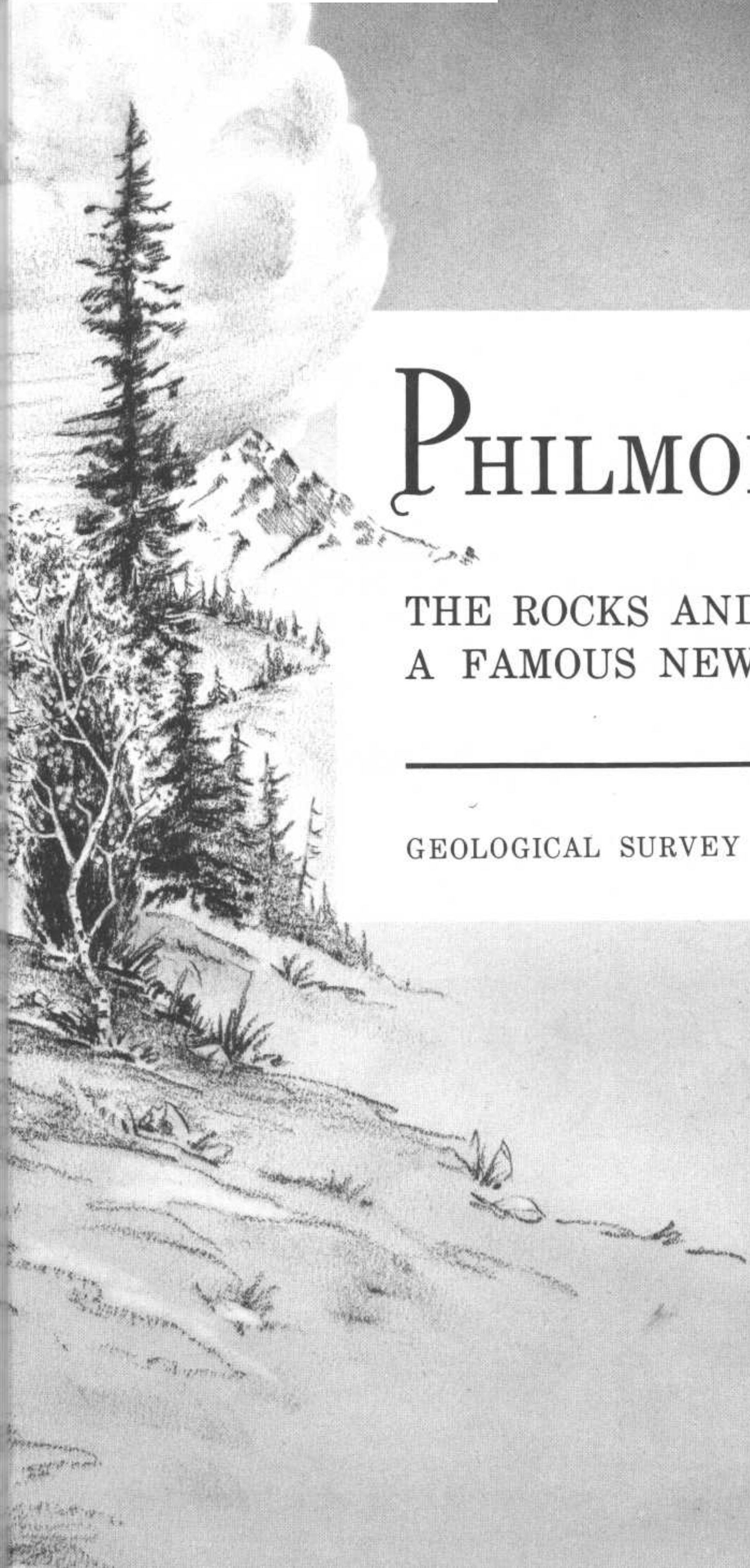


PHILMONT COUNTRY

THE ROCKS AND LANDSCAPE OF A FAMOUS NEW MEXICO RANCH

GEOLOGICAL SURVEY PROFESSIONAL PAPER 505

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

PUTTING THE ROCKS ON PAPER

Naming and mapping formations

Now we have a practical way to put on paper what we have seen on the ground. We can make a rock map by tracing across country the units recognized in the canyon traverses, for these units are large enough to show on a small piece of paper.

We have 20 units to work with. The 9 units of solid sedimentary rocks noted in our traverses make 12 map units, as unit 4 has three parts and unit 1 can be split into two intertonguing units—a western one of coarse sandstone and conglomerate, and an eastern one of finer grained rocks, including much shale and a little coal. Older than all of these are two units, the granodiorite and the metamorphic rocks. Younger than the solid sedimentary rocks are six units. Three are igneous rocks: (1) sheets and irregular masses that formed below the surface, including dacite porphyry, diorite, andesite, and lamprophyre; (2) basalt lava; and (3) volcanic bomb beds and other crater rocks. The other three are loose sedimentary rocks: (4) sand and gravel on benches; (5) landslides; and (6) sand and gravel on valley floors. By pooling the information in the columns of figure 86, we can show all 20 units in a single column—plate 2, in the back pocket—that summarizes the rock sequence.

