DOCUMENT RESUME

ED 178 338 SE 029 274

AUTHOR Boyer, Robert E.
TITLE Field Guide to Rock Weathering. Earth Science Curriculum Project Pamphlet Series PS-1.
INSTITUTION American Geological Inst., Washington, D.C.
SPONS AGENCY National Science Foundation, Washington, D.C.
REPORT NO ESCP-PS-1
PUB DATE 71
NOTE 43p.; For related documents, see SE 029 275-283; Not available in hard copy due to copyright restrictions; Photographs and colored drawings may not reproduce well

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Chemistry; *Earth Science; Environment; *Environmental Influences; Field Trips; Instructional Materials; *Meteorology; *Science Activities; *Science Course Improvement Project; Science Education; Science Instruction; Secondary Education; Secondary School Science; Soil Conservation; Urban Environment
IDENTIFIERS *Earth Science Curriculum Project; National Science Foundation

ABSTRACT

Highlighted are the effects of weathering through field investigations of the environment, both natural rocks, and the urban environment's pavements, buildings, and cemeteries. Both physical weathering and chemical weathering are discussed. Questions are presented for post-field trip discussion. References and a glossary are provided. (Author/RE)

field guide to ROCK WEATHERING

Robert E. Boyer

Without plants there would be no animals, and plants grow in the soil—a product of weathering. Every day we witness changes taking place about us as materials adjust to their environment by weathering. Paint chipping, metal rusting, roads cracking, rocks crumbling are all signs of the never-ending change. This pamphlet highlights weathering through field investigation of our environment—rocks, pavements, buildings, and a cemetery.

Dr. Robert E. Boyer is Professor of Geology and Education at The University of Texas at Austin. He is interested in geology in the field and his publications have been primarily in field-based studies in structural geology. Dr. Boyer has served as Editor of the *Texas Journal of Science* and the *Journal of Geological Education*, and is Editor of the ESCP *Pamphlet Series*.

ISBN 0-395-02615-6

FIELD GUIDE TO

Rock Weathering

Robert E. Boyer

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

New York · Atlanta · Geneva, Ill · Dallas · Palo Alto

Contents

Rock Weathering

INTRODUCTION

What changes have the Egyptian pyramids undergone after almost 4000 years? Do the lofty peaks of mountains remain the same forever? What provides the rock material that the Mississippi River pours into the Gulf of Mexico at the rate of 2,000,000 tons a day? These are only a few among many similar, intriguing questions about the earth's surface. Understanding rock weathering and its relation to the unrelenting force of gravity and the long-term effects of erosion will help answer such questions.

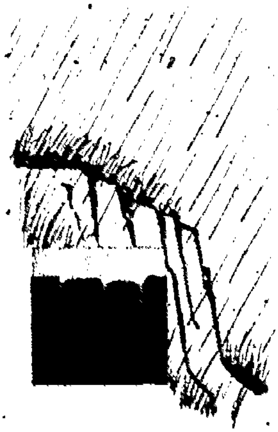
Minerals, rocks, and man-made products near and at the earth's surface are constantly changing because of exposure to air, water, and the activities of living things. These changes are called *weathering*. Depending on the point of view, weathering may be either constructive or destructive. A quarryman interested in cutting fresh granite slabs for buildings, statues, or tombstones views weathering differently from the farmer plowing fields of loose, fine rock and dirt. To the quarryman, weathering means "breakdown" or "rotting," and the weathered rock loses its usefulness. But to the farmer, weathering is a necessary processing of rock into the material he needs—soil.

Weathering affects all materials—house paint, glass, concrete, even steel. Any surface exposed to water and air will weather. Some materials merely take longer than others to show the effects. Weathering has been powerful enough to alter, and alter again, the entire surface of the earth. Field trips can enable you to see effects of weathering on materials in your community, and to see that the process is going on continually everywhere.

WEATHERING PROCESSES

Most rocks form under conditions very different from those existing at the earth's surface. As rocks become exposed to the atmosphere and the hydrosphere (the water portion of the earth), they respond to this new environment by weathering. Weathering occurs not only at the earth's surface, but at any depth penetrated by air and water. Weathering is one of the more important processes that occurs at an *interface*, or zone of interaction, among the atmosphere, hydrosphere, and lithosphere (the solid outer shell of the earth).

What actually happens to a rock or mineral when it weathers? First, it may be broken or shattered into small pieces. This type of weathering is a *physical* process. Second, the rocks can be altered chemically, generally by removing chemical elements from the minerals or by adding elements from some other source. Usually both processes occur at the same time. These types of weathering are *chemical* processes. Although it is simpler to discuss the physical and chemical processes separately because different principles are involved, they seldom operate alone. Each aids the other, and they generally occur simultaneously.



Physical Weathering

In most rocks physical weathering begins long before their exposure at the earth's surface. While still deeply buried, they are under considerable pressure. (Imagine the pressure exerted at the bottom of 5000 meters of rocks!) As overlying rocks are eroded away, the pressure on the rocks below is lessened and they expand upward. Frequently cracks form, providing pathways for water to move through the rocks.

Sometimes in deep mines (such as the gold mines of South Africa), the release of pressure bursts the rocks with such explosive violence that miners are killed by flying fragments. Quarrymen occasionally witness sudden pressure releases that cause an upheaval of the quarry floor. For example, in a granite quarry in Georgia, a quarryman and his jackhammer were said to have been tossed two meters in the air when part of the quarry floor popped up.

Water too can break rocks. Water stored in *bedrock* (solid rock usually overlain by loose rock and soil) moves along cracks and through rock pores and other openings. The water in near-surface cracks and openings freezes and expands to produce a wedging action, which can be strong enough to fracture the rocks and form new channels for additional water seepage. As this process is repeated, more and more rocks are broken up (Figure 1).

Figure 1. Water freezing and cracking bedrock below the surface.

Figure 2. The wedging action of tree roots on bedrock.

You have probably seen tree roots growing in rocks, as shown in Figure 2. Which do you suppose came first—the root or the crack in the rock? The roots of plants, particularly those of large trees, can grow not only into the soil, but also into tiny cracks in bedrock. As they wedge and pry the rocky material, the roots widen the cracks. Such openings are then invaded by water, and chemical weathering results.

Animals also promote weathering. Some animals break up rocks by trampling on them. Others burrow into the ground, exposing rocks to the air. Even the earthworm aids in the weathering process by passing loose rock material through its digestive tract.

Man's continuing efforts to adapt the earth's surface to all his needs also effectively help to break up rocks. Drainage systems, irrigation projects, highway and dam construction, and mining and quarrying activities all cause considerable rock fracturing and earth movement, and expose large sections of fresh bedrock to the atmosphere.

Chemical Weathering

Rocks are simply aggregates of *minerals*, and chemical weathering is the chemical reaction of substances in the atmosphere and the hydrosphere —particularly carbon dioxide, oxygen, and water— with these minerals. Each mineral is made up of combinations of a certain chemical element or elements that give it a more or less distinctive chemical composition. Elements composing some minerals exist as *ions*, atoms or groups of atoms of a substance that are electrically charged because they have lost or gained electrons. Picture such a mineral as containing ions of different elements held together by the mutual attraction of their opposing electrical charges. For example, common table salt consists of grains of the mineral called *halite*, composed of two elements, sodium and chlorine, in a ratio of one ion of sodium to one ion of chlorine (Figure 3). Chemists have given each element a shorthand symbol: sodium is *Na* and chlorine is *Cl*. This makes the chemical formula for halite *NaCl*.

