discrepancy–surface rocks have an average density of about 2.7 g/cm^3 whereas the whole earth has a density of 5.5 g/cm^3? One explanation is that the material of the earth's interior is different from that of the surface material. Clearly, they cannot be the same. The interior must be different and composed of denser kinds of matter, but this clue–density variations–doesn't tell us that material's composition.

Another clue about the center of the earth is found by studying earthquake waves. When an earthquake occurs, the energy released spreads in all directions in the form of waves. Some waves travel around the earth along the surface, and other waves travel through the earth. These latter waves provide additional clues to the deep interior.

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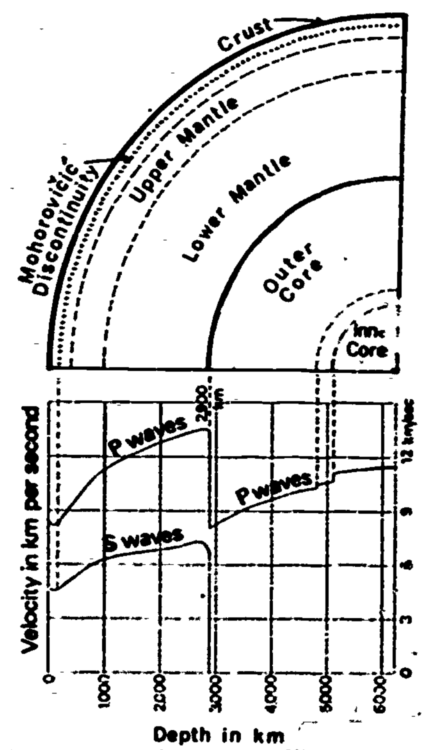
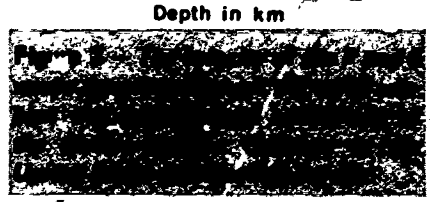
Two kinds of earthquake waves travel through the earth—the *P* waves and *S* waves. *P* waves, sometimes called *push-pull waves*, travel through solids, liquids, and gases. In the material carrying the *P* wave energy, particles of matter vibrate back and forth along the wave path. Similarly, sound waves are transmitted through air from a speaker's voice to a listener's ear. *S* waves, sometimes called *shake waves*, travel only through solids. In the material carrying the *S* wave energy, the particles of matter vibrate at right angles to the direction the wave travels. This is analogous to shaking a long rope that is fixed at one end. The energy from your hand is carried along the rope, but the rope, itself, moves up and down.





Remembering the distinctions between *P* and *S* waves, study the velocity of *P* and *S* waves traveling through the earth as indicated in the lower part of Figure 2. Drastic increases and decreases in the *P* wave velocity as the wave travels through the earth must be considered by the practicing geologist. What possible explanations suggest themselves? Are these explanations consistent with our previous calculations about density variations in the earth's interior?

The *P* wave provides us with excellent clues as to what's deep underground. It is as though the earth is built of concentric shells of different material delineated by the readily discernible changes in velocity of the *P* waves. (See lower portion of Figure 2.) Based on our conclusions about density variation we would expect the concentric shells to surround a very dense core. However, geologists can only infer something about the nature of the material composing those shells.

To understand how *S* waves tell about the deep interior, you will need a globe which indicates degrees of latitude and longitude. Place an X on the globe to indicate the location of an earthquake in California. Using the earthquake location as the center point, (see Figure 3) draw two circles; one passing through all the points located 105 degrees from the earthquake, the other located 142 degrees from the earthquake. Experience shows that recording stations within the band between the two circles do not directly record *P* or *S* waves from the California earthquake. This region is called the shadow zone.

Beyond the shadow zone, outside of the 142 degree circle, we find that no *S* waves—only *P* waves—are registered at recording stations. What happened to the *S* waves? (See Figure 2) Notice that *S* waves stop at about 2,900 kilometers. Geologists explain this

