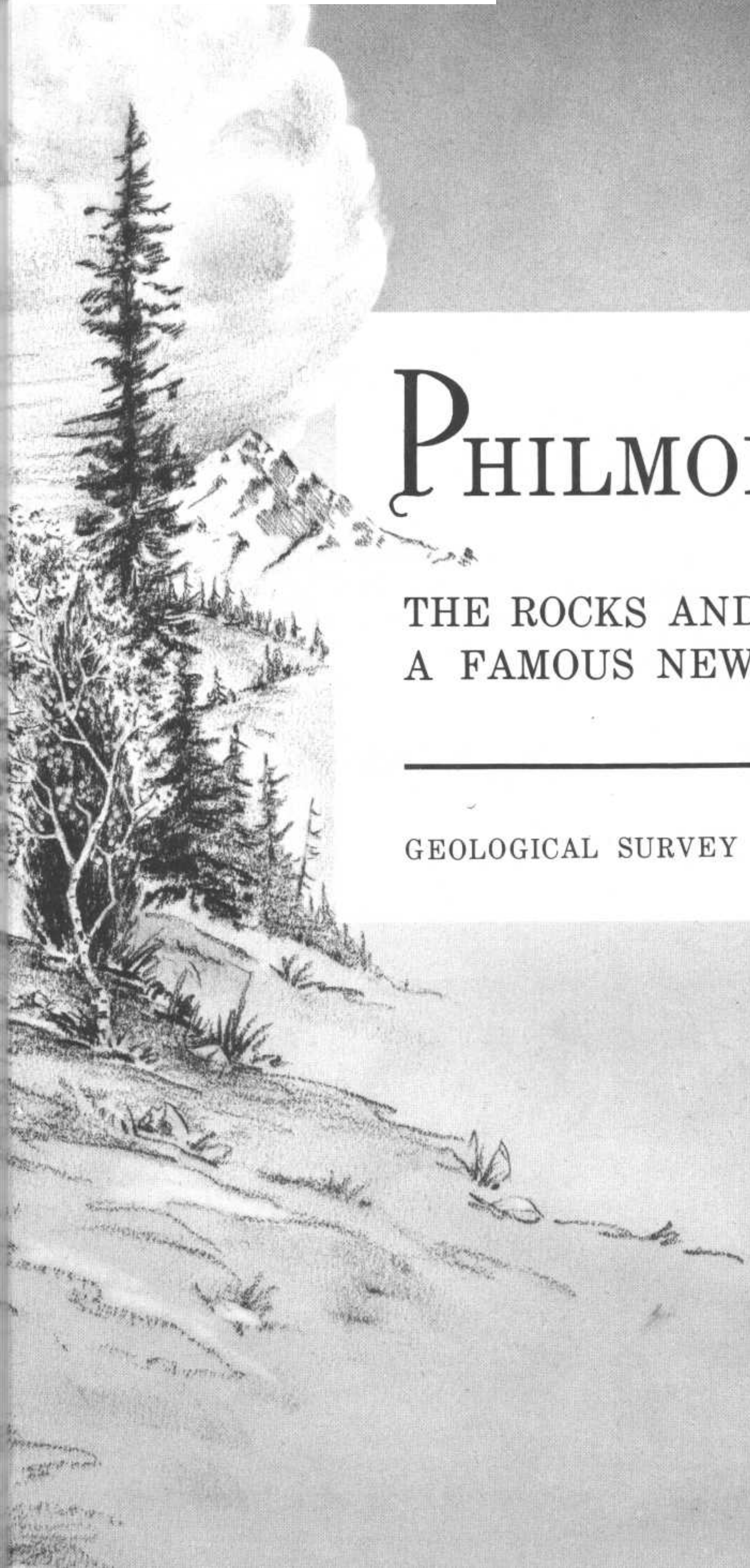


PHILMONT COUNTRY

THE ROCKS AND LANDSCAPE OF A FAMOUS NEW MEXICO RANCH

GEOLOGICAL SURVEY PROFESSIONAL PAPER 505 beyond the waterfalls may be structural benches cut on the bias.

The evidence of geologically late uplifts in the region, however, leads to a different possible explanation of the mountain meadows along middle Bonito Creek. Perhaps Bonito Creek once reached a stage at which it flowed through an ever widening valley across metamorphic, sedimentary, and igneous rocks alike to its junction with the Canadian River. Then a pulse of mountain uplift started a wave of downcutting that has worked its way headward only as far as the present mountain front, so that the meadows are the remnants of an older, interrupted episode of valley widening.

The future of waterfalls is interesting to consider. The waterfall best known to Americans is Niagara Falls, which is in flat rocks; everyone has heard or read that it is retreating upstream, and it is natural to assume that all falls do the same. Waterfalls in flat-lying rocks *do* retreat upstream. But in rocks that dip, the matter is more complicated. If the dip is upstream, or is downstream but at an angle lower than the slope of the stream channel, falls retreat as in flat beds. If the dip is downstream, though, as it is along nearly all the mountain front, the falls will advance. Falls across vertical beds, as on South Fork Urraca Creek, will not migrate at all.

The marshy meadows along lower Agua Fria Creek (fig. 10) at the junction with Rayado Creek look like those on upper Bonito Creek, but they cannot have had the same origin; for there are no hard sandstone or dacite ledges just downstream, and Rayado Creek valley does not have a broad meadow reach near the junction. Agua Fria Creek has been able to cut its bed down faster than other streams in the Rayado Creek system, so that it meanders sluggishly on a marshy flood plain, partly because it is running in crushed rocks along a fault and partly because it drains a much larger area than the other creeks and so has had more water to work with. Agua Fria Creek is reminiscent of Cimarron Creek, which has cut its bed much lower than neighboring streams for apparently the same reasons.

MOUNTAIN MEADOWS where Bonito Creek runs on metamorphic rocks, upstream from hardrock ledges at the mountain front. (Fig. 127)

The rugged mountain country

The mountains begin where hard layered rocks—Dakota Sandstone and dacite porphyry sills—crop out and dip 25° or more. The most rugged mountains are not deep in the range but at the very front, where these same moderately to steeply dipping hard layers alternate with soft ones of shaly rocks. The highest part of the mountain country, Touch-Me-Not Mountain, is held up mostly by thick sills of hard dacite porphyry that have moderate to low dips near the crest of the Cimarron Range anticline. Even the shale between the sills is a fairly hard rock, because it has been baked and hardened by the intrusions. It seems clear that the mountains exist because their hard rocks have been arched up, faster than streams could strip them away, in a great surge in middle Tertiary time and in many lesser pulses since.