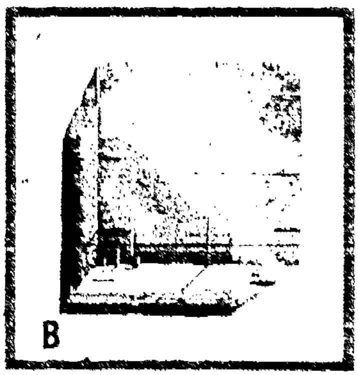


Figure 3. (A) Atomic structure of the mineral halite showing sodium and chlorine ions (B) Natural appearance of halite

A more complicated mineral is a type of olivine called *fayalite*. It is made up of three elements: iron (Fe), silicon (Si), and oxygen (O). The ratio of these elements is two atoms of iron to one atom of silicon to four atoms of oxygen, held together by sharing electrons between the atoms. In chemical shorthand, fayalite is represented as Fe_2SiO_4.

Water can dissolve some minerals. Halite, for example, dissolves readily—its sodium and chlorine ions become dispersed in the water. On the other hand, water *combines* with some substances to form weak acids. An example is the reaction of water (H_2O) with carbon dioxide (CO_2) from the atmosphere. The two combine to form carbonic acid (H_2CO_3). This process can be expressed by the chemical equation

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Carbonic acid is particularly effective in promoting weathering.

Much of the carbon dioxide that combines with water in the ground comes from decaying organic material. Dead plant matter accumulates and rots to form *humus*, which contributes carbon dioxide to the soil, where it is picked up by circulating water and turned into carbonic acid. Plant rootlets also produce acids that react with minerals. Even tiny lichens are actively decomposing the rocks to which they cling.

Oxygen from the atmosphere is another cause of chemical weathering. It combines with some minerals through the process of oxidation to form new minerals. Iron-bearing minerals are particularly subject to oxidation. For this reason the surfaces of objects made of iron must be protected from exposure to the air. A car fender quickly begins to rust after the paint has been scratched off. Furthermore, when the iron in a mineral is exposed to air and moisture, it is oxidized, and the mineral tends to separate from the mineral structure. This process exposes new surfaces and aids in weathering.

The mineral fayalite can take part in an oxidation reaction, as shown below. One of the oxidation products is the familiar iron oxide *hematite* (Fe_2O_3).

$$\underbrace{2Fe_2SiO_4}_{\text{fayalite}} + O_2 \rightarrow \underbrace{2Fe_2O_3}_{\text{hematite}} + \underbrace{2SiO_2}_{\text{soluble silica}}$$

Hematite, and another iron oxide, limonite, are commonly quite soft and range in color from rusty red to yellow-brown. Rub your finger over rusty iron and notice the color. These same minerals cause streaks of discoloration where water runs over iron that has been left outdoors, as in pipes and fences. The Indians powdered hematite and limonite, using the red, orange, and yellow-brown colors as "war paint." Because of their bright colors, these iron oxides were also once used for commercial paints. As iron ores they are important in supplying steel mills.

Water alone may produce chemical weathering. It dissociates or separates into hydrogen (H^+) and hydroxyl (OH^-) ions, which react with many minerals:

$$H_2O \rightleftharpoons H^+ + OH^-$$

Another source of H^+ for reaction is the dissociation of carbonic acid:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

It is thus not as H_2O, but as H^+ and OH^- ions, that water acts as a powerful chemical agent on some minerals, breaking them down by reacting with their elements. This process is called *hydrolysis*, and it affects silicates, composed mainly of silicon and oxygen, the most abundant minerals in the earth's crust. The hydrolysis of silicate minerals commonly produces clay minerals and free ions in solution. An example is the hydrolysis of *orthoclase*, the most common silicate mineral:

$$\underbrace{2KAlSi_3O_8}_{\text{orthoclase}} + H_2O + 2H^+ \rightarrow \underbrace{Al_2Si_2O_5(OH)_4}_{\text{clay}}$$

$$+ \underbrace{4SiO_2}_{\text{soluble silica}} + \underbrace{2K^+}_{\text{potassium ions}}$$

Water can also lead to chemical change by another process called *hydration*. In this process, water is added to the minerals in rocks. As the water is absorbed, expansion takes place and new minerals are formed. The mineral anhydrite ($CaSO_4$) combines with water to form the mineral gypsum ($CaSO_4 \cdot 2H_2O$) as follows:

$$CaSO_4 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

The change from anhydrite to gypsum increases the volume by approximately 40 percent.

Clay minerals are common products of chemical weathering processes. There are many different types of clay minerals. They are commonly composed of silicon and aluminum oxides in combination with the other common rock-forming elements like sodium, potassium, calcium, and magnesium. Illite and kaolinite are two common clay minerals.

"Swelling clays" that expand when wet present construction problems. During rainy periods, buildings on rock containing such clay may heave, cracking the foundations and causing the doors and windows to jam. On the other hand, clay minerals are used in the manufacture of bricks and porcelain and as filler in chocolate bars and beauty preparations.

THE SPEED OF WEATHERING

How rapid is weathering? Does the rate of weathering differ from place to place and from time to time?

About 1500 B.C. two stone obelisks that came to be known as Cleopatra's Needles were shipped from granite quarries near Aswan, Egypt, and set up at Heliopolis, on the bank of the Nile. In the ancient Egyptian religion the obelisks represented the sun, symbolic of light and life, and the daily

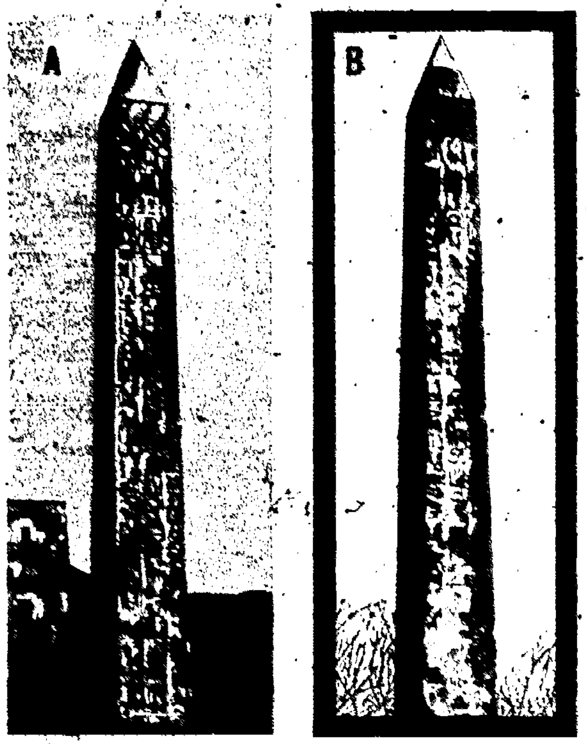


Figure 4. (A) Cleopatra's Needle in Alexandria, Egypt, in 1880's. (B) Cleopatra's Needle in Central Park, New York City, today.

course of Ra, the sun god. About 14 B.C., Caesar Augustus had the two obelisks moved to Alexandria to decorate the Caesareum. Still later, in 1878 and 1881, respectively, the obelisks were given to England and the United States. One now stands on the Thames embankment in London, the other in Central Park in New York City. Juxtaposing the appearance of one of the obelisks after almost 3400 years in Egypt and after less than 100 years in Central Park provides an interesting comparison of weathering rates (Figure 4).

The hieroglyphics inscribed on both the obelisk in London and the one in New York (Figure 4B) are defaced, indicating extensive weathering. Some scientists attribute the rapid weathering to the transition from a hot, arid climate in Egypt, where the obelisks presumably remained essentially unchanged for almost 3400 years, to their present variable, moist climates. Others suggest that they were already deeply weathered in Egypt, and that moving them to the present climates simply increased the flaking of weathered material.