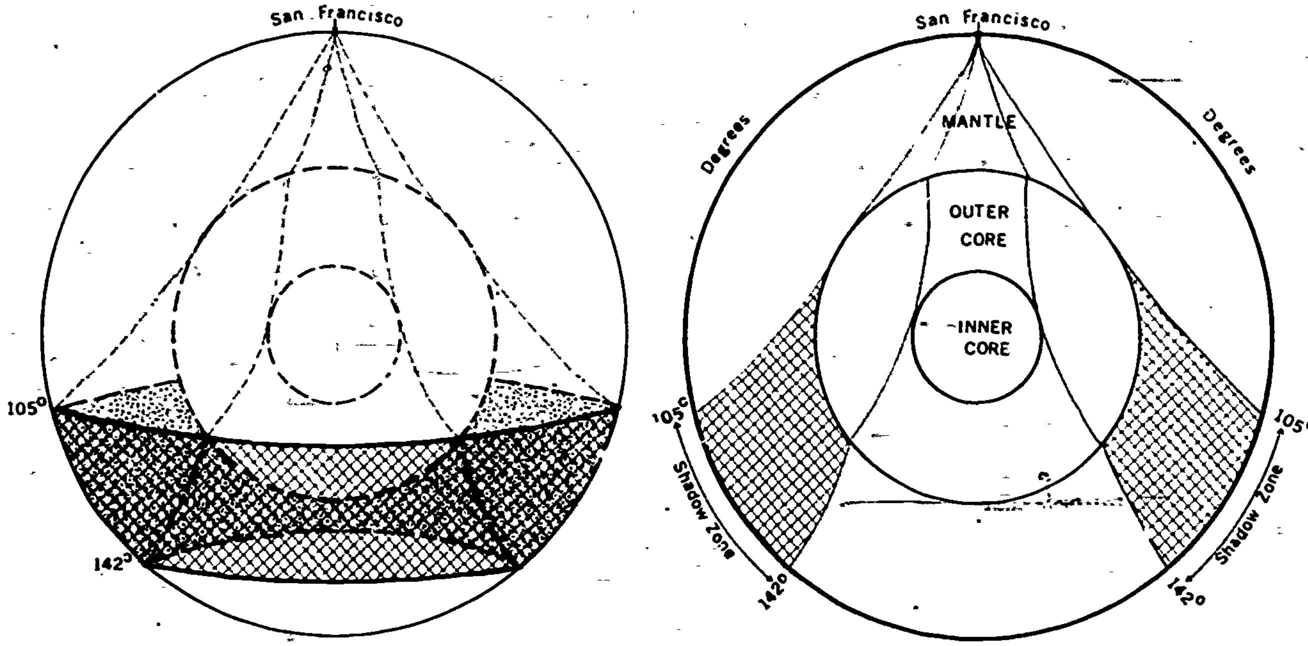


Figure 3 — The band between the two circles passing through all the points 105 degrees from an earthquake centered in San Francisco defines the shadow zone, where recording stations do not directly record P or S waves from the earthquake. Courtesy of the United States Information Service.

phenomenon by saying that the *S* waves encounter material that absorbs the energy and does not transmit it. It is as though there is a liquid-like material inside the earth. Geologists refer to this material as the outer core of the earth.

Thus, earthquake waves do not tell us what kind of material makes up the interior of the earth. However, on the basis of all the evidence that geologists have studied, it is hypothesized that the structure of the interior of the earth is like the sketch in Figure 2.

It may seem strange but we know more about the surface of the moon, located a mean distance of 238,857 miles or about 385,253 kilometers away, than we know about the center of the earth located only 4,000 miles or about 6,452 kilometers beneath our feet. Perhaps, this will remain true unless we discover a way to penetrate very deeply into the earth.

WHAT'S NOT SO DEEP UNDERGROUND?

The outermost shell of the earth makes up what is called the earth's crust. In Figure 2, you can see that the Mohorovicic discontinuity marks the lower limit of the crust. This boundary was found by studying the change in velocity of earthquake waves. Above this boundary lie the less dense rocks that make up the crust.

Observations of the immense variety in color, texture, and density of surface rocks would quickly lead us to conclude that the earth's crust is composed of many kinds of different materials. But is the crust layered in the same way as the interior? To determine whether or not the crust is layered we must look for more clues.

The first of these clues is supplied by a very simple device—a pendulum bob. Surveyors who made measurements to determine the shape and size of the earth found that their measurements didn't seem to check. When their measurements were made near a high mountain range, it appeared that the pendulum bob did not hang true, that is, the bob did not point toward the gravitational center of the earth. The measurements made near mountains seemed to indicate that the pendulum bob was deflected slightly away from the mountain. (See Figure 4)

Further analysis of this discrepancy indicated that the mountain was exerting less of an effect than it should have, considering how much material was standing higher than the point of measurement. It was as though the material lying beneath the mountain were less dense than elsewhere. Perhaps, the mountain has a "root" or thick support of rock which extends deep into underlying, more dense material.

To determine whether this explanation was reasonable, studies of other clues, such as heat flow, were necessary. Geologists have studied the heat flow across mountain