At first glance, the Precambrian metamorphic and igneous rocks in the mountain core do not seem very resistant to erosion, judging by the general roundness of the terrain, the scarcity of outcrops, and the many small closely-spaced streams. All this surely means that weather and water easily attack these rocks at the surface through the countless openings provided by cleavage, joints, and other fractures. But appearances are often deceiving, and a soft glove often covers a hard fist. Precambrian crystalline rocks form the core not only of the Cimarron Range but of many ranges throughout the Rocky Mountains, some of them far loftier and more rugged than the Cimarron Range. They must, therefore, be among the most resistant of rocks to erosion in Rocky Mountain climates and at Rocky Mountain altitudes. Evidently, the fractures that lead to easy breakdown are open only near the surface. Farther down, most of the cracks are too tight for ground water to move and work in them, and these rocks, unlike many sedimentary rocks, have none of the connected pores between grains that allow fluids to circulate. The mantle of soil, at lower altitudes, and rubble, at higher altitudes, that forms so readily on these crystalline rocks thus simply serves to protect them.

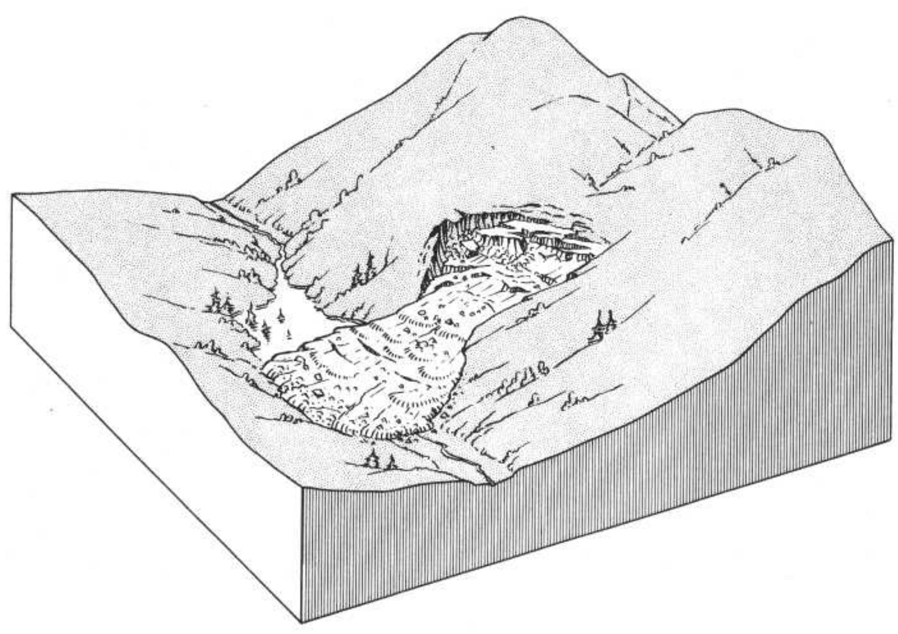
Hummocky hillsides: Fossil landslides

Something like 50 square miles of Philmont has rough, hummocky hill slopes that resemble great landslides. (But not all the area shown as landslides on the geologic map is really underlain by slides; included are some areas of rockfall and hillwash.) These are slides of the past, for they are overgrown with soil and trees. Why did they form, and when?

No landslides have been seen in motion at Philmont, but there is little doubt about what happens in most slides, for small ones are familiar events: on a steep hillside after heavy rains, or in a streambank after a flood, a scoop-shaped mass of soil and rock suddenly slides downhill as a unit (fig. 128). Its front is a wall of jumbled rock and soil; its surface is broken by concentric cracks and humps and is dimpled with depressions in which water may collect. Most landslides are small—a few tons of rock slide a few feet. In many mountainous regions, however, very large landslides often endanger or destroy lives and property. Some are shaken down by earthquakes caused by faulting or volcanic activity. Most landslides, however, seem to happen when fractured rocks or soils exposed on steep surfaces are heavily wetted for a long time. The water increases the weight of the rock and lubricates the fractures, so that the rock can no longer support its own weight and starts to slide.

Most of these conditions are met over a large part of Philmont, where there are many thick exposures of black shale that are steep because they are protected by hard caprock—dacite porphyry or sandstone (fig. 3) or basalt (fig. 45). The mere fact that black shale is soft and slippery is not enough. If it were, much of the benchlands and all the plains would be vast landslide jumbles, for black shale is at the surface or not far below. To slide, the shale evidently must be exposed so that surface water can soak in it, and it must have steep slopes so that the rock is already near the sliding point.

One condition that favors landsliding, however, is not met at Philmont. In the present semiarid climate, there is not enough moisture to keep the shale wetted for very long. This is why the slides are not very active now. They are relics of a wetter past. When was this? It was after the higher graveled plains were built, for the slides extend far lower in some places, and in others, such as around Urraca Mesa, they ride out over the plains. It was before the flood plains of the present streams were built, for several of these are cut into slides. And it was not all at once, to judge by differences in the amount of dissection of the slides. The slide



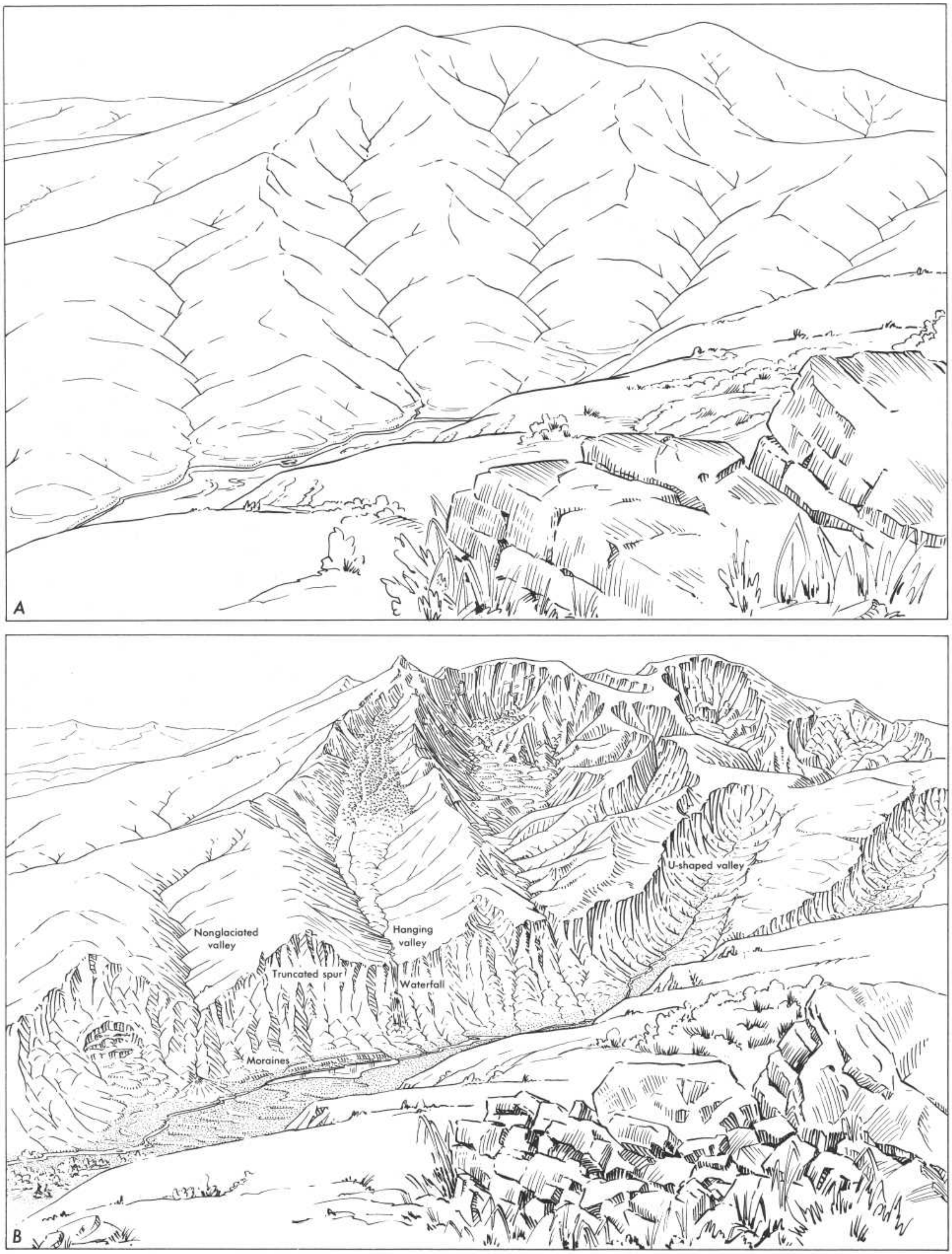
TYPICAL LANDSLIDE. A lake has formed upstream from the landslide. (Fig. 128)