In general, several factors—including the nature of bedrock, climatic conditions, and the abundance of plant and animal life—influence the rate at which weathering progresses. And usually the effects of weathering take years to become readily noticeable. A limestone may resist weathering in a semiarid region like Arizona, showing little alteration after many years; but in a humid state like Kentucky the same kind of rock may develop caves and sinkholes. A massive outcrop of granite may weather slowly in one area, but because of intensive fracturing or a difference in climate be worn away completely after only a few years in another region.

Also important is an area's topography. This affects such features as water runoff, vegetation, and the rate of erosion of weathered materials. For instance, loose rock material and soil will accumulate in flat-lying areas, but may quickly be removed in mountainous ones, thereby exposing more bedrock to be weathered.

In general, the most rapid chemical weathering can be expected in areas with abundant rainfall and high temperatures. Abundant rainfall promotes growth of dense vegetation, while high temperatures increase both the rate of plant growth and the rate of decay of dead plant material. The rotting plants in turn supply acids to the ground moisture. A tropical rainy climate is thus ideal for chemical weathering (Figure 5A). In the United States, the humid subtropical parts of several southeastern states most closely approximate these conditions, although the continental United States does not have a true tropical climate.

Physical weathering, by contrast, is most active where temperature changes are frequent and extreme, and where rainfall is scanty. Under these conditions, bedrock is commonly exposed to physical weathering because vegetation is sparse (Figure 5B). Consequently, physical weathering is a major factor in arid regions like Arizona and Nevada, and in areas with alternate freezing and thawing, as at high altitudes and polar latitudes.

Figure 5 (A) Temple ruins in humid jungle (B) Scrub brush in arid desert

B

PREPARING FOR A FIELD TRIP

Weathering occurs everywhere. There are many common products and results of weathering to look for on field trips.

Does the area you plan to visit display a variety of natural features—such as different types of visible bedrock, varying amounts of bedrock disturbance, changes in types and density of vegetation, and a varied topography? If so, be sure to plan your field trip or trips so that you visit as many different sites of weathering as possible. Comparing field observations of a variety of geologic features will help you better understand the weathering processes.

It is important to have the necessary equipment when you take a field trip. Be sure to wear old clothes; shoes that protect your ankles when climbing on the rocks are also a good idea. The following materials are useful:

Compass
Dilute hydrochloric acid (10% solution in a 1-oz dropper bottle; available in most drug stores)
Rock hammer (geologic pick)
Hand lens (magnifying glass)
Notebook
Felt pen for labeling samples
Pencils with erasers, a few colored pencils
Pocket knife
Ruler
12 paper bags

FIELD TRIP TO AN OUTCROP

Your first question might logically be where to find an outcrop to study rock weathering. Some areas are full of exposed bedrock and outcrops

Figure 6. Road cut shows effects of weathering on different rock types.

are easy to find, but in others the bedrock is covered by a thick layer of soil and dense vegetation. If exposures are scarce, check along all streams and rivers; their flowing water rapidly removes loose material overlying bedrock. Man-made exposures of bedrock are an alternative source: Check road cuts and quarry sites or any area where there has been construction work (Figure 6).

After choosing a good location, be sure to get permission before going on private property. Obey all trespass laws. Landowners are generally cordial and willing to have you on their land *if* you ask them before you enter their property. When you arrive at the outcrop, first get an overall impression of the exposure you will be studying. Carefully look over the terrain; observe such features as topography, drainage, size of the outcrop area, and vegetation. Then ask yourself: "Why is there an outcrop here? How did it get here? Has it been here a long time?"

When you begin to observe weathering of the outcrop, also consider the following factors:

1) The kind of rock exposed and the identity of some of its minerals.
2) The changes you notice by contrasting samples of fresh and weathered rock, such as their color and hardness, and the size, shape, and arrangement of particles.
3) The physical and chemical weathering processes that have been active, and the relative importance of each.
4) The economic implications—both favorable and unfavorable—of this weathering as it affects man.
5) What the weathering products are.

How to Examine the Rock

Because weathering can be considered an adjustment of materials to a new environment, you should first look for any changes that have taken place.

It is important to have *representative* samples of fresh and weathered rock. Look over the outcrop carefully, then decide where to get samples of both kinds (Figure 7). Get a solid piece of weathered rock, avoiding highly crumbly areas. Break off a piece of hard, firm rock to get a sample of fresh rock. *Be careful when striking rock.* Small chips may fly off and can be dangerous, especially to the eyes. Shield your eyes, and do not hit rocks while other people are standing nearby.

Inspect the two pieces of rock carefully, observing their similarities and their differences. Then use your hand lens to examine the individual minerals in each sample. What visible features are different in the two samples? Remember—such differences are probably the result of weathering.

Color is probably the first feature you will note. Compare the two samples for overall color. Then check the color of the minerals in each sample. Do you notice any changes in color between the fresh and weathered samples? Does one sample have more minerals that are dark colored?

Hardness is a property that can be easily tested. The hardness of a rock is related to the strength with which the individual mineral grains are held together. Hence it is a measure of the cementing or interlocking strength of a rock. Test the rock hardness by lightly hitting or rubbing the samples with your hammer. Does the rock crumble into loose material, or does it remain hard and firm?

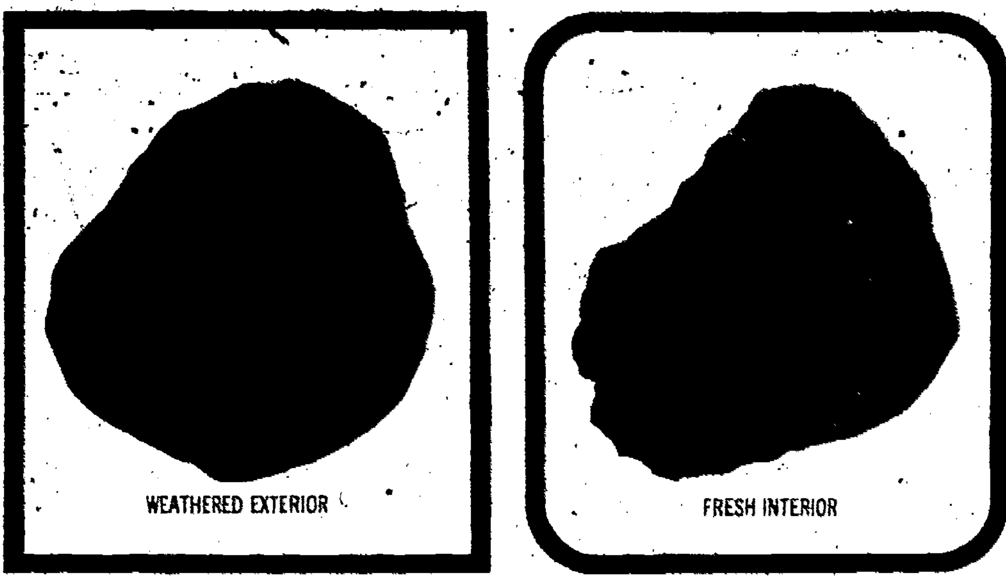


Figure 7. Contrast between fresh and weathered rock.

Mineral hardness refers to the resistance of a mineral when you try to scratch it. The amount of resistance indicates the compactness and firmness of the arrangement of atoms inside the mineral. This type of hardness can be tested by trying to scratch the minerals with your pocket knife, a penny, or even your fingernail. If even the pocket knife cannot scratch one or more of the minerals in the rock, try scraping the edges of these minerals against the knife blade to see if they are hard enough to scratch it. Does one sample appear to have more hard minerals than the other?