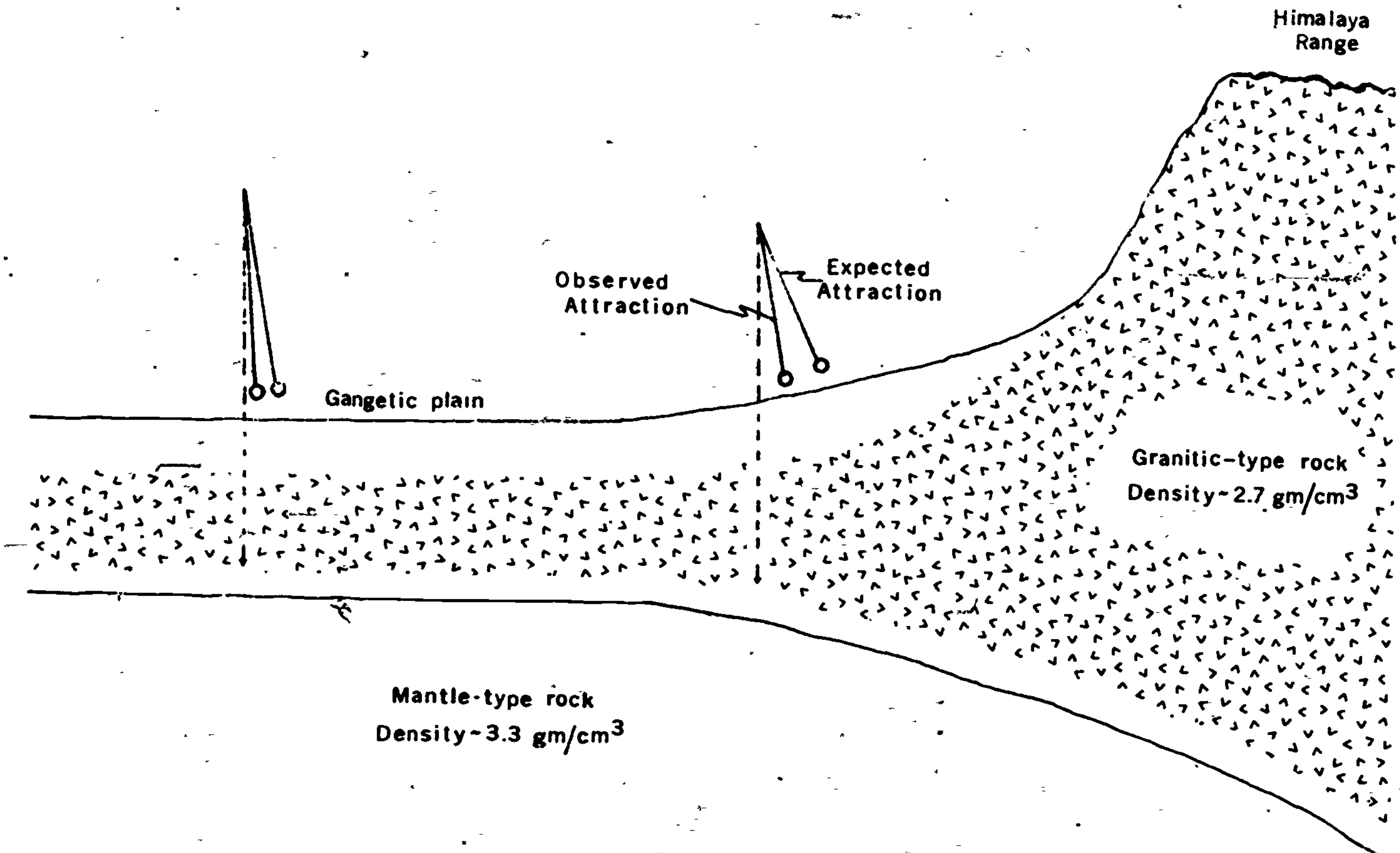


Figure 4 – Attraction of the Himalaya for a pendulum bob on the Gangetic plain is not as great as might be expected for so large a mountain mass.

ranges by measuring the earth's temperature in many different places. By selecting the places to measure the temperature in such a way that the temperature profile lines crossed the mountain ranges, the geologists could determine how the temperature varied. Temperature measurements indicated that there was a rise as the lines crossed over some mountain ranges. This was a larger rise than expected if the mountain did not extend from a large mass under the earth's surface. (The cause of this temperature increase is attributed to the release of heat that accompanies the decay of radioactive elements in granite.) Does this unexpected temperature rise support the "root" theory?

A set of measurements related to the pull of gravity showed a similar discrepancy. Measurements of the pull of gravity along profiles that crossed the mountain ranges reinforced the idea that mountain ranges have a "root." In other words, mountains appear to be floating, as an iceberg floats in water, on something else–a more dense layer.

The search for clues to the identity of this more dense layer involves the study of rocks that come from volcanoes and the study of earthquake waves. In general, these rocks are basaltic in composition, and basalt has a density of about 3.5 g/cm^3. It is theorized that the mountains have a granitic core with a density of about 2.7 g/cm^3. On the basis of this clue, what would you expect the layer underlying mountain ranges to be composed of? Information gleaned from earthquake waves traveling near the surface of the earth's crust indicates that these waves travel faster across the oceans than across the continents, and the surface wave velocity across the oceans is about the same as that through basaltic material.

Combining the evidence supplied by these clues geologists have hypothesized that the earth's crust is composed of two layers–the sima (basaltic in composition) and sial (granitic in composition). Figure 5 shows the earth's crust as we know it today.

Under the oceans, the oceanic crust is essentially sima and has an average thickness of approximately 5 km above the Mohorovicic discontinuity. The crust under the continents contains both sialic and simatic material. However, as shown in Figure 5 sialic material predominates and it thickens under mountain ranges. Under the Rocky Mountains, the Mohorovicic discontinuity has been found to be 56 km below the surface.

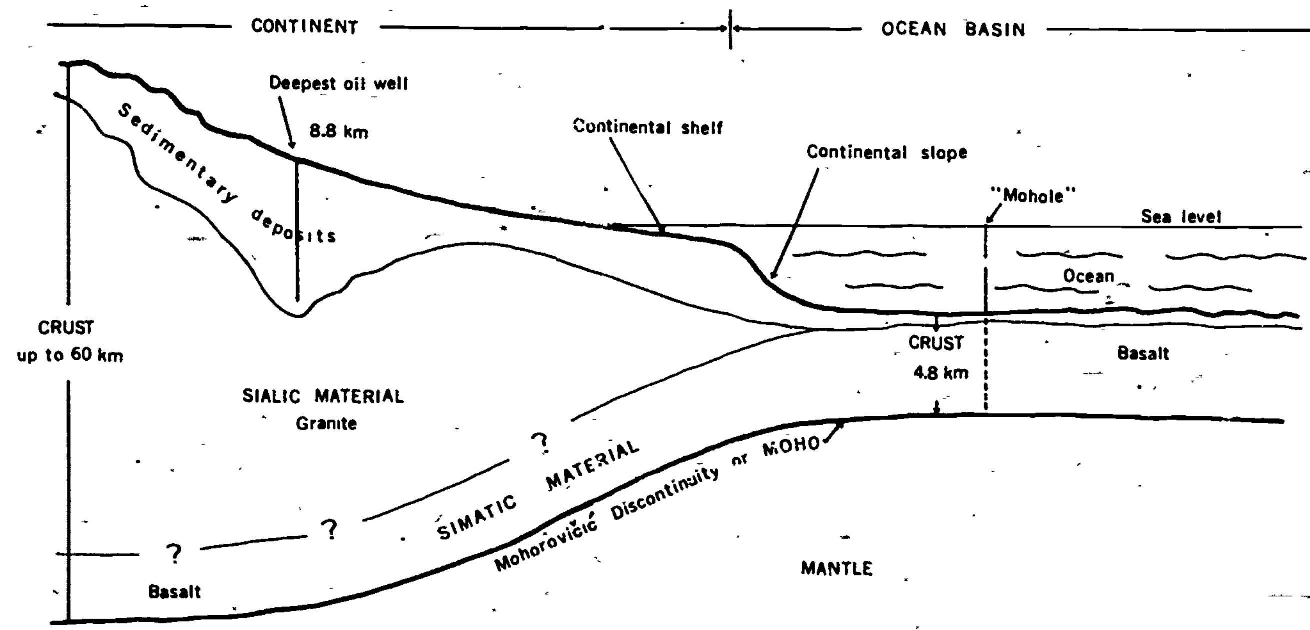


Figure 5 — *Cross-section about 645 kilometers long through the earth's crust.*

WHAT'S JUST BELOW THE SURFACE?