CRATER LAKE. Not a crater but a water-filled depression in an undissected landslide. (Fig. 129)

areas in southern Philmont, which are beneath basalt caps, seem distinctly younger than those farther north, as they have fewer streams and many more undrained depressions. Crater Lake is a water-filled depression in an undissected landslide and is not in a crater at all (fig. 129).

The landslides, then, were moving during earlier parts of Quaternary time when the climate was much wetter. Probably this was when ice sheets were advancing from Canada over the Great Plains far to the north and east and when valley glaciers nestled between the high peaks of the Sangre de Cristo Mountains nearby to the west and north. Although there seem to have been two main times for landsliding, it does not follow that the slides all formed in two great rushes. More likely, individual slides a few hundred feet wide oozed down at the rate of a few feet a day or month with long pauses between, so that the large slide areas were growing for thousands of years. Piecemeal formation like this may not be romantic, but it is the way things usually happen in nature.

Not always with landslides, though. Some huge and catastrophically sudden ones are known. One of the largest and most destructive in modern times roared through the Swiss village of Elm in 1881. Late one September afternoon, after heavy rains, a steep quarry face cut into a slate cliff 2,000 feet high suddenly gave way, and 13 million cubic yards of rock fell 1,500 feet in less than a minute, spreading rubble 30 to 60 feet deep over a third of a square mile, destroying houses and everything else in its path, and killing 115 people. Blocks as large as 20 feet across travelled almost a mile. The average speed of the slide front was 93 miles an hour!



VALLEY SCULPTURE by a mountain glacier. A, Before glaciation. B, After the glacier melts. (Fig. 130)

Glaciers?

The landslides are among the few mementos of the Ice Age at Philmont. There are no landforms and no deposits to suggest that glaciers ever grew on the slopes of the Cimarron Range. As there are still many mountain glaciers in the world, a great deal is known about their habits, and this statement can be made with confidence.

Mountain glaciers form at the heads of streams, where they scoop out bowl-shaped depressions (fig. 130). If enough ice forms so that it overflows and moves downstream, the ice, which is not as fluid as the running water it has displaced and is a much better scouring tool, deepens and widens the originally V-shaped valley to a U shape and straightens it out by grinding off projecting rock spurs between tributaries. The tributary valleys, which are too small to support glaciers, are not deepened along with the main valley; instead, they hang high in the air, and, when the glacier retreats, their streams drop to the main valley in waterfalls. The glacier scrapes and plucks innumerable large and small chunks of rock off the valley walls and floor and carries these pieces to the glacier front, along with rocks that tumble down the valley side onto the glacier. The piles and fields of glacier-borne rock, called moraines, are left after the glacier itself melts and disappears. Other spoor left by glaciers in valleys are two kinds of lakes: rock-rimmed tarns near valley heads, where the ice has scooped out basins, and finger lakes dammed by moraines. None of these signs of glaciers appear in even the highest parts of Philmont.

Landscapes of the past

Philmont seems to have been above the sea for most of the billion or so years since the Precambrian rocks were turned to gneiss and schist. Only for 60 to 70 million years, during the Cretaceous Period, was it submerged for certain. The modern landscape started after the Cretaceous sea departed, so we have considered only a tiny fragment of Philmont's surface history.

The changing landscapes of the remote past may perhaps be as interesting as those of today, but with only bits and pieces of information to work with—the curve of an unconformity seen in a cliff, the direction of thickening or coarsening of one formation, the kinds of plants or animals buried in another—we cannot hope to reconstruct them except in the most general way.

If a landscape begins when an area emerges from the sea and ends when the sea again covers it, only one landscape and a fraction of another have existed for sure in the long history of Philmont. The first began some time before the Sangre de Cristo Formation started to form in the Pennsylvanian Period and ended with the invasion of the Early Cretaceous sea. It may have endured for hundreds of millions of years before the Pennsylvanian, or the unconformity beneath the Sangre de Cristo rocks may be all that is left of an elaborate cavalcade of alternate landscapes and seascapes. About all that can safely be said about how Philmont looked in pre-Cretaceous time is that it was mostly lower land than neighboring regions from the Pennsylvanian through the Jurassic but may often have been a highland before that.

Another way to think of landscapes is simply as surfaces of erosion on land, for landscapes are far more cut than built. Looked at this way, there have been at least half a dozen landscapes at Philmont, as every unconformity records both an erosion surface and its extinction by burial.

RESTLESS MOUNTAINS
RESTLESS PLAINS
The geologic history of Philmont

Bit by bit we have discovered the main events at Philmont during the last 300 million years, and we have collected some helpful hints about happenings in the billion years before that. Where time has been involved, we have usually worked backward. Now let's try to put the main pieces in chronological order. And, to make the story more readable, we will tell it as though we know the answers to many unanswered questions. It should be read, then, with slightly lifted eyebrows.

It will be a lively tale, but almost lifeless: living things will be ignored, except for a few vague remarks about vegetation. Surely organisms of increasing complexity have flourished at Philmont for much more than a billion years, but there is not enough local evidence on which to build a history of life at Philmont.