Rock fabric is the arrangement of the particles (grains, minerals, rock fragments, fossils) in a rock. Observe the arrangement of particles in both the fresh and the weathered samples. Do you see any alignment in the rock fabric—bands, layers, or wavy streaks? What is the effect of weathering on the rock fabric? Can you see the fabric more clearly in the fresh or in the weathered sample?

On closer inspection you may notice that some particles weather more rapidly than others; consequently, the particles with more resistance (quartz, for example) stand out on the surface more than weathered particles do. Perhaps the rocks are layered; then a layer of the more resistant particles may be next to a layer of particles that weather more rapidly (Figure 6). This is called *differential weathering*.

The reaction to dilute hydrochloric acid (HCl) may be a useful test of the degree of rock weathering. The H^+ ions from dilute HCl react with carbonate rocks (most commonly the mineral calcite, $CaCO_3$); carbon dioxide (CO_2) is set free in the form of a gas, as shown by the vertical arrow in the equation:

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

The escaping carbon dioxide causes the rock to bubble and foam. The rate at which this occurs can be used to measure the relative amount of calcite present and, thereby, the amount of weathering that has taken place.

Several processes that occur during weathering tend to increase the foaming. As rock is weathered, it becomes softer as the attachment between individual grains is loosened. As a result, the acid penetrates the rock more easily. Since the acid then comes in contact with more rock surface, if this surface contains calcite the rock will foam more freely. Also, as water moves through rocks during weathering, the carbonate material in solution is commonly precipitated as calcite, which coats the fracture surfaces and fills rock pore spaces. This concentration of calcite is detected by increased foaming. Again, the weathered sample should foam more freely than the fresh rock sample.

Joints are fractures or breaks, common in all rocks, that generally occur in a regularly arranged pattern (Figure 8). They are formed by such methods as the release of confining pressures through the erosion of overlying rocks, the contraction when rocks are formed as melted materials from the earth's interior cool, the compaction of loose sediments to form sedimentary rocks, and the squeezing and folding of rocks caused by movements within the earth.

Joints play an important role in rock weathering. They are excellent channelways for the circulation of water downward through the rocks; this water, in turn, widens the joints by dissolving minerals, by decomposing rock next to the joints, and by carrying away fine particles of loose material. The joints may be further expanded by root wedging and by freezing and expanding of trapped water.

Figure 8. Bedrock showing the effect of jointing in weathering. (A) Cretaceous limestone in Williamson County, Texas. (B) Paleozoic sedimentary rocks in Burnet County, Texas.

Look for the root systems of any trees or large shrubs that may be growing near the outcrop. See if these roots follow along joints that are present in the outcrop. Do you notice any grasses or other small plants growing along the joints? Is there any discoloration in the rocks adjacent to the joints (Figures 2 and 8)?

Look for other features that may affect the way the rock is weathering, as, for example, the bedded layers of sedimentary rocks or the mineral bands or layers in some igneous and metamorphic rocks. These features may act as zones of weakness along which the rock subdivides into boulders and slabs. Rocks with closely spaced planes of weakness, such as thinly bedded shale or highly fractured deformed rocks, weather more rapidly than unfractured rocks. Count the number of joints as you walk along the outcrop for a distance of three meters. Compare the number that are hair-thin or unweathered with the number that show some width and are deeply weathered.

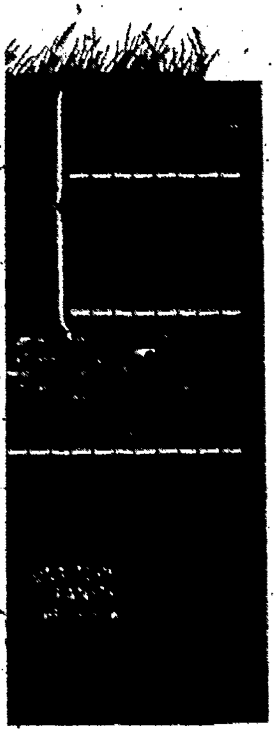


Figure 9. A soil profile developed on granite shows weathered horizons.

Rock debris consists of pieces of rock that were loosened from the outcrop and fell to the bottom of the slope. The smaller ones are washed away by heavy rains; the larger blocks continue to weather and break down to finer pieces. Pick up some of the fragments lying loose at the base of the outcrop and look at them carefully. Since they came from the outcrop, they contain the same minerals.

The soil profile consists of several zones or "horizons" of loose rocks and soil between the bedrock and the ground surface. The upper zones may be rich in organic material, decomposed rock, and products of chemical weathering such as clay minerals, aluminum, and iron oxides. These are the zones that support plant life; farther down, the degree of chemical weathering decreases and the material simply becomes loose rock debris that grades into the solid bedrock below (Figure 9).

See if you can observe the changes in the nature of the soil profile from top to bottom. Notice how the rock fragments change in size as you move from the surface down to the unweathered bedrock; and how the color of the material changes. Finally, measure the thickness of the weathered rock and, if possible, subdivide it into zones of highly altered, partly altered, and slightly altered material. This breakdown will give you a good basis for comparing the degree of weathering of this rock with the weathering of other rock outcrops you may visit.

Sedimentary Rocks

Bedding or layering is present in nearly all rocks that have been formed as sediments became pressed together. These are called sedimentary rocks. Variations in such features as color, grain size, and grain composition occur in the individual beds. Sedimentary rocks such as *sandstone* and *shale*, which are composed of rock particles and mineral grains of various sizes, show the bedding pattern most clearly. If the outcrop you visit is sandstone or shale, carefully examine the material that makes up the different beds. What differences distinguish one bed from another?

Can you recognize that some beds are more weathered than others? Differential weathering may have resulted from differences in the composition and size of the materials making up these beds. What features made some beds less resistant to weathering?

Now look at the surfaces between beds, called the *bedding planes*. Do you see any evidence that weathering has been more severe in the rocks adjacent to these planes? Are there any plant roots along these planes, or is there any evidence that the rocks along these planes have been pried or loosened?

Joints and bedding planes control the shape taken by weathered fragments of rock. Shales often have closely spaced joints and thin beds, so their weathered pieces occur as chips and fragments a few centimeters long. In contrast, sandstones tend to

Figure 10. Role of solutions in the development of caverns in limestone bedrock.

be more thickly bedded and to have widely spaced joints; they characteristically break into large blocks.

Sandstone and shale form by the accumulation of particles of weathered rock, but not all sedimentary rocks have the same origin. Some are made from material precipitated from solution. Rocks formed from precipitated material include such deposits as anhydrite and rock salt and many carbonate rocks, composed chiefly of the minerals calcite and dolomite.

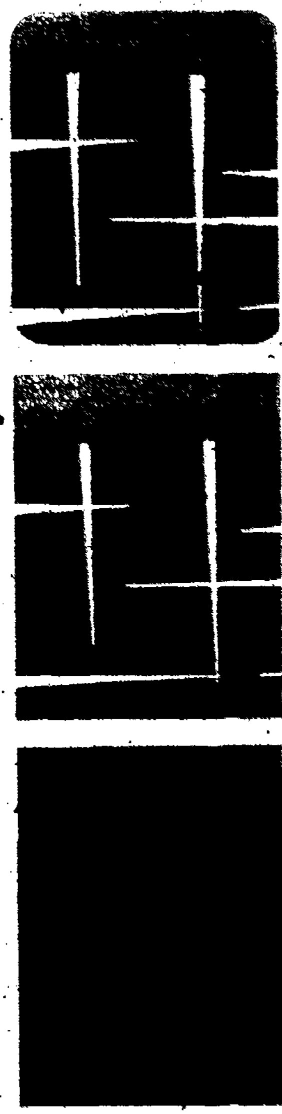
Much weathering of carbonate rocks occurs as water percolating down through them dissolves the material of which they are composed. As the dissolved material is carried away, spaces open in the rocks; these spaces may enlarge into caverns or caves. If the outcrop you visit is carbonate rock, look for evidence that the solution process has been at work. Do you see any openings along joints or bedding planes (Figure 10)?