On a scale far different from that of mountain ranges, geologists have learned to interpret clues found on the surface to tell them what lies beneath their feet. The best clues are seen in stream valleys—e.g., the Grand Canyon in Arizona and the Royal Gorge in Colorado. To simplify the explanation of how clues of this type can be used to tell "what's just below the surface," consider an analogous situation—a highway road cut. Highway construction processes remove material to form slices (windows) so that we can observe the inside of the earth.

To understand how these slices can be used to see inside the earth, look at Figures 6, 7, and 8.

In Figure 6, the layers of rock are horizontal. Two geologists are shown as looking at the rocks. Assuming that geologist X is seeing the rocks in cross-section, and geologist Y is seeing the surface rocks, what can geologist X tell geologist Y about the earth under his feet?.

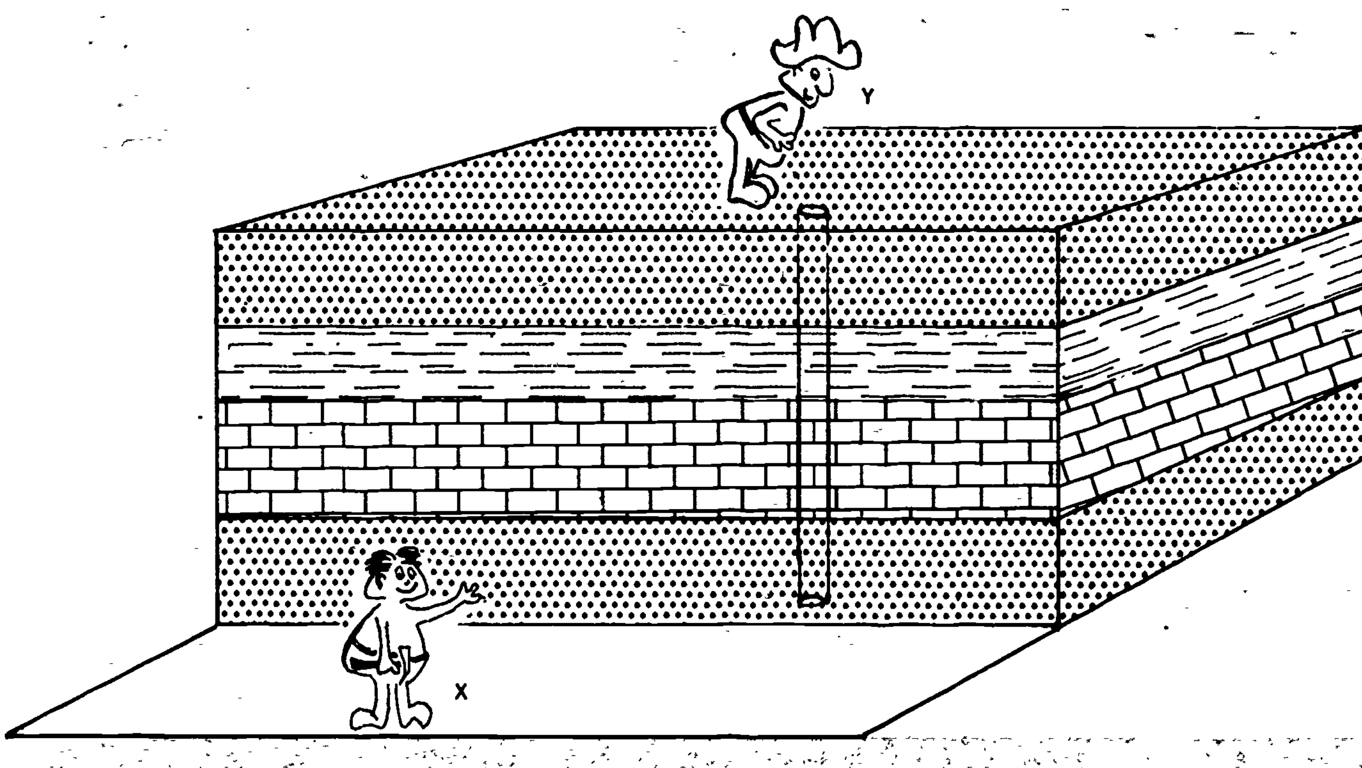


Figure 6 — *Cross-section sketch showing horizontal layers of sedimentary rocks.*

Again in Figure 7, geologist X and Y are looking at the rocks. The layers of rock are tilted—dipping into the earth toward the left. What kinds of rocks would you tell geologist Y are under his feet?

In Figure 8, geologist Y is shown in three different positions. In each position, the kinds and/or the amounts of rocks are different. What is the nature of the rock underground at each position?