The first 2 to 3 billion years at Philmont—indeed, almost everywhere on the earth—are still veiled in darkness. The veil lifts briefly a billion or more years ago: layered rocks, at least some of which had been deposited in water, are folded deep within the earth and recrystallized by heat and rock pressure to become gneiss, schist, and quartzite. Some of the downfolded rocks become hot enough to melt partly and to flow upward, intruding the metamorphic rocks, and crystallize to granodiorite; in water-rich parts of the melt, crystals grow large, to become granodiorite pegmatite. The metamorphism, melting, intrusion, and crystallization take millions of years, during which much of the rock cover that supplies the metamorphic pressure is being stripped off by erosion, and the granodiorite is metamorphosed but slightly.

At Philmont the veil descends again for the rest of Precambrian time and for most of Paleozoic time. A good guess is that Philmont is land near the southeast edge of a great island for most of these 700 million years or more. In all that time, streams and other agents of erosion would surely have leveled the highest mountain range several times over; probably, then, the island does not merely sit there but is often uplifted. At other times it may sink or be eroded so low that it collects sediments, but any that collect before Pennsylvanian time are stripped away after uplifts.

By Pennsylvanian time, 300 million years ago, erosion has gone so deep that the same Precambrian rocks we now see are near the surface. Southern Philmont is part of the broad valley of a great east-flowing river and is only a few hundred feet above the sea, which laps gently on low shores not many miles to the east and south. Northern Philmont is rolling hill country. Mountains, which are fairly high but rounded and have deep red soil on the slopes between stream valleys, loom to the west. The climate is warm and damp, perhaps almost tropical, and lush low-growing vegetation abounds. Philmont is far more like present-day northern Georgia than northern New Mexico. A river laden with red-stained gravel, sand, and mud from the mountains wanders sluggishly across the valley floor in southern Philmont, dropping gravel and sand along its channel and carrying fine mud beyond to the sea. In rare floods, the river overflows its banks, leaving layers of mud on the bordering plain. In some stagnant ponds on the flood plains, calcium carbonate settles out of the water and collects as lime mud on the bottom. In other ponds, algae take up the calcium carbonate and turn it into biscuit-shaped pebbles of limestone.

This is Philmont for 80 million years, through the Pennsylvanian and Permian Periods. In southern Philmont, 5,000 feet of stream and pond deposits pile up; and finally even the high country of northern Philmont is buried by gravel and sand, out of which protrude only a few low ridges of gneiss, schist, and granodiorite. As the loose wet sediments age and are buried deeper and deeper, they gradually become the solid rocks we call Sangre de Cristo Formation.

As the Paleozoic Era ends, 230 million years ago, Philmont is part of a vast plain that is near sea level despite the great pile of sediment it has been receiving. It has been sinking about as fast as the sediments have been piling up.

If any sediments are deposited in Early Triassic time, they are soon eroded. Probably, the mountains to the west have been worn so low that they are not supplying much sediment to streams, and there is neither much deposition nor erosion at Philmont.

In Late Triassic time, 200 million years ago, the deeply weathered mountains to the west are again uplifted; streams begin again to deposit red gravel and sand on Philmont, and again limestone mud settles out of overflow ponds. Uplift in the mountains fails to keep pace with erosion, and toward the end of Triassic time the streams are depositing mostly mud and fine sand. These red sediments, which are 400 to 500 feet thick, will eventually harden into the Dockum Group. The basin of which Philmont is now a part continues to sink as sediments thicken, and at the end of the Triassic Period the Philmont plain is still near sea level, and the nearest salt water is only miles away to the east.

Through Late Triassic time the climate remains warm but becomes gradually drier. By 170 million years ago, in Early Jurassic time, the region around Philmont has probably become a coastal desert not unlike the Sahara. Desert winds and rare rainstorms begin sweeping fine sand and clay from the bare and still loose upper part of the Dockum Group; but any deposits they make in Early Jurassic time they soon destroy. In later Jurassic time, however, winds and floods pile up about 50 feet of dunes and layers of nearly pure quartz sand on the desert floor; these are not destroyed but become the Entrada Sandstone. Then the mountains to the west again rise; the climate grows damper, and streams again start dumping red mud and sand on Philmont; and once more limestone starts forming in overflow ponds. By the end of the Jurassic, 135 million years ago, 400 feet of these sediments, which will become the Morrison Formation, has collected.

For at least 150 million years, Philmont has been sinking more often than rising but has stayed a little above the sea. Now, in Early Cretaceous time, it sinks a little faster than streams can build it up, the sea washes over it, and Philmont becomes a tidewater beach. Waves and currents pick up small fragments, mostly of clay and mica, and carry them offshore and dump them in mud banks. The sand remains on the beach, washed and winnowed many times by waves and, in places, piled up into dunes by winds. After 50 feet of beach and dune sands accumulates, the sea advances westward, and so does the line of coastal dunes. Philmont itself is covered by deeper water; the sand is buried by mud carried from the land. Once more the sea retreats; Philmont is again a tidal beach whipped by winds, and another layer of mixed beach and dune sand grows. The two sand layers and the muds between will eventually become the sandstone and shale of the Dakota Sandstone, 100 to 200 feet thick.

Again, Philmont sinks faster than the sediments thicken, and in Late Cretaceous time the sea again advances, this time far to the west, leaving Philmont under shallow salt water for many millions of years, long enough for several thousand feet of offshore deposits to pile up, mostly black clay mud washed off lowlands far to the west. Now and then, clouds of light-colored ash from volcanoes still farther west shower on the water and settle to the sea floor. In quiet waters bypassed by muddy currents, pods and thin layers of lime mud grow. The clayey and ashy mud deposits harden to become the Graneros, Carlile, Niobrara, and Pierre Formations, together more than 3,000 feet thick; widespread lime-mud layers above the Graneros Shale solidify to become the Greenhorn Limestone, about 30 feet thick, and others above the Carlile Shale become the Fort Hays Limestone Member, about 50 feet thick.

Then, 100 million years ago, in very late Cretaceous time, land reappears to the west, and the sea starts retreating eastward. Philmont becomes part of the seashore again and is covered by 100 feet of sand brought by streams from the new land and spread by waves and current along the beach—the Trinidad Sandstone.

The sea now oscillates rapidly across Philmont as the land to the west is worn down to a plain. When the shoreline moves east, Philmont is a maze of coastal swamps and lagoons in which brown mud and masses of partly decayed vegetation gather; when Philmont is in the shore zone, layers of sand pile up. Thus form the yellow and gray sandstone, brown shale, and coal of the Vermejo Formation, more than 150 feet thick.

A bit more than 70 million years ago, just before the end of the Cretaceous Period, the land to the west rises abruptly, and western Philmont rises with it. The sea retreats eastward, never to return. The retreating sea and the new streams that start flowing eastward down the tilted surface strip the Vermejo and Trinidad rocks off western and southern Philmont. Then the streams blanket most of Philmont with gravel as sinking to the east creates the Raton basin and reduces stream gradients.