If the openings in the rocks become large enough, the overlying material may slump into the open spaces and disturb the bedding. This slumping may make the surface of the ground highly irregular and even cause pits to develop. Are there any known caves in your area? If so, can you spot them by the surface topography?

Igneous and Metamorphic Rocks

Many igneous and metamorphic rocks, which develop from the molten material deep within the earth, occur as massive outcrops with few joints or other planes of weakness. Others may be extensively jointed. These rocks may weather to form shells or sheets, which peel off when you pry them with your pick, or they may become rounded by weathering—a characteristic of coarse-grained rock such as granite (Figure 11). The igneous or metamorphic rocks you examine may contain minerals in bands or prominent layers of different rock types. If they do, these layers or bands may affect the weathering, and the weathering features you find may resemble those in sedimentary rocks.

A



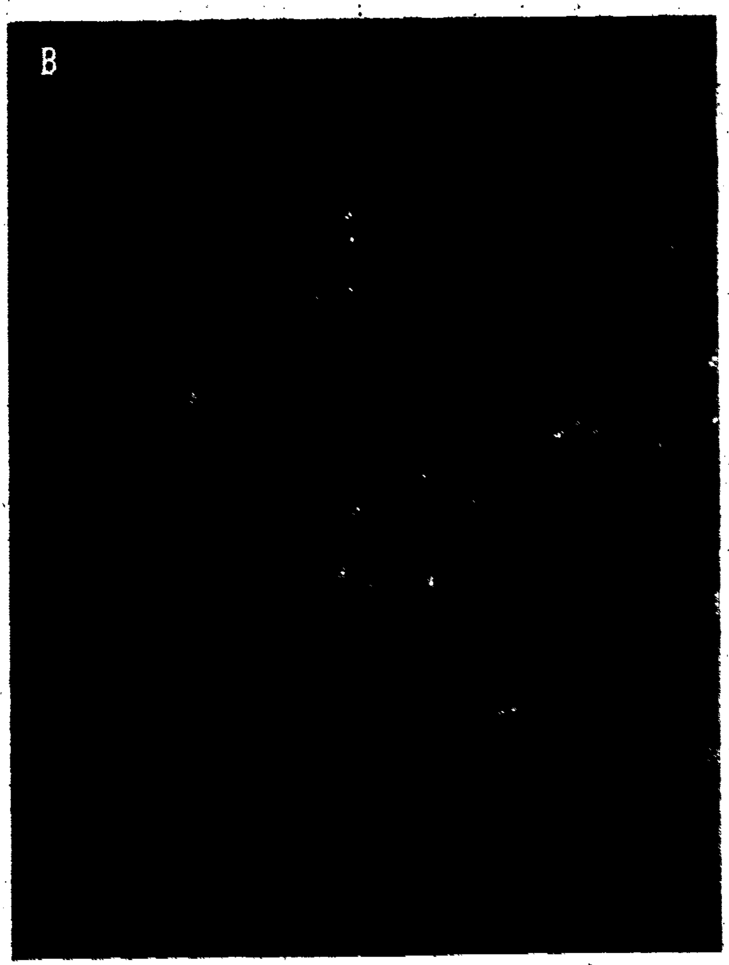


Figure 11. (A) Development of exfoliation, or scaling, in massive nonlayered rock, shown diagrammatically. (B) Exfoliated boulders in an outcrop.

Sketching the Outcrop

Prepare a detailed sketch of the outcrop. Make it large enough to include a section of outcrop about five meters wide and extending upward from the base of the exposure to the top of the ground (including the soil). The sketch should include the following observed weathering features:

1) Soil profile. Try to subdivide it into layers based on changes in color, size of rock fragments, and general abundance of organic material.
2) Bedrock. Include
   a) Color changes in the rock.
   b) Joints; draw their pattern as carefully as possible.
   c) Bedding, layering, banding, and other prominent features of the rock fabric.
   d) Differential weathering.
   e) Rounding or other changes in the shape of bedrock blocks; stress particularly any effects that may show a progressive change from top to bottom of the bedrock exposure.
   f) Slumpage or other disturbances of the rock that may have occurred as materials were dissolved from between rock layers.
   g) Any zones or defined limits of rock (for example, joint fillings) that react to dilute hydrochloric acid.
   h) Any other bedrock features that appear significant.
3) Rock debris at the base of the outcrop. Some areas may lack such material, but others may have prominent concentrations of loosely piled rock debris. The position of this debris may be directly related to the quantity of bedrock in the outcrop that has weathered.

This detailed sketch is your permanent record. You may also wish to photograph the outcrop. If so, first take a picture showing the entire area you sketched. Then, if you wish, photograph some of the detailed features. Always include a person or a familiar object, such as a hammer, ruler, or notebook, in the picture to indicate the scale of the view.

Sampling for Laboratory Study

You may also wish to take samples for later examination in the laboratory. So that your data will be meaningful, carefully select each sample as representative of the rock. Samples should be carefully labeled. Don't forget to indicate where each sample was taken on the outcrop sketch. This procedure makes it possible later to correctly relate your laboratory studies to the outcrop.

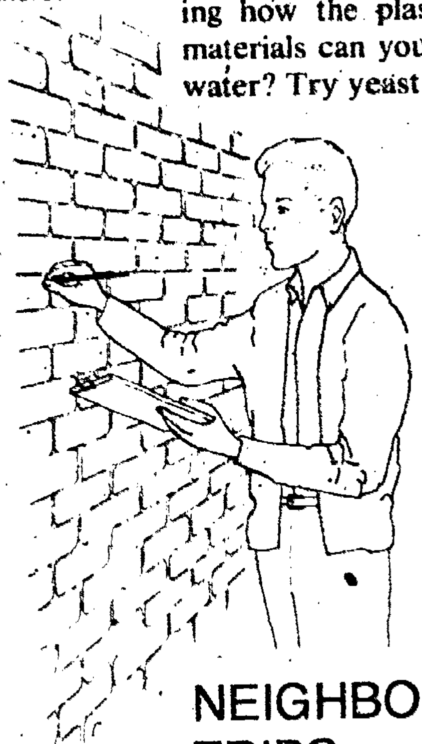
Several laboratory investigations can be used to measure changes that occur as rocks weather. For example, since rock density decreases as the rock weathers, one interesting experiment is to measure and compare the *specific gravity* (density per unit volume) of a fresh rock with that of progressively more weathered samples of the same rock. To do this, sample the rock both where it has been exposed for a long time and, by breaking out some rock, below the surface where it appears fresh. If one is available, use a *Jolly balance*, a double pan spring balance, to weigh each sample in air (W_a) and in water (W_w). The specific gravity is determined as follows:

$$\text{specific gravity} = \frac{W_a}{W_a - W_w}$$

The chemical composition of the rock, which changes during weathering, can also be measured. Changes in calcium carbonate ($CaCO_3$) content are easy enough to estimate by applying dilute hydrochloric acid to the samples and noting the degree of foaming.