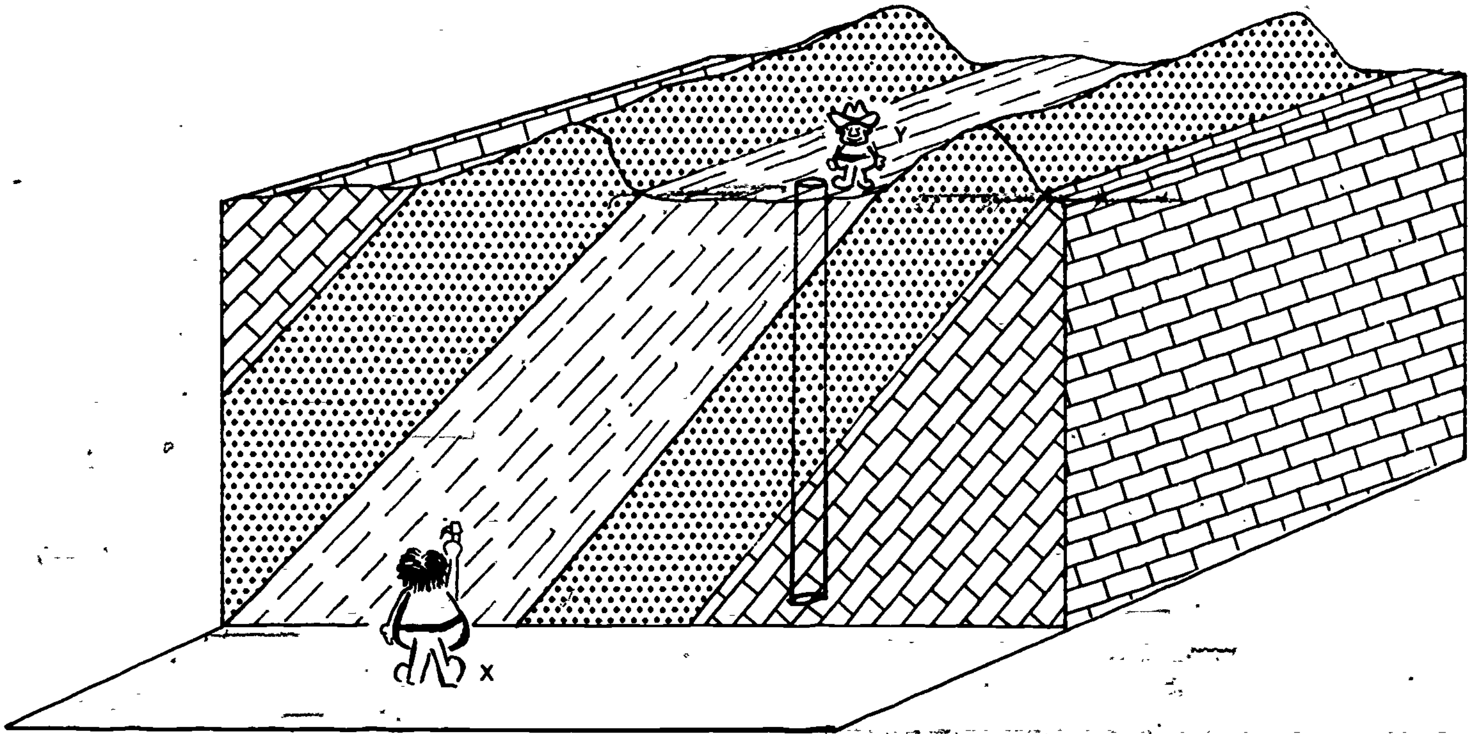


Figure 7 – Cross-section sketch showing tilted layers of sedimentary rocks.