As late Cretaceous time passes imperceptibly into early Tertiary time, the main range to the west keeps rising fast enough to supply coarse gravel as well as finer debris to east-flowing streams; but continued sinking east of Philmont leads to poor drainage and swampy conditions in northeastern Philmont. Philmont now lies between a rising range on the west and a foundering basin on the east. The mountain streams dump their gravel and coarse sand in western Philmont, and their fine sand and mud in swampy eastern Philmont and beyond. The climate is still warm and wet, and low eastern Philmont is a green jungle, something like the Everglades of Florida. Matted piles of partly decayed vegetation become peat and are buried by mud as the shifting streams overflow. In this way the Poison Canyon Formation grows on the west at the same time as the Raton Formation grows on the east. After especially rapid uplifts on the west, tongues of coarse Poison Canyon rocks reach far out into the basin; when uplift is especially slow, layers of fine-grained Raton rocks reach far west. As early Tertiary time goes by, the climate turns drier, and the Raton basin ceases to be a swamp, after 1,500 feet of Raton Formation has accumulated in northeastern Philmont. But the main range of the Sangre de Cristo Mountains keeps rising and shedding coarse Poison Canyon sediments that finally become more than 2,000 feet thick and bury all of Philmont.

For a while Philmont is again a low rolling plain crossed by a few sluggish streams. It is less than a thousand feet above the sea but is hundreds of miles from the nearest salt water.

Now comes the birth of the Cimarron Range. A gigantic block of Precambrian metamorphic rocks, stretching southeastward from the ancestral Sangre de Cristo Mountains into western Philmont, begins to rise. It arches the sedimentary rocks above it, crumples and in places breaks through those on its sides, and sends waves of folds outward. Magma begins to rise along cracks and faults, especially at the margins of the rising block. The magma creeps between the sedimentary rocks in some places, spreading them apart; in other places it squeezes the soft sediments out. Soon the cover and flanks of the rising arch are laced with sills and dikes of dacite porphyry and andesite. Far out on the flanks a different kind of molten rock is rising up cracks, to freeze into lamprophyre; or perhaps the lamprophyre is intruded somewhat later. Though it is still rather early in Tertiary time, the Cimarron Range has developed the geologic structure it has today. It may, too, be a mountain range like that of today, though uplift may be slow enough for erosion to keep the mountains low. On the rising arch, streams form a radial drainage pattern and begin carrying rock debris to the sea.

For a while the range is simply part of the eastern foothills of the nobler range to the west, but then a series of north-trending faults drop a long tract of country to form ancestral Moreno Valley, which drains to the south. The Cimarron Range becomes, as it still is, a rocky peninsula jutting southeast from the Sangre de Cristo Mountains. Now the streams, deprived of their headwaters and of much of their fall by the creation of Moreno Valley, begin wandering back and forth, dropping their burdens, until Philmont is covered by a thick blanket of sand and gravel. Once again it is a lowland plain probably no more than 2 to 3 thousand feet above sea level; vestiges of this plain may still be preserved as the Park Plateau.

Near the end of the Tertiary, the pace of deformation, and therefore of erosion, quickens. The range starts rising again, and the streams, refreshed, begin stripping off the loose sand and gravel blanket and digging into the solid rocks beneath. In southern Philmont, and beyond to the south and west, volcanoes erupt. Lava fills many shallow valleys and then piles up in broad sheets that spread a little way out on the plains south of Philmont to form the Ocaté Plateau. Lava also dams the southern outlet of Moreno Valley.

Streams in northern Philmont, and those which quickly grow in the volcanic rocks of southern Philmont as volcanic activity wanes, probably empty into an ancestor of the Canadian River that flows southwestward into Philmont near where Cimarron will be, swings westward in a broad arc, and then swings eastward to skirt the base of the lava-capped Gonzalitos Mesa.

As the range rises several thousand feet, a little at a time, the plains to the east rise with it, but not as much, so that the old plateau surfaces are tilted eastward. The east-flowing streams, gaining strength from steepening slopes and from increased water supply as the mountains rise high enough to become cloud barriers, rapidly deepen their canyons and extend themselves back into the range; Cimarron Creek nibbles away at the range until it cuts through and captures the waters of Moreno Valley. Meanwhile, the Canadian River, in response to repeated uplifts on the west, keeps shifting eastward and building new, successively lower flood plains on the soft Cretaceous shales; changing Quaternary climates, as Ice Ages come and go, may also cause shifts between downcutting and flood-plain building. The remnants of these abandoned flood plains make up the present Las Vegas Plateau.

During long wet spells in early Quaternary time, soft shale exposed in deep streamcuts at plateau fronts in central and southern Philmont becomes saturated and slides in scoop-shaped masses toward the plains, carrying chunks of sandstone or basalt with it, until 50 square miles is covered by hummocky landslides.

Beyond the flood plains and the landslides, varied rocks and structures have gradually been exposed by stripping off of the loose Tertiary gravel and are controlling the shapes of the land forms being sculptured, mainly by gravity and sheetflow. Steeply dipping dikes, sills, and hard sedimentary rocks become narrow ridges; alternate hard- and soft-layered sedimentary and volcanic rocks that have low dips become steepsided benchlands; intricately fractured metamorphic rocks in the range core are chopped into narrow canyons and ridges.

Today, the range is higher and more rugged than it has ever been. Even if the crust beneath stays quiet, the range will loom above the plains for many thousands of years. It will become ever more deeply sculptured, until the range crest itself is attacked; then it will gradually be worn lower and rounder. If the recent past is any guide, though, the earth beneath Philmont will remain restless and the range will continue to rise, and the bordering plains with it, creating even grander vistas for our remote descendants to wonder at and enjoy. It is probably rising at this moment . . . . .

INDIAN WRITINGS from canyon of North Ponil Creek. (Fig. 131)

EXIT WONDERING

Our four-dimensional tour of Philmont is over. We have seen and said much, but it still is only a beginning. If Philmont is well thought of as a cake, we have seen the layers and sampled the icing, but we could not begin to write the recipe. We have a fairly good idea of what happened in the last 300 million years on the surface and for a few miles beneath, and we have some broad hints about the billion years before that; but we have very little idea of why any of these things happened.

Take, for instance, a sand grain in Cimarron Creek. It is easy to decide that it is there because the water, flowing downhill under the pull of gravity, was able to pick it up from a weathered outcrop and move it; using a little imagination, we can even predict that the lofty Cimarron Range may finally be worn down to a monotonous plain by this process. But we have made few observations of exactly how debris is supplied to streams and other transporting agents, and how the erosion process really works; we have given little thought to the marvelous interplay of climate, rock type, structure, and time that control the nature and history of streams.

Why is the Cimarron Range there in the first place? To say that the mountains were tilted or folded or faulted up describes what happened but not why. Why do parts of the earth's crust rise against the pull of gravity? And, once risen, how can tall mountains like the Cimarron Range loom above the plains for many millions of years when the rate of erosion suggests that they should be leveled in a few million years? Some mountains must keep rising as they are eroded—why? On the other hand, all mountains do not rise indefinitely—if they did, the sedimentary cover would have long since been stripped from all of them, as it is beginning to be stripped from the Cimarron Range. Why do they stop rising?