Weathering processes such as hydration and oxidation can be reproduced in the laboratory by using inexpensive materials commonly found at home or school. Study the factors, such as solutions, temperature, and particle size, that affect the rate of a chemical reaction. For example, compare the rate of rust formation (an oxidation process) of a steel-wool pan cleaner and an iron nail under various conditions. Every day for one week, observe samples of each kind of iron dry, soaked in tap water, and soaked in salt water. You can also vary temperatures by using an oven. Or, observe hydration by adding water to plaster of Paris and observing how the plaster of Paris swells. What other materials can you think of that will react quickly to water? Try yeast and salt.

Figure 12. Student examining bricks to see how much they have weathered.



NEIGHBORHOOD FIELD TRIPS

Brick Buildings

Walk past several brick buildings in your town or city. Choose an old building with unpainted bricks. Buildings of that period sometimes have the date of construction on a cornerstone or near the front top arch. Examine the brick walls carefully and watch for the following features (Figure 12):

1) Is the brick surface smooth or rough and irregular, or does it vary from brick to brick?
2) Are the corners of the bricks angular or rounded?

3) Are the brick edges straight or irregular?
4) Are there many cracks or chips in the bricks?
5) Is the color of the bricks uniform, or does it differ from brick to brick? Does the brick have a different color where it has been chipped?
6) Is the mortar between the bricks nearly flush with the brick surface, or do the bricks protrude more than one centimeter beyond the mortar?

Next, examine the walls of a brick building built in the past 10 to 20 years. Go through the same list of questions and compare your findings for the two buildings (Figure 13A).

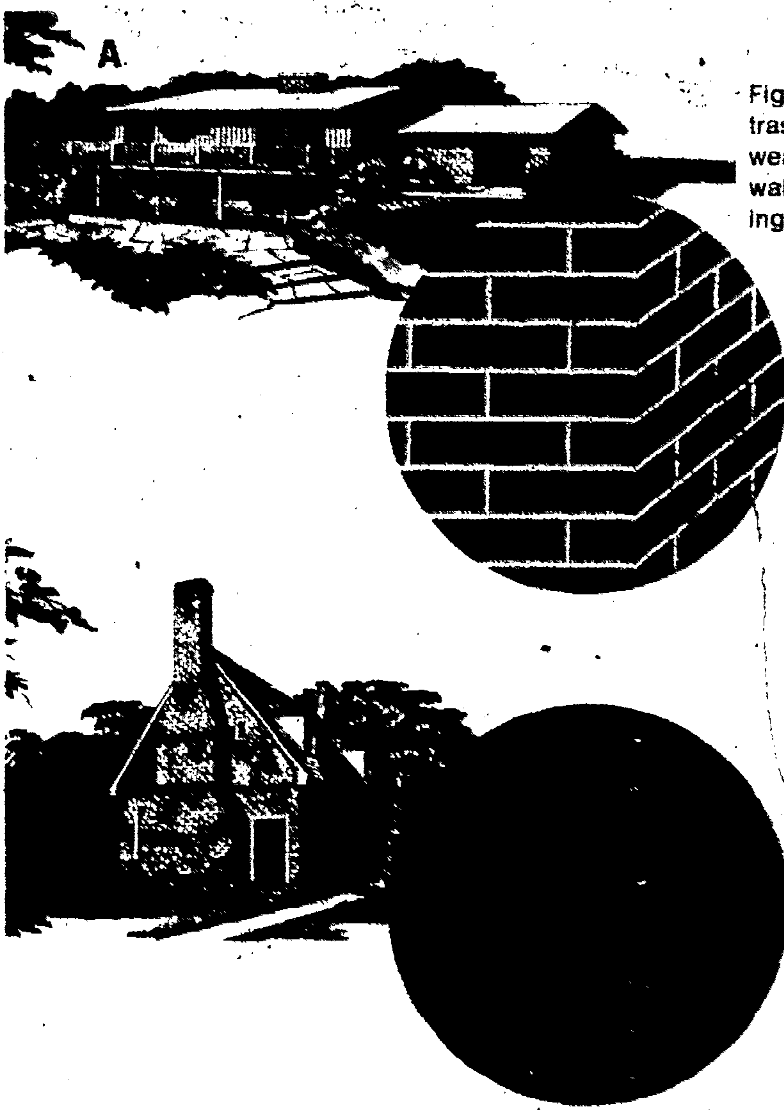


Figure 13. (A) Contrast of fresh and weathered brick on walls of brick buildings.

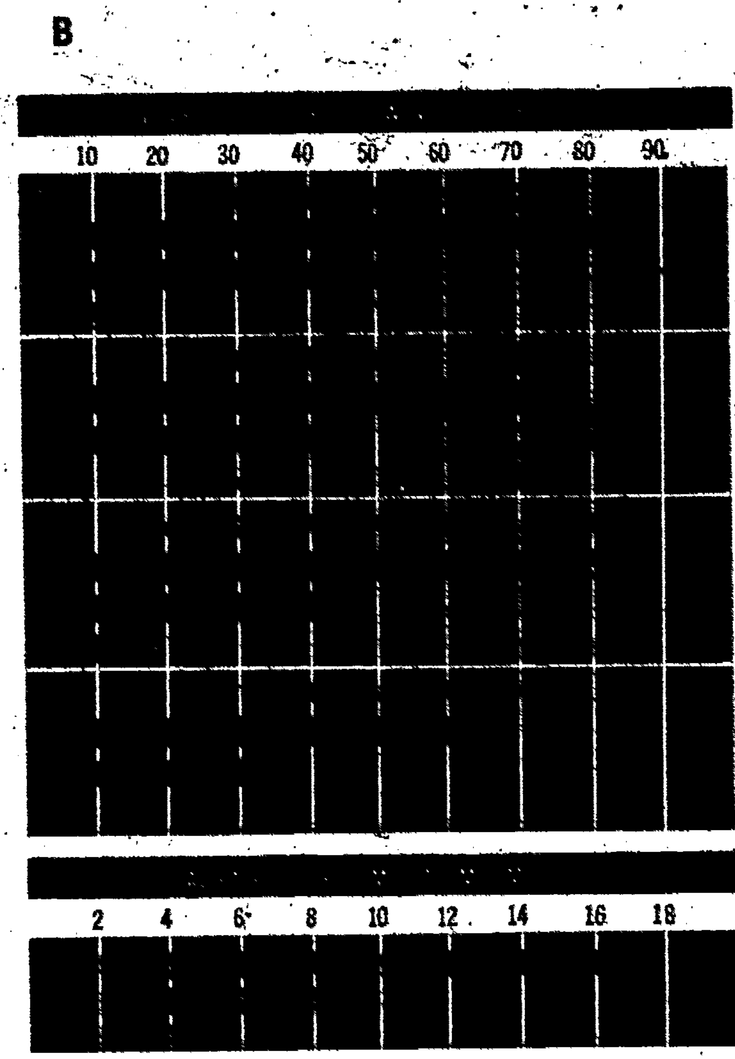


Figure 13. (B) Graph compares weathering features of bricks on buildings erected in different years.

Do you think that by examining the bricks you can estimate the age of most brick buildings? Choose three brick buildings built about 1900, 1930, and 1960, respectively. Visit each of them and, at eye level, observe 100 bricks in a row. Count and record how many of the bricks in each group of 100 show the following features:

1) A rough and irregular surface.
2) Two or more rounded corners.
3) At least one long edge that is irregular.
4) A crack or chip.

Also estimate the average distance (in millimeters) between the mortar and the brick surface.

Then compare your data on the three buildings and plot the results (Figure 13B). For each building, draw a horizontal bar from left to right out to the number of bricks that showed each feature. Label this bar with the age of that building. In the same way, indicate the average depth of mortar below the brick surface. When you have done this for all three buildings, you have measured the weathering features of the bricks and graphically demonstrated their relation to the age of the buildings.