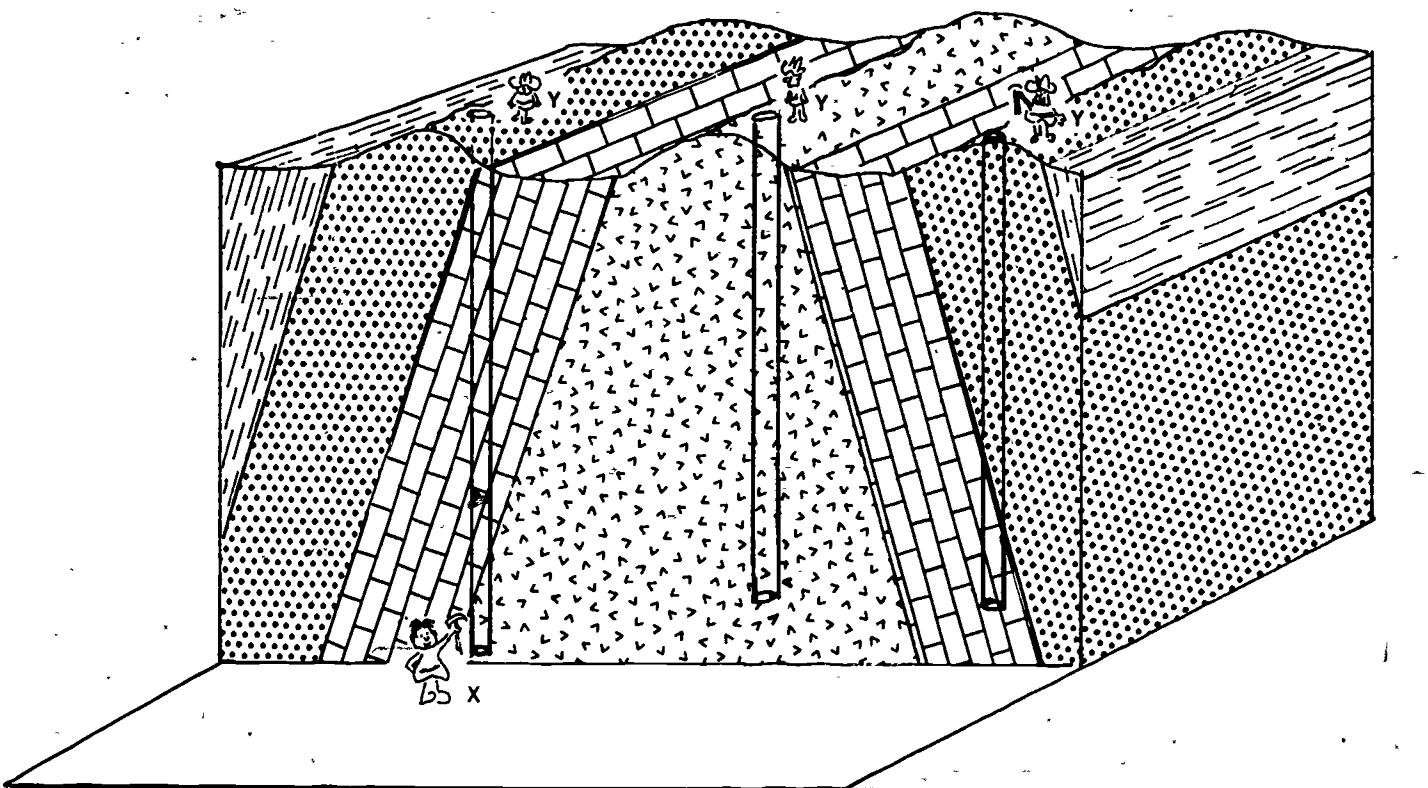


Figure 8 – Cross-section sketch showing folded sedimentary rocks.

Another clue as to what's underground is provided by the data from well logs. When a well is drilled, the driller commonly keeps a record of the rocks through which the drill passes. In Figure 9, a record of several different well logs is shown.

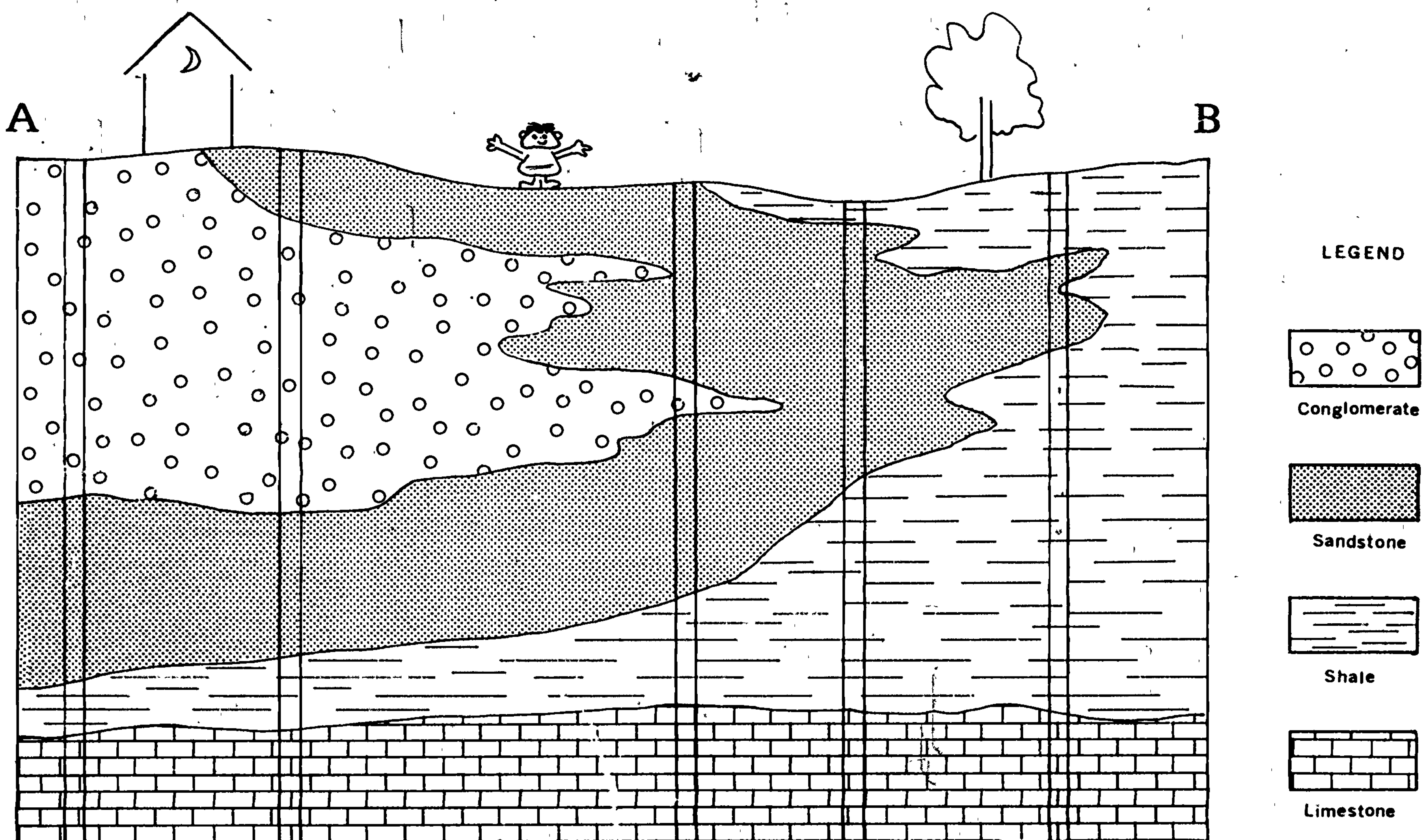


Figure 9 — Cross-section sketch illustrating how well logs show what's underground.

Imagine you are walking from A to B. You would walk across conglomerate, sandstone, and shale. Under your feet as you walked would be several different columns of rocks. You would not know what kind of rocks were there unless you had the data from the well logs. However, with that data you could reconstruct a picture of what's underground.