And what of our sand grain and its neighbors, worn and washed off the mountains? How is it that sediments can become thousands of feet thick below a mere film of water on a river flood plain or in shallow waters no more than a few hundred feet deep on the ocean rim? Parts of the earth's crust must sink as sediments accumulate, just as neighboring parts rise—why? Why did Philmont stand a little above or a little below the sea for most of the several hundred million years of Paleozoic and Mesozoic time and then get caught up in a spasm of crumpling and faulting in its western part in early Tertiary time? Why did the rest of it not crumple too? And why, after the crumpling stopped, did the mountains, and plains too, rise thousands of feet almost straight up in later Tertiary and Quaternary time?

While we are asking embarrassing questions about earth movements, we might try to ask a few about the dacite porphyry and other igneous rocks that invaded the Philmont cake during the main time of folding. Perhaps these rocks were produced by folding sediments down so deeply and compressing them so much that they melted enough to flow. But if this is so, where are the Tertiary metamorphic rocks that should have formed at earlier stages in the same process? Still buried? Or are these igneous rocks brand new, from melts that have never been at the surface before? If this was their first trip through the metamorphic cycle, had they been liquid ever since the earth formed (and when was that?) or were they solid through most of geologic time until something happened (what?) to melt them and force them toward the surface in early Tertiary time? No matter how they formed, how did these sticky liquids make room for themselves, if they did not melt the solid rocks above? How did they get so different in their makeup and appearance, to end as dacite porphyry and andesite, basalt, and lamprophyre? And how do the gold and copper deposits fit into the story?

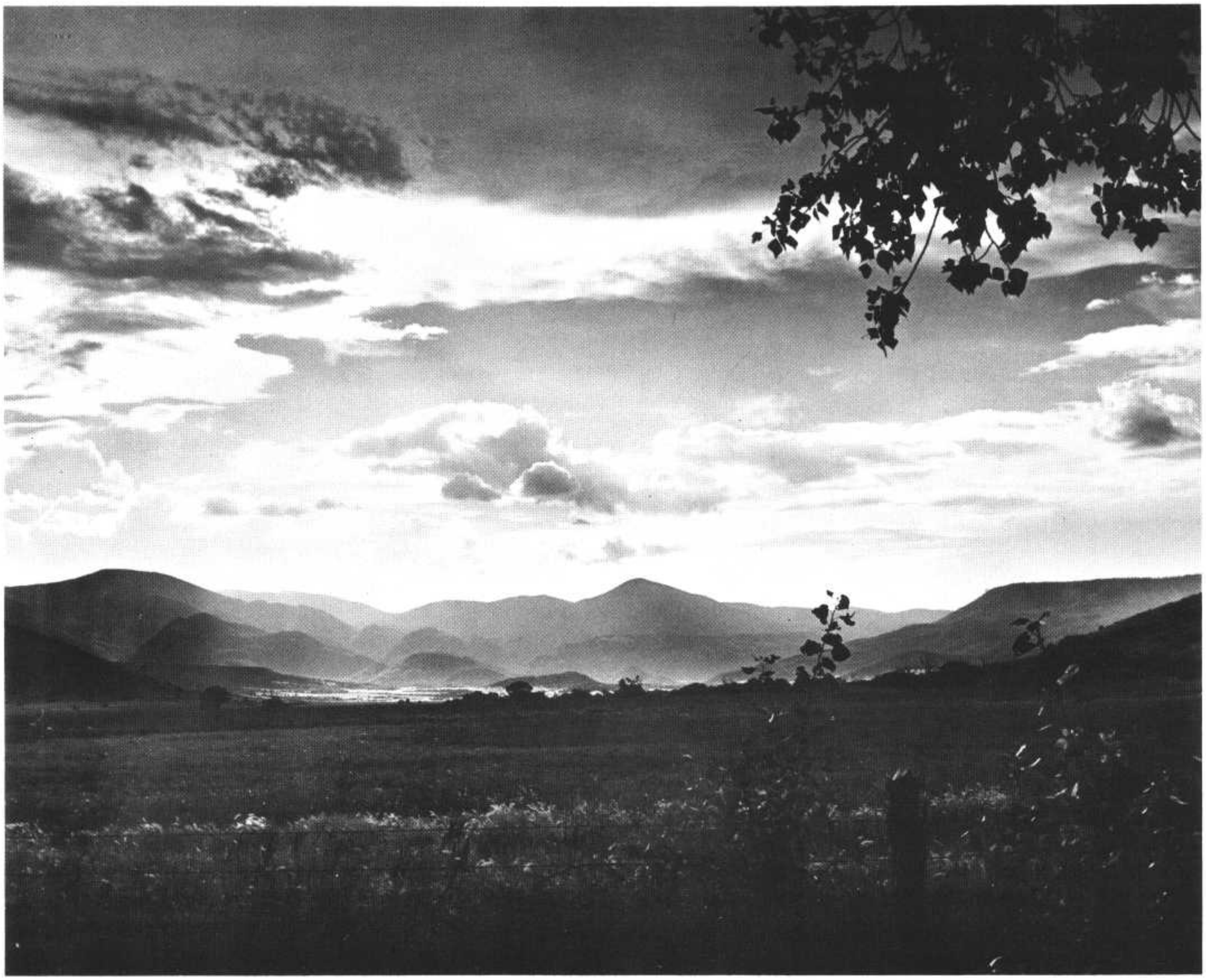
We have paid little attention to perhaps the most fascinating part of geology—the geology of living things. Why and how do new forms of plants and animals develop? Why do animals and plants become extinct? Do changes in surface conditions, such as retreats and advances of the sea or changes of climate, have anything to do with the rise and extinction of plant and animal species?

In this book we have not tried to answer any of these hard questions, although in the century and a half since geology came to be recognized as a science, convincing explanations have been carefully worked out for some of them and for many others that arise whenever a bit of the earth is looked at thoughtfully. A visit to the stacks of a large geological library gives an idea of what is known about geology and related sciences. Millions of books and articles about geological subjects have been printed, and thousands are added each year.

But there is so much more to learn! Only a few percent of the earth's land surface has been mapped even in the same crude detail as Philmont. The earth is nearly 8,000 miles across, but the deepest man has himself gone is less than 2 miles below sea level on land and less than 8 miles at sea. The deepest he has probed by drilling is less than 6 miles below sea level. He had explored only a tiny fraction of the sea and its floor, and the sea covers more than two-thirds of the earth's surface.

Man's personal sample of geologic time is even smaller than his sample of geologic space. His most ancient writing with the faintest geologic flavor—the drawings of animals made by Cro-Magnon man in the caves of southern France—take us back no more than 10,000 years, and continuing reliable records of geologic phenomena—such as sea and land levels, climate, streamflow—have been made only for a few decades and in a few places.