Next, test your data. Choose another building—one whose age you do not know. Study 100 bricks as before, and plot your new data on the graph. Then compare your findings with the record for the other three buildings. From these results, estimate the age of the undated building.

Don't be surprised if you find that occasionally an old brick building has withstood weathering better than a newer one. Bricks are made from rock materials, and the materials used during one period of time or by one brick factory probably differ in composition from those made at another time or by another factory. Then, too, a building may be relatively more or less sheltered than another of the same age. Would you expect a building located on a windswept hill to weather at a different rate than one protected by trees in a valley?

Sometimes your results may vary, depending on which side of the building you examine. Have you ever noticed how snow melts faster on the sunny, southern exposure of a hillside? Along many east-west highways in mountainous regions, and in the northern states during the winter and spring, it is common to see banks of snow restricted to the north-facing slopes of road cuts (Figure 14). The slopes facing south have been exposed to warm sun that has melted their snow. Has this also affected the degree of weathering of the rocks on the opposite sides of the highway? The north side of a building will not only have snow near it longer, but will remain wet longer after a rainstorm for the same reason.

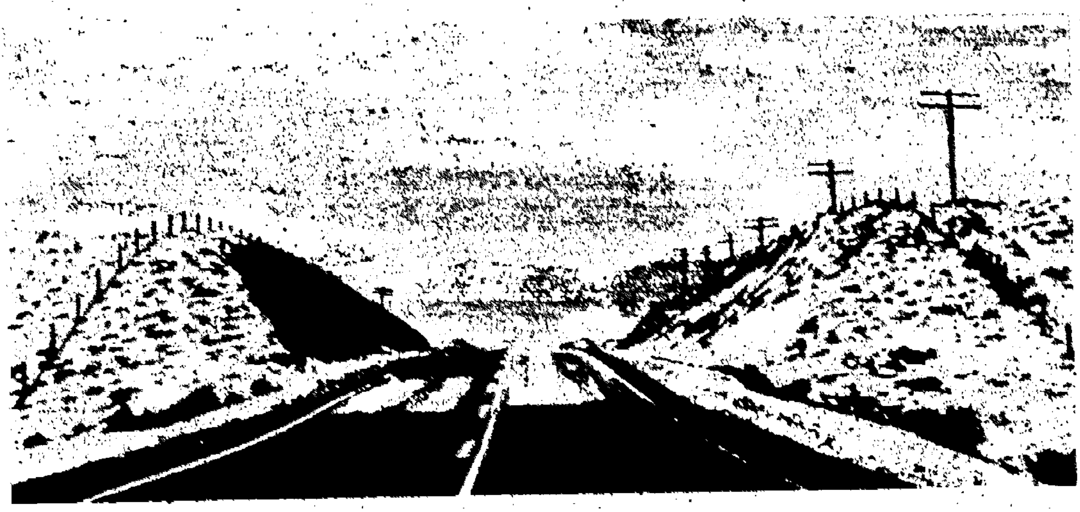


Figure 14. Snowbank remains on north-facing slope of road cut (right), has disappeared on south-facing slope (left).

Careful observation may also reveal that the sides of a building with greater exposure to moisture may contain abundant algae and lichens and be more severely weathered. The rows of bricks closest to the ground generally show a higher degree of weathering; so do those around doors and windows, particularly at the corners of window sills. Here again is evidence of a relationship between exposure to moisture and degree of weathering. What effect might prevailing wind direction have on the weathering of a building? To ensure the greatest accuracy in your observations, try to be consistent and always study the same side or exposure of the buildings you compare. If there are hills in your area, compare the amount of vegetation on the north and south slopes. Which have more vegetation? Can you explain why?

1) When old buildings are torn down, the bricks are saved for building new homes. Why do you think these "antique bricks" are considered so desirable by home builders?
2) Builders sometimes use bricks made with rough, ribbed surfaces when constructing new buildings. We would expect bricks with such surfaces to weather faster. Why are they used?

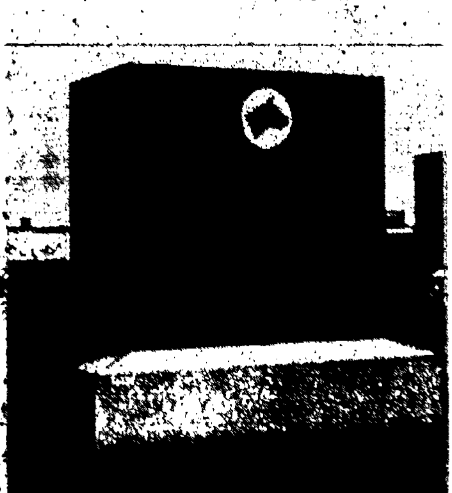
Old stone buildings or those with stone facings are also interesting to examine on a neighborhood field trip. These can be studied in the same manner as brick buildings.

Tombstones in a Cemetery

Visit a cemetery and examine tombstones made of different rock types such as granite, marble, and limestone. Compare tombstones in newer parts of the cemetery with those in older sections (Figure 15). In many cases it is much more difficult to read the inscriptions on the older tombstones. Remember that a cemetery should be visited with proper respect. Do not deface tombstones or destroy private property. Also be cautious about the dangers of falling tombstones. Many headstones consist of a tall engraved stone that rests insecurely on a flat base stone and can be easily toppled. This is especially true in older cemeteries.

1) Compare the color of old and new tombstones of similar rock type. Notice how the surfaces of the older ones are commonly discolored—spotted or streaked. Do the spots or streaks occur with respect to any arrangement of particles in the rock?
2) Examine the individual minerals within these same tombstones. Some minerals have changed more than others, both in color and hardness. Are these generally the lighter or darker minerals?

Figure 15. Comparison of old and new tombstones.



3) Do you see any stains on the tombstones? If so, what minerals appear to be the source of this staining?
4) Compare the nature of the surface of old and new tombstones. Use a hand lens to see these features more clearly. Do some particles of the rock stand out in relief on the surface? In banded or bedded stones, do some layers stand out on the surface?
5) Notice how irregular and worn the edges and corners of many older tombstones are. Look for *spalling*, the breaking loose of flat chips or flakes, of these stones.
6) Examine the different types of rock from which the older tombstones were made. In many areas a "local stone" was commonly used for the old tombstones. What types of rock are most common? Do you recognize any as similar to local rock types? Which of them appear to be less weathered?
7) Why would you expect tombstones made of limestone and marble to withstand weathering considerably better in Nevada than in Tennessee?
8) Do you know of a readily accessible type of local stone that could be used for making tombstones for your cemetery? If it is not being used, why not?
9) Do you think that by studying their weathering features you could estimate when the tombstones were erected?

Old Concrete Sidewalks

Find an old sidewalk made of concrete and examine it carefully.

1) Why is such a sidewalk (or a concrete highway) commonly cast in separate slabs?
2) Many older sidewalks show cracks. What are the possible causes of this cracking?
3) Find a place where a large tree is growing close to the sidewalk. Has the growth of the tree had any effect on the sidewalk?

Stone or Concrete Pillars

Walk around a pillar made of stone or concrete; look carefully at the surface. Notice that the weathering is not uniform, but instead shows marked differences depending on the exposure. If the pillar has a sheltered side, for example, if it is the corner post of a porch, is the least weathered surface the one best protected by the porch roof?

QUESTIONS AFTER THE FIELD TRIPS

Base your answers to the following questions on your observations in the field, as well as on your knowledge of your community and neighboring region.