A geologic map has been made by tracing these units, or formations, throughout Philmont on a topographic map, used as a base. It is plate 3, which also is in the back pocket. If you are visiting the area, it might be impractical to take along this book, but you may find it stimulating to take along the geologic map.

Nature makes rocks; geologists invent formations to make the rocks mappable. It is worthwhile to learn a little about this basic working tool. Formations are practical units that are thick enough and cover enough area to show at the scale of mapping but, if possible, are thin enough so that there will be several on the map. A formation may be mainly a single kind of rock like the cliff-making gray sandstone of unit 3, named Trinidad Sandstone in figure 86 and on the geologic map (pl. 3), where the name includes the rock type; or it may consist of a series of layers of two or more kinds of rock that are related in origin, like the thinly interbedded lowland deposits of sandstone, shale, and coal of unit 2, above the Trinidad Sandstone, named Vermejo Formation.

Sometimes it is useful to separate an established formation into parts or members; thus the thin limestone of unit 4b is the Fort Hays Limestone Member of the Niobrara Formation. On the other hand, it is sometimes impractical to map established formations. Thus unit 4a, referred to here simply as the Pierre Shale, actually combines two sequences of similar rocks: the shale part of the Niobrara Formation (bottom) and the Pierre Shale (top), which are mapped separately elsewhere. Unit 4c combines three—the Graneros Shale (bottom), Greenhorn Limestone (middle), and Carlile Shale (top)—because there was no time to find and map the very thin Greenhorn Limestone; without the Greenhorn, the two shales, which look alike, cannot be separated. Also, two or more formations that have a lot in common are sometimes combined in a group; thus, unit 8, called Dockum Group, is divided elsewhere into the Santa Rosa Sandstone (bottom) and the Chinle Formation (top).

Twelve of the formations at Philmont, or all the solid sedimentary rocks, have been given names, as a practical way to identify and remember them; they are referred to by these names on plate 2, on the geologic map (pl. 3), and from here on. A formation is usually named for a geographic feature—a city, a river, a mountain, a county—near which it is well exposed or, commonly, was first mapped. The formations at Philmont draw most of their names from nearby New Mexico and Colorado—Poison Canyon, Raton, Vermejo Creek, Trinidad, Sangre de Cristo Mountains—but the Fort Hays Limestone Member was named for Fort Hays, Kansas, 270 miles away; the Pierre Shale, for Pierre, South Dakota, 600 miles away; and the Entrada Sandstone, for Entrada Point, Utah, 400 miles away.

No new formation names are used in this book. Several names, such as Dakota and Pierre, have been used for a hundred years; all the others have been in use since early in the century. But this does not mean that the rocks of the United States were all satisfactorily named long ago: fewer than 2,000 names had been applied to American rocks by 1900, but something like 10,000 were added by 1936, and more than 5,000 additional names were coined between 1936 and 1955!

Most of these names are for sedimentary and volcanic rocks, but several thousand are applied to metamorphic and intrusive igneous rocks. This does not mean that the rock column of the United States is so thick and varied that it takes many thousands of named formations to describe it. Rather, it shows how often cautious gologists have given the same rocks different local names because the rocks have not been traced between areas and the identity is not sure. The country is so large and so much of its geology has not been mapped in any detail that rocks of what may someday be called by one name now have as many as 50 local names. The rocks may be dead, but the task of describing, interpreting, naming, and relating them to each other is still very much alive!

At Philmont we confidently use names that were first used far away, because the formations have been traced across country by following the outcrops or by drilling. To name formations in this way is practical as well as convenient. The relation of local rocks and the events that made them to neighboring rocks and events is learned by following recognized formations across country. This may merely satisfy curiosity, or it may be of economic value. If a certain formation, for example, has yielded oil or coal or uranium in one area, it makes sense to prospect it carefully elsewhere.

That some formations can be traced over hundreds or thousands of square miles gives an idea of the extent of certain individual rock layers laid down on the floors of ancient oceans or on the broad flood plains of vanished rivers. It also suggests why we have not bothered to name the bedded rocks of small extent, such as the landslide aprons, the gravel and sand caps of the plains and valleys, or the basalt flows, even though they may be a large part of the local geology.

We can also place the intrusive igneous rocks on plate 2 because we know the relation of some of them to dated sedimentary rocks—they must be younger than sedimentary rocks they cut and older than sedimentary rocks that lie on their eroded surfaces—and because we assume that in an area the size of Philmont all the intrusive rocks that look alike and are of similar composition are of the same age, if there is no positive evidence to the contrary.

Formation names are not given to the igneous rocks, though this is often done elsewhere, because it would serve no useful purpose here. We cannot relate them to other igneous rocks beyond Philmont and do not need formal names for them in this book.