With so much of the earth unknown, it is not surprising that geologists have not reached agreement about all the processes going on near the surface or about some of the more difficult questions of deeper structure, earlier time, and fundamental causes. This is what keeps geology exciting as well as useful. If you want to go further into what geologists have done and thought, a world of stimulating and entertaining literature awaits you in practically any library. Books you might start with are listed on the next page.



THE SUN SETS behind the Cimarron Range. View from State Highway 21 near Scout Ranch Training Center. (Fig. 132)

SUGGESTED READING

General geology and geophysics

GEOLOGY, C. L. Cooper and others, New Brunswick, N.J., Boy Scouts of America, 1953. Merit badge series.

MODERN EARTH SCIENCE, by W. L. Ramsey and R. E. Burckley. New York, Holt, Rinehart, and Winston, 1961. 630 p. High school text.

EARTH SCIENCE, THE WORLD WE LIVE IN, by S. N. Namowitz. 2d ed. Princeton, N.J., Van Nostrand, 1960. 614 p. High school text.

DOWN TO EARTH: AN INTRODUCTION TO GEOLOGY, by C. G. Croneis and W. C. Krumbein. Chicago, University of Chicago Press, 1936. 499 p. Paperback; easy college text.

PHYSICAL GEOLOGY, by L. Don Leet and Sheldon Judson. 2d ed. New York, Prentice-Hall, 1958. 502 p. Detailed college text.

PRINCIPLES OF GEOLOGY, by James Gilluly, A. C. Waters, and A. O. Woodford. 2d ed. San Francisco, Freeman, 1959. 534 p. Detailed college text.

THE PLANET EARTH, by the Editors of "Scientific American." New York, Simon & Schuster, 1957. 176 p. Paperback; on the forces that stir the earth's crust, oceans, and atmosphere.

A PRIMER ON WATER, by L. B. Leopold and W. B. Langbein. Washington, U.S. Government Printing Office, 1960. Paperback.

Landscape and seascape geology

GEOMORPHOLOGY: AN INTRODUCTION TO THE STUDY OF LANDSCAPES, by A. K. Lobeck. New York, McGraw-Hill, 1939. 731 p. Splendidly illustrated college text.

THIS SCULPTURED EARTH: THE LANDSCAPE OF AMERICA, by J. A. Shimer. New York, Columbia University Press, 1959. 255 p. Non-technical account of the origins of our scenery.

GLACIAL AND PLEISTOCENE GEOLOGY, by R. F. Flint. New York, John Wiley & Sons, 1957. 553 p. College text.

MOUNTAINS, by L. J. Milne and Margery Milne. New York, Time, Inc., 1962. 192 p. (Life Nature Library.)

THE DESERT, by A. S. Leopold. New York, Time, Inc., 1961. 192 p. (Life Nature Library.)

THE EARTH BENEATH THE SEA, by F. P. Shepard. Baltimore, Johns Hopkins Press, 1959. 275 p.

THE SEA AROUND US, by Rachel L. Carson. New York, Oxford University Press, 1951. 230 p.

VOLCANOES; IN HISTORY, IN THEORY, IN ERUPTION, by F. M. Bullard. Austin, University of Texas Press, 1962. 441 p.

History of the earth and its life

BIOGRAPHY OF THE EARTH; ITS PAST, PRESENT, AND FUTURE, by George Gamow. Rev. ed. New York, Viking, 1959. 242 p. Paperback.

THE EVOLUTION OF LIFE, by F. H. T. Rhodes. Baltimore, Penguin Books, 1962. 304 p. Paperback.

THE FOSSIL BOOK; A RECORD OF PREHISTORIC LIFE, by C. L. Fenton and M. A. Fenton. Garden City, N.Y., Doubleday and Co., 1958. 482 p.

FOSSILS, by F. H. T. Rhodes and others. New York, Golden Press, 1962. Paperback.

FOSSILS; AN INTRODUCTION TO PREHISTORIC LIFE, by W. H. Matthews. New York, Barnes & Noble, 1962. 337 p. Paperback

LIFE OF THE PAST; AN INTRODUCTION TO PALEONTOLOGY, by G. G. Simpson. 2d ed. New Haven, Yale University Press, 1961. 198 p. Paperback. Easy college text.

DINOSAURS, THEIR DISCOVERY AND THEIR WORLD, by E. H. Colbert. New York, Dutton, 1961. 300 p.

MANKIND IN THE MAKING; THE STORY OF HUMAN EVOLUTION, by W. W. Howells. Garden City, N.Y., Doubleday, 1959. 382 p.

Rocks and minerals

ROCKS AND MINERALS, by H. S. Zim and Paul Shafer. New York, Golden Press, 1957. 160 p. Paperback. Many colored pictures.

THE ROCK BOOK, by C. L. Fenton. New York, Doubleday, 1940. 357 p. Well-illustrated general book.

GETTING ACQUAINTED WITH MINERALS, by G. L. English and D. E. Jensen. 2d ed. New York, McGraw-Hill Book Co., 1958. 362 p.

A FIELD GUIDE TO ROCKS AND MINERALS, by F. H. Pough. 3d ed. Boston, Houghton Mifflin, 1960. 349 p.

For further information

EARTH FOR THE LAYMAN, by M. W. Pangborn, Jr. Washington, American Geological Institute, 1957. 68 p. (AGI report 2, 2d ed.). $1.00. A list of nearly 1,400 good books and pamphlets of popular interest on geology, mining, oil, maps, and related subjects, arranged by subject or area, and provided with notes indicating interest level and contents.

You may also wish to write to your State Geological Survey or to the U.S. Geological Survey, Washington, D.C., 20242, for further information on your own State, and to the American Geological Institute, 1444 N St., N.W., Washington, D.C. 20005, for information on geological careers and education.

ABOUT THIS BOOK

This book is an outgrowth of a regional study of the mineral-fuel resources of the Sangre de Cristo Mountains, a project under the direction of C. B. Read. A. A. Wanek and Read had planned to write a popular account of Philmont geology themselves and had made a start by preparing a geologic reconnaissance map of the Philmont quadrangle in 1956–57. By late 1957, however, it had become clear that other obligations would prevent their writing the text.

Encouraged by R. Maurice Tripp, then chairman of the Boy Scout Committee of the American Association of Petroleum Geologists, G. D. Robinson volunteered to complete the project. The geologic map made by Wanek and Read and a brief technical file report on the area by Wanek were generously turned over to Robinson. The map and report constitute the factual base for much of this book; indeed, the book could not exist without them. In addition, Read and Wanek spent several days at Philmont with Robinson, providing an invaluable introduction to the area and its geologic problems.