To help you practice how to do this, study Figure 10. In this figure four different well logs are shown. Complete the "picture" of what's underground by joining the layers of rocks in each well. If one kind of rock is not found in the neighboring well, it is said to "pinch-out." In this case, you must end the rock between the wells. This is done in the same manner as in Figure 9. For a completed picture of Figure 10, turn to Figure 11, page 9. Remember, the geologist assumes a continuity of rock between nearby wells unless the well log indicates the rock layer no longer exists.

Another kind of clue for determining "what's just below the surface" is found in volcanic rocks. Remember the story of the farmer plowing his field when the volcano burst forth? This was a rare experience for humans, but such an event—the eruption of a volcano—has happened many times. Since the source of the volcanic material is underground, a study of lava flows gives the geologist many clues as to what's beneath the surface. From studying volcanic materials geologists learn: (1) the kinds of materials found underground; (2) the temperature of the materials in their molten state; and (3) the kinds of processes that take place in moving material up to and over the surface. When you stand on a lava flow, you are standing on a good clue as to what's beneath your feet.

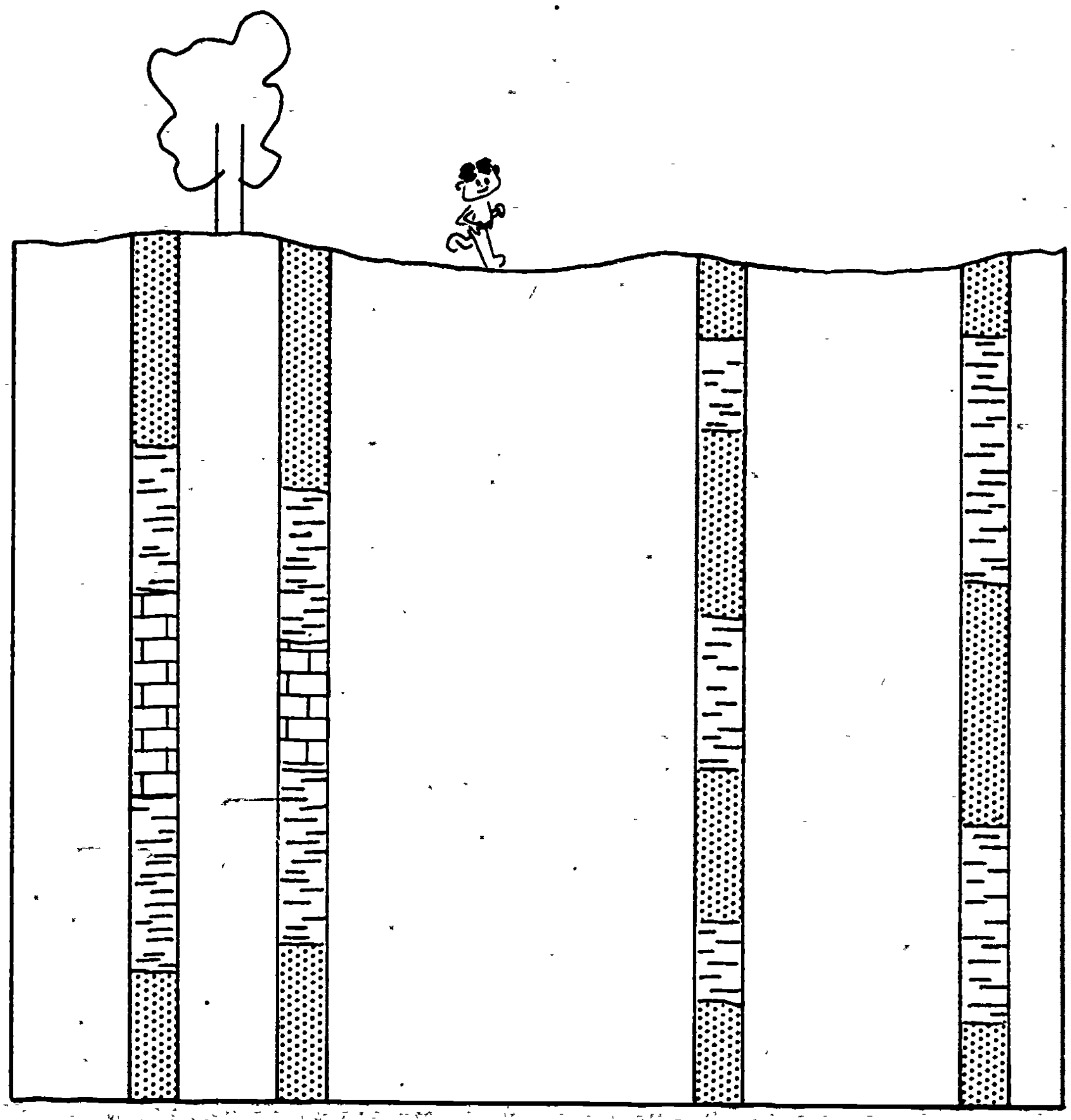


Figure 10 — Sketch showing what kind of rocks are found in different wells.