WHEN WAS THIS CAKE MADE?

The rocks are now arranged in the order of their relative ages, but what are their ages in years? If earth processes went on in the past at about the same creeping rate as they do now, vast stretches of time were needed to accumulate the many thousands of feet of rocks piled up here, to alternately submerge the area beneath the sea and raise it to mountainous heights, and then to carve the mountains away. Much time was needed, but how much? One way to get at this would be to measure the rates at which sediments like those of Philmont are now piling up on land and sea, and the rates at which mountains like the Cimarron Range are now rising—if they are—and at the same time being worn down. This plan sounds good, but it is beset with difficulties, mainly because not enough measurements have been made in enough places for a long enough time to serve as reliable yardsticks.

Far better than a theoretical yardstick is a natural clock built into certain rocks: radioactivity. A few elements continuously throw off particles from their nuclei and break down into simpler elements at a uniform rate that is not changed by heat, pressure, chemical conditions, or time. If we know the rate of breakdown, we can figure out how much time has passed since breakdown began by comparing the amount of the remaining original element with the amount of its disintegration products. These days almost everyone is familiar with the fantastically rapid disintegration rates, measured in fractions of a second, of elements such as plutonium that are used in atomic bombs and nuclear power plants. Rapid disintegrations of this sort are not of much use in dating rocks, but some elements disintegrate so slowly that measurable amounts of the original element remain after many millions of years.

Uranium is the most useful of these elements, for it is widespread though not very abundant, and 6,700 million years must pass for half of a given amount to disintegrate, mainly to lead, helium, and electrons. By comparing amounts of either lead and uranium or helium and uranium in unweathered specimens, we can determine the number of years since the uranium-bearing mineral became solid. Unfortunately, this can be done only with uranium minerals that crystallized from a melt. In a sedimentary rock there is no way of knowing how much of the lead in a sample is the product of disintegration of nearby uranium and how much was simply washed in with uranium.

Like uranium, the elements thorium, potassium, and rubidium are also radioactive and have extremely slow breakdown rates. They are also used in similar ways to date rocks.

Unfortunately, radioactive dating with these elements is terribly slow, difficult, and expensive, and requires absolutely unweathered material, so that only a handful of rocks have yet been reliably dated in this way. The oldest rock now dated by radioactivity in the United States—gneiss from Minnesota—is more than 3 billion years old.

Because of their slow rates of breakdown, elements like uranium, thorium, potassium, and rubidium are most useful in dating rocks that are hundreds of millions of years old. In younger rocks these elements have disintegrated so little that it is hard to collect enough material to make a good analysis.

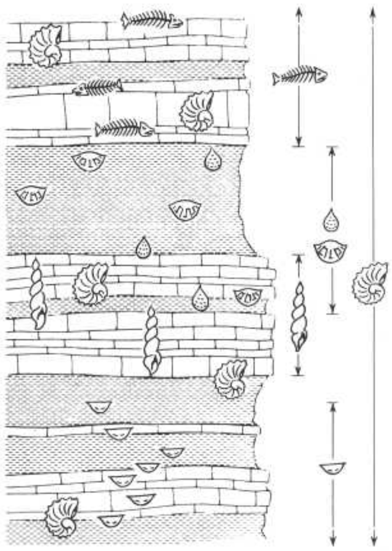
Some sedimentary rocks that contain organic material, if they are less than about 50,000 years old, can be dated by a radioactive form of carbon. This carbon (carbon 14) is formed by cosmic-ray bombardment and is absorbed by all living things and buried with them at death. It is preserved best in shellfish and trees. It breaks down so rapidly that half of any initial amount will disappear in 5,600 years.

Unfortunately, no radioactivity age determinations have been made of any rocks from Philmont. Crude limits on the clock age of the oldest rocks at Philmont—the gneiss and schist of the mountain core—can nevertheless be set in an indirect way. The gneiss and schist are near the south end of a belt of similar rocks that stretches for more than 500 miles along the Rocky Mountain front, from northeastern New Mexico to central Wyoming. Many radioactivity measurements have been made of the age of granite and pegmatite that cut these metamorphic rocks in central Colorado. Most of them range from 900 million to 1,500 million years. The metamorphic rocks must be still older.

The oldest rocks at Philmont, then, are probably more than 900 million years old. The youngest are still forming. Without any radioactivity dates, how do we get at the ages of those between?

Fossils—raisins in the rock cake—come to our rescue. Let's see how they are used. Animals and plants live and die almost everywhere on the land and in the sea. At death, the great majority of organisms simply vanish by being eaten, by completely decaying, or by being broken into unidentifiably small bits. Of those uncountable billions of animal and plant individuals living and dying, only a tiny fraction need be buried to preserve rich evidence of past life. If the evidence is enough to tell something about the appearance or habits of a former animal or plant, it is a fossil (from the Latin for "something dug up") It may be a hard part such as a shell or bone buried and preserved without change. Most often it is a part that has been partly or wholly altered by decay and by the action of percolating water but has retained its organic form. Some fossils are merely prints or impressions made in soft sediments that later hardened; soft thin organisms—worms, leaves, jellyfish—are most often fossilized in this way. Such indirect evidence of life as tracks, footprints, burrows, borings, and excretions may be preserved in one way or another and also serve as fossils. Some of the ways in which fossils are preserved were illustrated in the chapter on rocks.