Because the primary interest of Read and Wanek was in the fuel resources, their work emphasized the sedimentary rocks. Assisted by W. H. Hays and M. E. McCallum, Robinson spent the summer of 1958 at Philmont, refining and modifying their map in the areas of igneous and metamorphic rocks and collecting representative specimens of all rocks for laboratory study. Dan Hawkins also assisted briefly in 1958. Their stay at Philmont was facilitated by the generosity and cooperation of the Boy Scouts of America. Special mention must be made of the aid and encouragement of Ray H. Bryan, Assistant to the Chief Scout Executive, and of Jack L. Rhea, Director of Camping. Several residents of Cimarron, particularly J. W. Leitzell and William Brewster, supplied valuable aid and information, as did Mr. Richard Atmore, of Atmore Brothers Ranch, and Mrs. Doris L. Atmore, Postmaster at Ute Park.

During the summer, E. F. Patterson, Staff Photographer, joined the group for several days; and J. R. Stacy, Scientific Illustrator, accompanied them for several weeks. Patterson and Stacy each took photographs that were invaluable in preparing this volume; most of the photographs which illustrate it are theirs. In addition, Stacy made many on-the-scene sketches.

During the winter of 1958–59, Hays studied more than 200 thin sections, to provide the main basis for the descriptions of igneous and metamorphic rocks. McCallum spent several weeks at Philmont in 1959, further refining the geologic map of the flanks of Touch-Me-Not Mountain and of the northwest corner of Philmont.

Thus, essentially all the basic data for this book were in Robinson's hands by the fall of 1959. Owing to the press of other duties, however, the writing was not completed until the winter of 1962. During this part of the task, Alfred Clebsch, Jr., and S. W. Lohman assisted materially in the preparation of the sections on ground water. Concurrently, Stacy worked on the diagrams and sketches; assisted by E. P. Krier and Anthony Denson, he also prepared the final photographic copy. Credit for the individual photographs has been given in the list of illustrations.

The reading list in the preceding chapter was prepared with the help of Mark W. Pangborn, Jr., of the Geological Survey Library.

Peter W. Lenz, of Wheat Ridge, Colo., an Eagle Scout who recently spent a summer at Philmont, read the manuscript, and many members of the Geological Survey reviewed part or all of it. It has profited much from their suggestions.

Except for casual mention by naturalists attached to early armies of exploration and surveys of the West, Philmont was bypassed by geologists until the start of this century. Then, L. C. Graton briefly examined the gold deposits and prospects in the Baldy district and on Cimarroncito Creek. During and just after World

War I, W. T. Lee intensively studied the coal-bearing rocks in northern Philmont. He also examined the Aztec gold mine near Baldy. In 1941, J. F. Smith, Jr., and L. L. Ray made a geologic reconnaissance of the Cimarron Range, as a sequel to their study of Moreno Valley in 1939.

The main publications resulting from the previous work are:

Graton, L. C., 1905, Colfax County, *in* Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68.

Lee, W. T., 1916, The Aztec gold mine, Baldy, New Mexico: U.S. Geol. Survey Bull. 620–N, p. 325–330.

Lee, W. T., and Knowlton, F. H., 1917, Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U.S. Geol. Survey Prof. Paper 101, 450 p.

——— 1922, Description of the Raton, Brilliant, and Koehler quadrangles, New Mexico–Colorado: U.S. Geol. Survey Geol. Atlas, Folio 214, 17 p., 2 sheets, illustrations, 10 maps.

——— 1924, Building of the southern Rocky Mountains: Geol. Soc. America Bull., v. 34, no. 2, p. 285–300.

Ray, L. L., and Smith, J. F., Jr., 1941, Geology of the Moreno Valley, New Mexico: Geol. Soc. America Bull., v. 52, no. 2, p. 177–210.

Smith, J. F., Jr., and Ray, L. L., 1943, Geology of the Cimarron Range, New Mexico: Geol. Soc. America Bull., v. 54, no. 7, p. 891–924.

To make this book more palatable to the casual reader, the trappings of scholarship that customarily adorn more technical writings have been omitted. The main omission has been of references. Yet it must be plain that this book, far more than most technical reports, depends on the work and thoughts of others; to far more than the customary degree, the local information presented, and its interpretation, had to be borrowed from the colleagues and predecessors named above. A search of their cited works will reveal the extent of indebtedness—as well as occasional differences of opinion. For another thing, this volume offers a host of general geologic concepts, and many examples from beyond Philmont, that could not possibly arise from any writer's direct experience. They are part of the common property of geology; they normally would not be documented in technical reports and are not further supported here. It seems appropriate, however, to document certain borrowed observations and ideas that are neither common property nor published in the works already listed. Their sources are listed below, in their order of appearance in the text.

Scattered statements about human history, such as Coronado's march and the founding of Cimarron

Federal Writer's Project, 1953, New Mexico: Hastings House, New York.

Production of gold, iron and gravel

U.S. Bureau of Mines, 1960, Mineral facts and problems: Bull. 585.

Resemblance of Halymenites to filled crab burrows

Weimer, R. J., and Hoyt, J. H., 1961, *Callianassa major* burrows, geologic indicators of littoral and shallow neritic environments: Geol. Soc. America Spec. Paper 68, p. 321.

Rank and quality of Philmont coal

Lee, W. T., 1924, Coal resources of the Raton coal field, Colfax County, New Mexico: U.S. Geol. Survey Bull. 752, 254 p.

Age of Precambrian rocks in Colorado Front Range

Aldrich, L. T., and others, 1958, Radioactive ages of micas from granitic rocks by Rb–Sr and K–A methods: Am. Geophys. Union Trans., v. 39, no. 6, p. 1130.

Phair, George, and Gottfried, David, 1958, Laboratory data on the age of the Precambrian batholithic rocks and skarn deposits of the Colorado Front Range [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1739.

Giffen, C. E., and Kulp, J. L., 1960, Potassium-Argon ages in the Precambrian basement of Colorado: Geol. Soc. America Bull., v. 71, p. 219–222.

Radioactivity dates in table on page 93

Holmes, Arthur, 1960, A revised geological time scale: Edinburgh [Scotland] Geological Society, v. 17, pt. 3, p. 183–216.

Faul, Henry, 1961, Geologic time scale: Geol. Soc. America Bull., v. 71, p. 637–644.

Thick Tertiary gravels north of Philmont

Johnson, R. B., 1961, Coal resources of the Trinidad coal field in Huerfano and Las Animas Counties, Colorado: U.S. Geol. Survey Bull. 1112–E, 180 p.

Pre-Pennsylvanian strata in surrounding regions

G. H. Dixon, oral communication, 1962.

W. W. Mallory, oral communication, 1962.

G. H. Bachman, oral communication, 1962.

Measuring dip and strike

Gilluly, James, Waters, A. C., and Woodford, A. O., 1959, Principles of geology: 2d ed., San Francisco, Freeman, p. 91–92.

Possible underthrust origin of the Precambrian core of the Cimarron Range

C. B. Read, oral communication, 1958.

The Elm landslide

Gilluly, James, Waters, A. C., and Woodford, A. O., 1959, Principles of geology: 2d ed., San Francisco, Freeman, p. 178–179.