1) What industries use local materials that are directly related to weathering? Consider agricultural activities, suppliers of gravel and similar materials, and others. What economic products result?
2) Approximately how many families in your community are directly or indirectly dependent on the ranchers, farmers, and workers in these industries, and on the business and professional people who deal primarily with them?
3) What action could or should be taken in your community to utilize the products of weathering? To reduce its undesirable effects? (Don't overlook erosion control and soil conservation as important possibilities.) What economic losses in your community result from weathering?
4) List and rank the factors that in your opinion influence the rate and products of weathering in your community. Remember that several factors may be closely related, as, for example, the amount of rainfall and the ruggedness of topography.

5) Are any rocks quarried in your locality for use as facing material on buildings? If so, how does their rate of weathering compare with that of brick buildings?
6) How does weather affect construction work on either homes or highways in your community? Keep in mind that weathering may cause serious problems in foundation construction, as by swelling clays or producing sands too loose to be dependable.
7) What amusement, recreational, and scenic interests in your community and neighboring region are wholly or in part the result of weathering? The attractions in many parks are particularly important in this regard.
8) Choose two or three geographic regions of the United States that have climates markedly different from those in your local area. What changes would you expect in rates and products of weathering if the climatic conditions of these other regions existed in your local area?
9) Do you think that the rock on the surface of the moon is weathered? Is the lunar rate of weathering more or less rapid than the rate of weathering on earth? Why? Is there soil on the moon?

References

Earth Science Curriculum Project. *Investigating the Earth*. Boston, Houghton Mifflin Company, 1967. Chapter 12, "The Land Wears Away," pp. 270-273.

Heller, Robert L., ed. *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools*. New York, Holt, Rinehart and Winston, Inc., 1962. Chapter 8, "Weathering," pp. 141-148; Chapter 22, "Geologic Topics for Chemistry Courses," pp. 407-435.

Keller, Walter D. *Chemistry in Introductory Geology*, 4th ed. Columbia, Mo., Lucas Brothers Publishers, 1969. Chemical weathering, pp. 35-49.

Keller, Walter D. *Principles of Chemical Weathering*, rev. ed. Columbia, Mo., Lucas Brothers Publishers, 1957.

Kellogg, Charles E. *The Soils That Support Us*. New York, The Macmillan Company, 1941.

Leet, L. Don, and Sheldon Judson. *Physical Geology*, 3rd ed. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1965. Chapter 7, "Weathering and Soils," pp. 72-90.

Longwell, Chester R., Richard F. Flint, and John E. Sanders. *Physical Geology*. New York, John

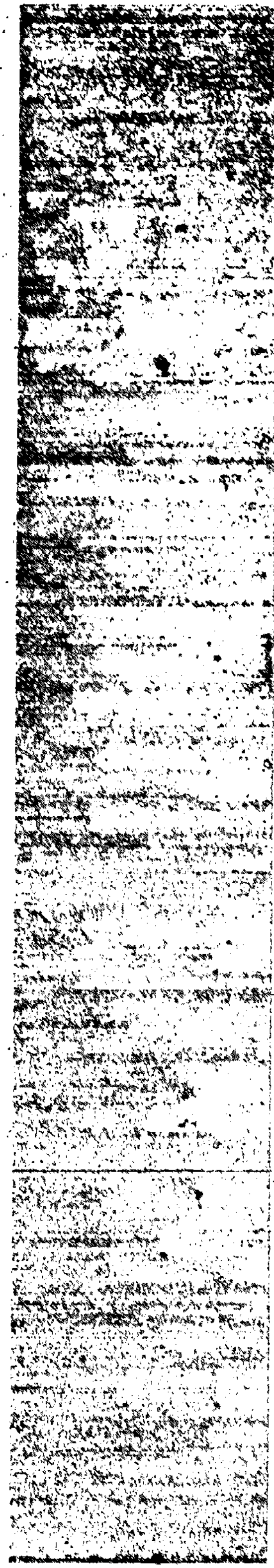
Wiley & Sons, Inc., 1969. Chapter 7, "Weathering and Soils," pp. 135-158.

Matthews, William H., III. *Selected References for Earth Science Courses.* Earth Science Curriculum Project Reference Series: RS-2. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1964. List of references on weathering and soil formation, pp. 14-15.

Namowitz, Samuel N., and Donald B. Stone. *Earth Science—The World We Live In,* 4th ed. New York, American Book Company, 1969. Chapter 7, "Weathering, Mass Wasting, and Soils," pp. 88-103.

Ramsey, William L., and Raymond A. Burckley. *Modern Earth Science.* New York, Holt, Rinehart and Winston, Inc., 1969. Chapter 11, "Weathering and Erosion," pp. 234-252.

Reiche, Parry. *A Survey of Weathering Processes and Products,* 3rd ed. University of New Mexico Publications in Geology No. 3. Albuquerque, N.M., The University of New Mexico Press, 1950.



Glossary

bedding—observable, discrete layers of rock. Each bed is set apart from rocks below and above it by differences in rock type, planes of separation (called *bedding planes*), or both.

bedrock—solid rock sometimes exposed at the surface but commonly underlying unconsolidated earth material.

differential weathering—a variation in the rate of weathering of different sections or layers in a rock mass. It results from variations in the chemical composition or differences in the degree of weathering within these sections or layers of rock.

hydration—a chemical reaction in which the addition of water to a compound produces a new compound.

hydrolysis—a chemical reaction of water (commonly dissociated as H^+ and OH^- ions) with other compounds, or one of the ions of water with another ion. By the process of hydrolysis, relatively insoluble compounds may be broken down.

joint—a fracture or break in a rock along which there has been little or no movement parallel to the fracture surface.

mineral—a naturally occurring combination of elements with a composition expressable by a formula. An orderly arrangement of atoms gives most minerals a crystalline structure. Over 2000 minerals are known to exist.

oxidation—a chemical reaction involving the loss of one or more electrons from an ion or atom. Because this reaction most commonly involves the addition of oxygen, the process is known as oxidation.

rock fabric—the arrangement of the particles (grains, minerals, rock fragments, or fossils) in a rock.

silicate mineral—one of the many compounds containing SiO_4 tetrahedrons, either isolated or joined to other oxygen atoms, in its crystal lattice. Included among the silicates are many of the common rock-forming minerals such as quartz, the feldspars like orthoclase, the micas, and the amphibole and pyroxene groups.

soil—loosely speaking, all the unconsolidated earth material above bedrock. However, the term is generally restricted to earth material so altered by physical and chemical weathering as to support rooted plants.

soil profile—a vertical section of the soil from the surface down through the horizons (or layers) of different observable characteristics that have formed during the soil-building processes into the parent rock material below.

specific gravity—the ratio of the mass of a substance to the mass of an equal volume of water at 4°C. Specific gravity can be determined by dividing the weight of the substance in air by the weight of an equal volume of water. These comparisons are commonly made by a double pan spring balance known as a Jolly balance.

weathering—the alteration of material at or near the earth's surface through physical and chemical processes. Weathering is an adjustment of materials to environmental conditions in order to attain equilibrium.

PHOTO CREDITS

Page 4, left, U.S. Forest Service, G. B. Sudorth.

Page 11, top, American Museum of Natural History.

Page 13, U.S. Department of Agriculture.

ESCP Pamphlet Series

PS-1 Field Guide to Rock Weathering ★

PS-2 Field Guide to Soils

PS-3 Field Guide to Layered Rocks

PS-4 Field Guide to Fossils

PS-5 Field Guide to Plutonic and Metamorphic Rocks

PS-6 Color of Minerals

PS-7 Field Guide to Beaches

PS-8 Field Guide to Lakes

PS-9 Field Guide to Astronomy Without a Telescope

PS-10 Meteorites