The assortment of fossils in each formation is not haphazard but is distinctive, and most fossil species have a limited range: they appear in a particular layer or formation or in several successive formations and then disappear (fig. 89).



FOSSILS and formations. (Fig. 89)

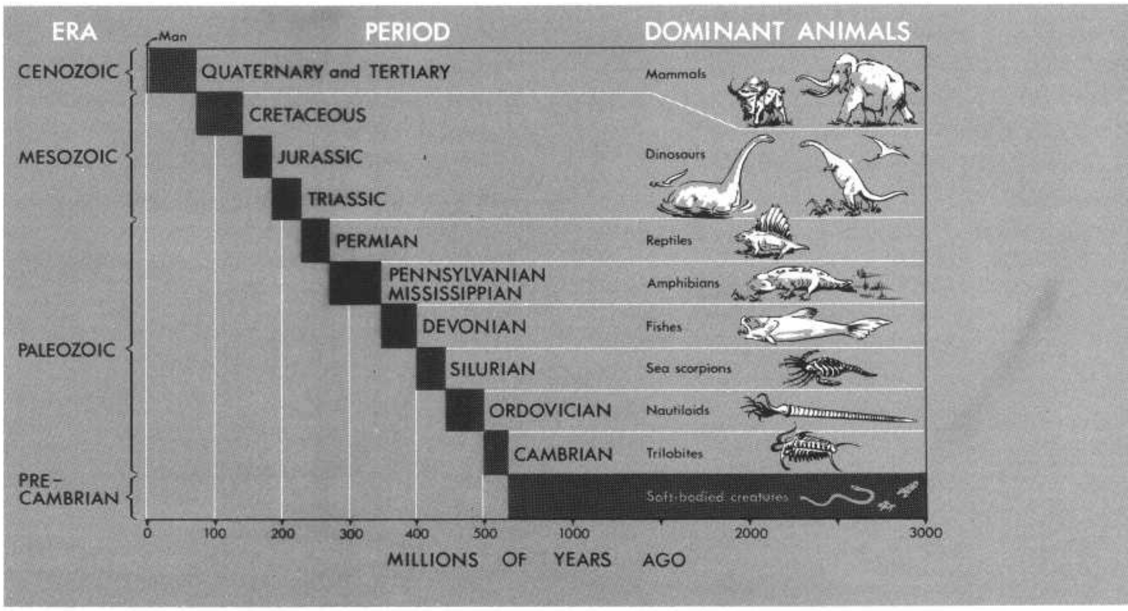
Once a species disappears—that is, when it becomes extinct—it is gone forever, never to recur in younger rocks. Thus, rocks having the same distinctive sets of animal remains—called faunas—or of plant remains—called floras—are of about the same age wherever they occur, even if at opposite sides of the earth. These ideas about fossils are now more than 150 years old and are supported by thousands of carefully located collections from all over the world.

Using fossils as tools, we are able to decide the relative ages of rocks anywhere that contain enough of them and to devise a worldwide scheme for expressing relative age, as well as for breaking geologic time into convenient units. The standard geologic time scale is shown in the chart below.

From the fossil sequence it is clear not only that fossils trapped in rocks of different ages are different from each other but that their variety and complexity increases toward the present. The younger a fossil fauna or flora is, the more it is like living communities.

The early geologists who made the geologic time scale had this in mind when they named the major divisions or eras—each name ended in "-zoic," from the Greek word for life. Three of the four eras now used retain these names: Paleozoic (ancient life), Mesozoic (middle life), and Cenozoic (recent life).

GEOLOGIC TIME CHART



Few fossil species in the Paleozoic rocks closely resemble any living plant or animal. In early Paleozoic time there were no land plants or animals—at least their remains have never been found in flood-plain and near-shore rocks of that time. The fossils in the lower Paleozoic salt-water rocks are remains of extinct species of such plants and animals as primitive shellfish that lacked backbones, structures like coral reefs built by algaelike plants, and markings made by worms. Land-plant and animal remains as well as salt-water fish appear first in middle Paleozoic rocks. Birds do not appear in the rocks until early Mesozoic time; and mammals, not until the end of Mesozoic time. Dinosaurs first lived in early Mesozoic time and were extinct by the end of the Mesozoic, whereas the remains of manlike creatures are not found in rocks older than late Cenozoic, so that no man ever saw a live dinosaur, contrary to the comic strips. Most living plant and animal species are only a little older than man.