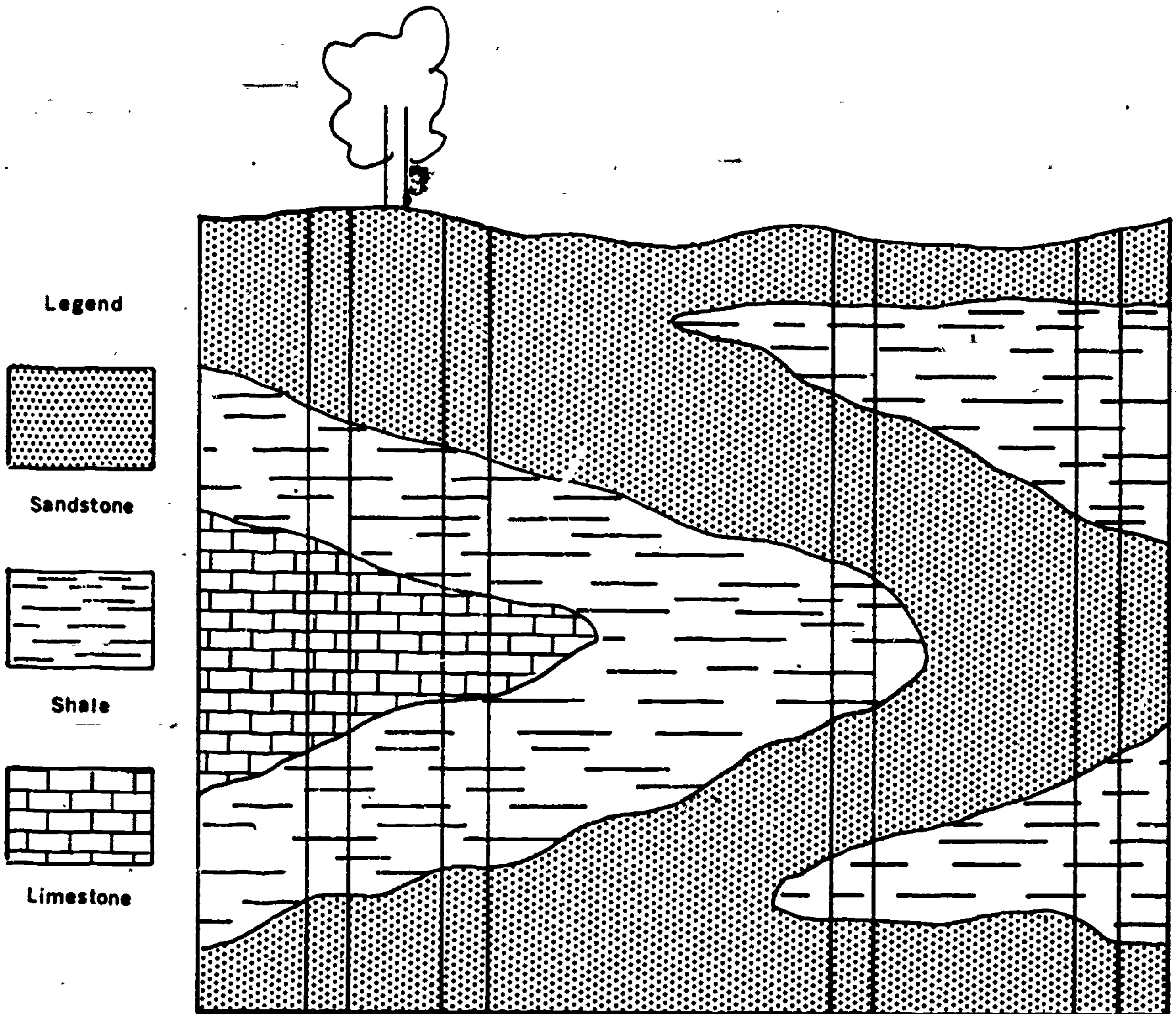


Figure 11 – *Completed cross-section of Figure 10.*

SOME UNSOLVED PROBLEMS OF WHAT'S UNDERGROUND

One of the most exciting problems that geologists face is related to the Mohorovicic discontinuity. What is the nature of the earth's materials just above, and just below the Mohorovicic discontinuity? Recently, geologists have been trying to find the answer to this question by drilling into the ocean floor, as in the Mohole Project some 10 years ago. (See Figure 2) However, with the cut-back in federal funds for this research project, the answer to this question is delayed. Nevertheless, the curiosity about what lies under the Mohorovicic discontinuity remains, and future generations will find it exciting to attempt to answer this question.

Many unsolved problems as to what's underground have economic implications. As the need for more raw materials increases and the surface or near surface sources of raw materials are depleted, the search for economic materials deeper underground introduces new problems. Without drilling wells, we have no way of determining whether oil exists in sufficient quantities for production. It would be a great boost for mankind if geologists could locate oil without having to drill. The same idea applies to many other economic materials. How to locate lead, tin, copper, iron, nickel, chromium, and gravel deposits without expensive mining operations remains a major geologic problem.

In summary, geologists have developed many clever ways to "read" the clues providing evidence for what's underground. Finding and interpreting such clues becomes a major task in the search for new scientific knowledge. Hopefully, this paper will help you start some of your students in a search for clues to what's underground.

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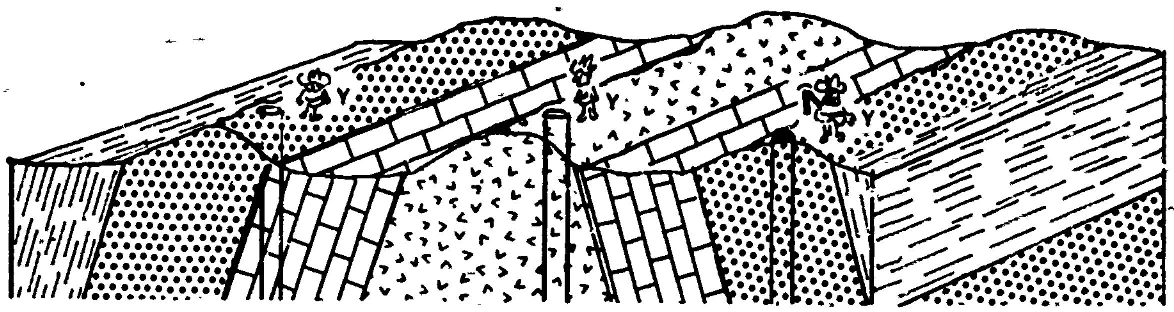

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