Each of the three life-rich era is divided into periods, 12 in all, as shown in the chart on p. 93. This is enough subdivision for our purposes though the periods have all been split further into epochs, and some epochs have also been split.

The names of the periods make a motley list. Eight of them are derived, like modern formation names, from places in which rocks of that age are well exposed and were early studied. The early geologists who chose them, however, were not overly concerned with words and bothered little about uniform usage. Cambrian, for example, comes from Cambria, an ancient name for Wales, and Permian comes from the province of Perm in Russia; but Cretaceous refers to the fact that rocks of this age in Britain are mostly chalk, which, in Latin, is *creta*. (As it happens, very few rocks of Cretaceous age elsewhere in the world are made of chalk; so that this is a very good reason for avoiding descriptive names for time units.) Triassic comes from the fact that rocks of this age, where first studied in Germany, were in three distinct formations. The two periods of the Cenozoic are relics of an early attempt to subdivide geologic time into four great episodes: Primary, Secondary, Tertiary, and Quaternary. This attempt was abandoned long ago, but the two youngest names remain.

Cambrian rocks are the oldest rocks that have abundant fossil remains useful for dating. Beneath them in many parts of the world are great thicknesses of rocks that lack distinctive fossils, and these rocks are now lumped together simply as Precambrian. Eventually, when better methods of dating are discovered, the Precambrian Era, like the other eras, will be subdivided into periods and epochs.

The world-wide geologic time scale is a remarkable achievement of men acting cooperatively, but it is still only a guide to relative age. And, as clock age can be determined from radioactivity only in igneous rocks, which rarely have any fossils, we might seem to have reached the end of the dating line. Fortunately, it is often possible to determine the *relative* ages of particular igneous and sedimentary rocks. If the clock ages of the igneous rocks are determined by radioactivity and the geologic ages of the sedimentary rocks by fossils (or by relations to other sedimentary rocks), then the two sets of ages can be put together to determine the clock ages of the sedimentary rocks and the geologic ages of the igneous rocks.

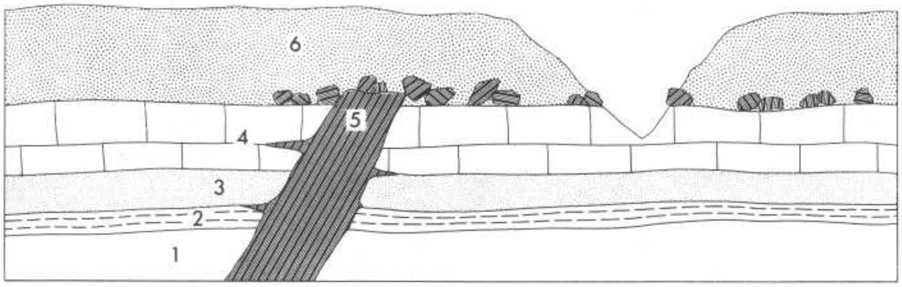
Deciding the age relations between igneous and sedimentary rocks is often even simpler than finding the relative ages of sedimentary rocks alone. Those igneous rocks that are deposited on the earth's surface—flows of lava and falls of volcanic debris—can be treated like sedimentary rocks: they are younger than the rocks beneath them and older than those above. Of course, the idea of superposition is of no use for dating the intrusive igneous rocks, but there are other ways to learn their relative ages: intrusive rocks are younger than any rock they intrude, older than any rock that is deposited on top of them after they have been exposed, and older than any sedimentary rock that contains fragments eroded from them, even if the two rock bodies are not actually in contact (fig. 90).

Suppose, for example, that a limestone formation containing Devonian fossils lies on a lava flow and is overlain by a conglomerate formation containing Mississippian fossils; the lava and limestone are cut and baked by an intrusion of pink granite that ends abruptly at the base of the conglomerate, which has pebbles of pink granite. This situation is sketched in figure 91.

If the lava has a radioactivity age of 400 million years and the granite, 350 million years, it seems safe to conclude that the Devonian formation (which may represent only a fraction of the entire Devonian Period) is between 350 and 400 million years old.

By weaving together the handful of really reliable clock-age determinations that have been made and the geologic ages of associated rocks, it is possible to give some crude estimates of the length, in years, of the geologic periods and eras. These are given in the chart on page 93. The technique of radioactivity age measurement is young and is rapidly being developed. By the time this book is in print, some of the numbers in the chart will no doubt already be obsolete. At any rate, they give us a fair idea of the vastness of earth time as well as confirmation of the fossil succession and of the geologic time scale. They also show that the periods based on fossils are of very unequal length, and become progressively shorter as they come nearer the present. This is not at all surprising: as with human history, the more recent an event, the better, more nearly complete, and, therefore, more detailed the record.

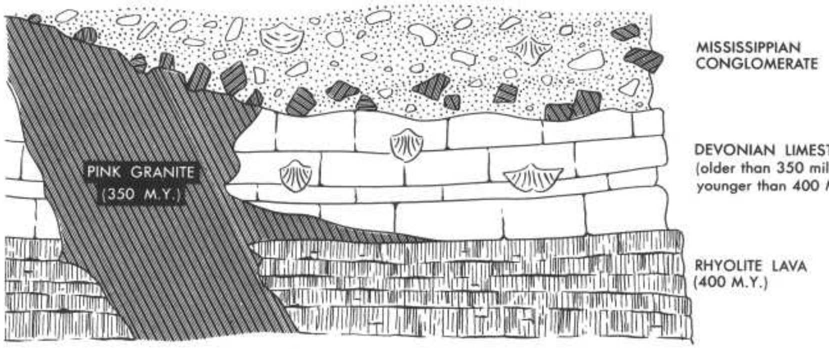
At last we can make some educated guesses about the ages, both geologic and clock, of Philmont rocks. Starting at the bottom, the metamorphic rocks are not merely older than the Sangre de Cristo Formation but are almost certainly of Precambrian age. From this we should not leap to the conclusion that metamorphic rocks everywhere are Precambrian. The "ancient" look of gneiss and schist may be very misleading. This has been proved by tracing fossil-bearing sedimentary rocks directly into areas where the same rocks are metamorphosed; even more dramatic are the few but remarkable discoveries of identifiable, though distorted, fossils in highly metamorphosed rocks. Metamorphic rocks like those at Philmont are known to be as young as Cretaceous in other parts of the United States—such as the Sierra Nevada of California—and of early Tertiary age in the French Alps, the Himalaya Mountains, and the Dutch East Indies. That no younger gneiss or schist is known probably means that erosion has not yet exposed such rocks rather than that metamorphic conditions have not existed deep below the surface in more recent time.



DATING INTRUSIVE IGNEOUS ROCKS. The age of an intrusive igneous rock can sometimes be read from its relation to other rocks. In this example, sedimentary formations 1, 2, 3, and 4 were deposited. Then they were intruded by a sheet of dacite porphyry (5). These rocks were eroded and, later, sandstone formation 6, containing pebbles of dacite porphyry, was deposited. The dacite is therefore younger than formations 1–4 and older than 6. Even if the dacite sheet itself is buried, fragments from it seen in the base of formation 6 (in the valley at right) are enough to date it. (Fig. 90)

All the named formations but the Entrada have enough fossils in, or not far from, Philmont to set their geologic ages, which are shown opposite the formation names on plate 2. Along with the geologic ages on plate 2 are estimates of clock ages from the chart on page 93. Together, these two kinds of ages tell much more about the history of Philmont than we could ever have learned from the most careful study of the rocks simply as rocks. For example, the clock ages in the chart make very plain the time gap—more, perhaps vastly more, than 700 million years—between the metamorphism of the gneiss and schist deep beneath the surface and the exposure of these rocks to provide part of the load of the sluggish streams that laid down the Sangre de Cristo Formation. Also, they bring out the curious fact that only a small part of the Cenozoic Era, some 70 million years long, is represented by any rocks at Philmont; and, because most of the Cenozoic rocks of Philmont lack fossils, we end by knowing less about the Cenozoic than about some earlier eras.

Once the geologic ages of the metamorphic and sedimentary rocks are known, we can work out, at least roughly, the geologic ages of the igneous rocks. The pink granodiorite and diorite porphyry, which are confined to the areas of Precambrian metamorphic rocks and are themselves slightly metamorphosed, are older than the Sangre de Cristo Formation and



BRINGING TOGETHER TWO KINDS OF TIME: geologic and clock. If the rhyolite lava has a radioactivity age of 400 million years and the granite, 350 million years, the Devonian formation is between 350 million and 400 million years old. (Fig. 91) therefore are of pre-Pennsylvanian age; most likely, they are Precambrian and only a little younger than the gneiss, schist, and quartzite. The dacite porphyry and andesite are of Tertiary age—younger than the early Tertiary Poison Canyon Formation but older than the oldest Quaternary gravel. The andesite is the younger of the two, for andesite sheets cut across dacite sheets north of Baldy Mountain. The lamprophyre and dark diorite, which are definitely younger than the Pierre Shale and older than the gravel, are probably of Tertiary age, too. Their age relations to each other and to the dacite and andesite are unknown. The lava flows and bomb beds associated with them are of Cenozoic age, as they are younger than the Late Cretaceous Pierre Shale and the presumed Tertiary dacite porphyry sheets that cut the Pierre, but are older than the late Cenozoic landslides. Probably the basalt is Tertiary rather than Quaternary but of much later Tertiary age than most, if not all, the other igneous rocks.

To show the rocks more vividly than on the flat geologic map, the surface geology has been sketched from the same bird's-eye position as the landscape model of plate 1. This geologic model (pl. 4, in pocket) is too small to show individual formations; instead, all the formations belonging to the same period or era are grouped together, and many small rock bodies, just large enough for the geologic map (pl. 3), are left off. Comparing the landscape model and the geologic model, we see that the patterns made by the rocks are like the pattern of the landscape units, and we begin to realize that the landscape did not just happen but is in some way controlled by the rocks beneath.

MISSING LAYERS

The Philmont cake has many missing layers, as plate 2 shows; indeed, rocks of more geologic periods are absent than are present. Rocks missing are just as important to the geologic story as rocks present: they tell of ancient landscapes and of times when old rocks were being eroded rather than new rocks deposited; they help to locate the source areas of old sediments and to trace the paths of former rivers and the wandering shorelines of vanished lakes and seas. Old surfaces of erosion, preserved by a cover of younger deposits, are called unconformities.

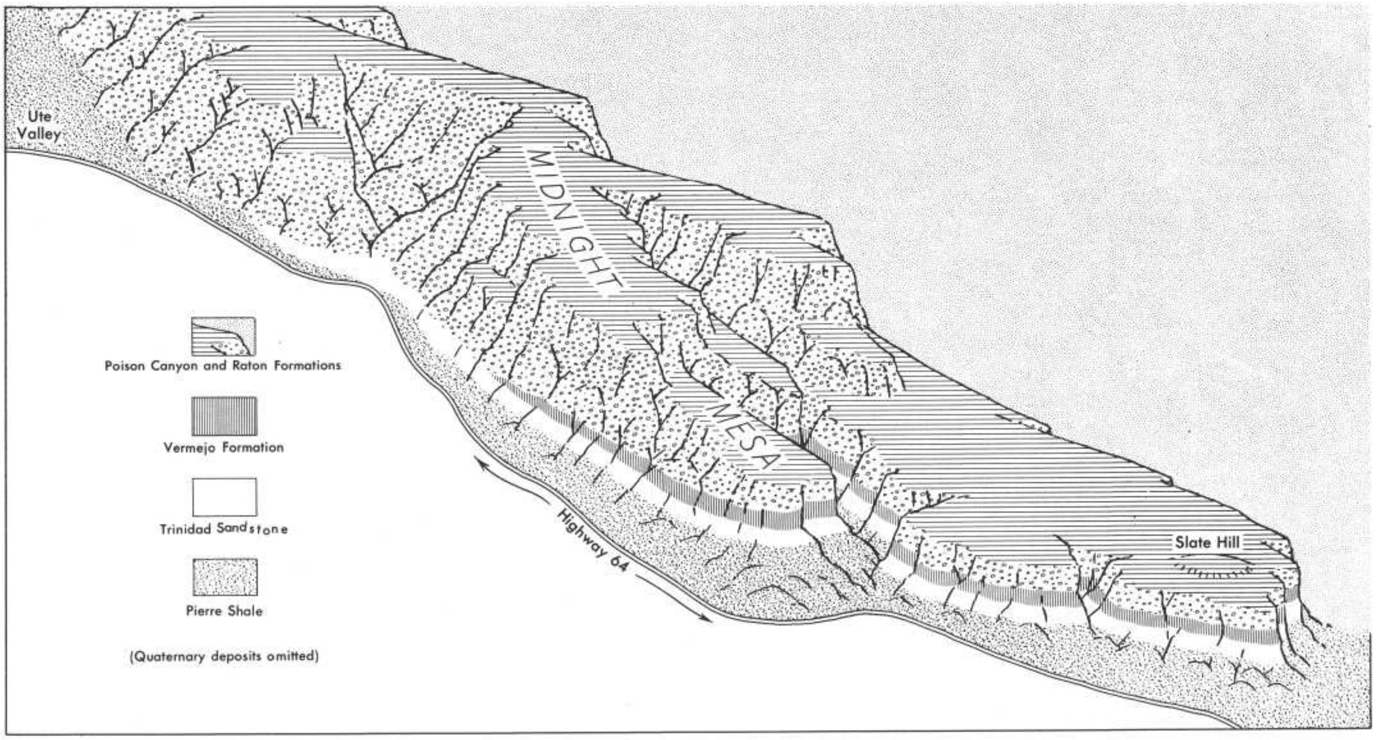
Starting from the top of the Philmont rock pile, we promptly meet a swarm of unconformities, represented by flat dissected deposits of stream gravel and sand at several levels in the lowland plains. Valleys had to be cut through each higher gravelled surface before the streams could establish themselves and deposit the next lower gravel; each episode of valley cutting resulted in an unconformity. In parts of the lowland plains, as many as four successively narrower and lower valley steps can be seen (three are visible in figs. 2, 8). No fossils have been found to date the times of gravel making; but probably no one of these unconformities represents very much geologic time, for all the gravel, even the oldest and highest, is loose and not much weathered.

The gravels as a whole, though, bespeak a large unconformity. They all seem to be of Quaternary age and no. more than a million years old. The youngest rock preserved beneath them at Philmont—the Poison Canyon Formation—is very early Tertiary, probably more than 60 million years old. This would suggest that all Philmont was being slowly eroded during the tens of millions of missing years.

Another possibility becomes evident when we learn that Tertiary rocks younger than the Poison Canyon are still preserved nearby. Beginning abruptly a few miles north of Philmont and continuing for more than 50 miles along the mountain front are sands and gravels thousands of feet thick that were deposited by mountain streams in early and middle Tertiary time. Philmont was very likely blanketed by some of these same soft rocks, but they were stripped off in late Tertiary time.

The same unconformity that underlies the gravel goes under the basalt cap of southern Philmont.

Beneath the Poison Canyon and Raton Formations is another, rather small, unconformity (fig. 92). It is easily seen from Highway 64 and on the geologic map.

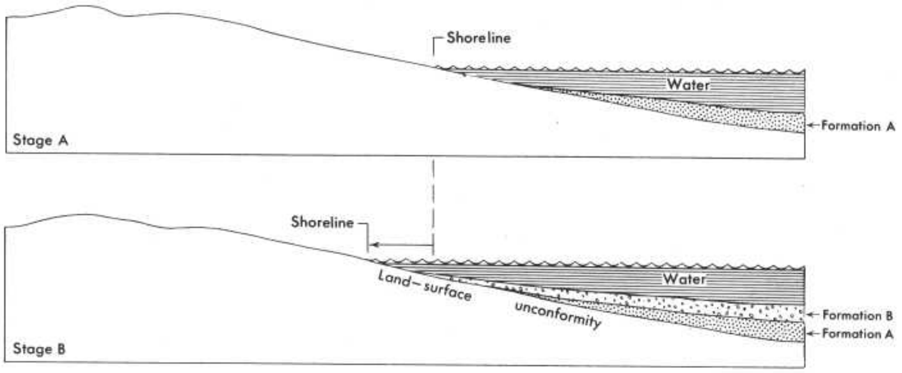


UNCONFORMITY beneath Poison Canyon and Raton Formations along U.S Highway 64. (Fig. 92)

Downstream from Slate Hill near Cimarron, the Raton Formation lies on 150 feet of the Vermejo Formation. At the base of Midnight Mesa, the fine-grained Raton intertongues with, and is displaced by, the coarse-grained Poison Canyon Formation, still lying on the Vermejo, which here, however, is considerably less than 100 feet thick. Near the entrance to Ute Creek Valley, the Vermejo thins to nothing, and the Poison Canyon lies on the 100-foot-thick Trinidad Sandstone. Within a mile to the northwest, the Trinidad too disappears, and the Poison Canyon lies on the Pierre Shale. The unconformity, therefore, cuts down across more than 200 feet of beds within a few miles. As the rocks above the unconformity are only slightly younger than the rocks below it, the break does not signify much time.

Thinning does not by itself prove unconformity. Every sediment, of course, thins to nothing at the edges of the valley, lake, or sea in which it is deposited; and as the boundaries of the sediment traps change—for example, as the sea advances across a continent—new formations may lap over the edges of the old ones and onto still older ones (fig. 93) without much change in conditions or break in the record. The Poison Canyon Formation, however, was not deposited by a sea moving west but by streams flowing east. Conditions changed radically between Trinidad time and Poison Canyon time, and the Poison Canyon Formation does not overlap the Trinidad but lies unconformably on it.

All the periods from the Cretaceous down through the Pennsylvanian are represented by rocks at Philmont. If there were episodes of erosion in this long span, or times when the region stood close to sea level and far from sources of sediment so that there was neither erosion or deposition, they were not long.



THINNING of a formation by overlap. (Fig. 93)

Below the Pennsylvanian part of the Sangre de Cristo Formation is the greatest unconformity recorded at Philmont. There are no Mississippian, Devonian, Silurian, Ordovician, or Cambrian rocks, representing nearly 300 million years, nor any Precambrian rocks to fill the rest of the gap from the start of the Cambrian, 600 million years ago, to the gneiss and schist, 1,000 million or more years old. The rocks that became gneiss and schist must have been squeezed, recrystallized at depth, and deeply eroded before the Sangre de Cristo beds were laid down. Evidence from surrounding areas does not help greatly in deciding whether any rocks were deposited here during this vast stretch of time. On the one hand, no rocks representing this time interval are known at the surface or in wells drilled for oil for scores of miles in any direction. On the other hand, the composition and thickness of the nearest pre-Pennsylvanian Paleozoic formations suggest sea rather than land at Philmont; rocks may have been deposited here during some or all of the first five Paleozoic periods, only to be eroded before Sangre de Cristo time.

Another great unconformity may be concealed in the metamorphic rocks. Possibly, the rocks that are now coarse-grained gneiss and schist were formed and partly metamorphosed before the rocks which became fine-grained schist and quartzite were even deposited, and then all these rocks were metamorphosed together. This might explain the great difference in grain size.