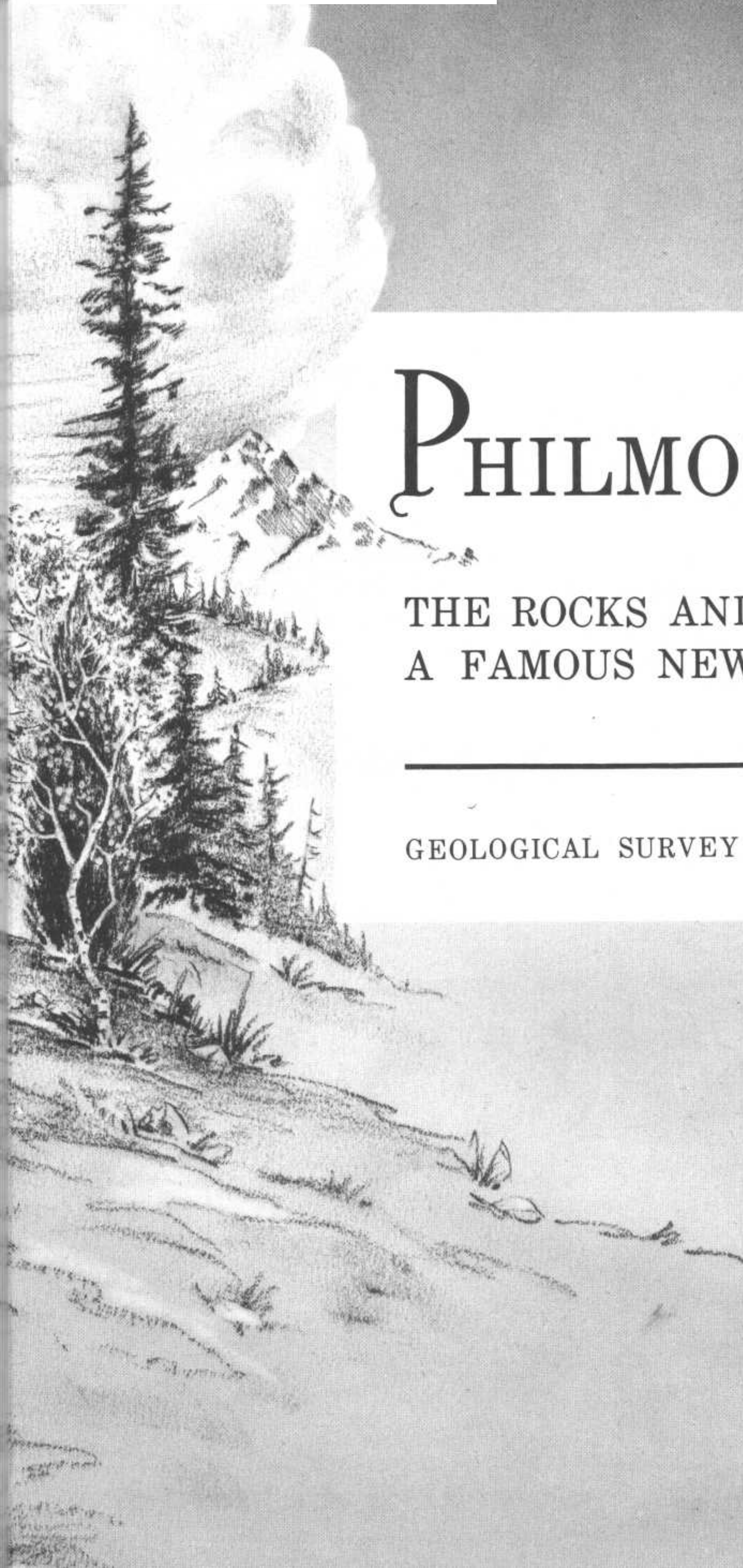

PHILMONT COUNTRY

THE ROCKS AND LANDSCAPE OF A FAMOUS NEW MEXICO RANCH

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a million square miles in the interior United States and Canada. Everywhere, it has beds of altered ash like these. Thin as they are, they add up to many cubic miles of volcanic dust and tell of tremendous eruptions somewhere to the west. The volcanoes themselves, however, no longer stand, and nó remains of them have yet been found.

Gray limestone

Tan- or white-coated low ledges of gray limestone rise gently above the sand-gravel blanket in the plains south of Philmont Ranch Headquarters and stand out on the sides of several benches. Limestone can easily be seen along the north side of the trail along South Fork Urraca Creek above the turnoff to Stone Wall Pass (fig. 30*A*) and on the Rayado Creek Trail at the entrance to New Abreu Base Camp (fig. 30*B*). The rock, in beds a foot or two thick, seems very hard and tough, but it is readily broken with a hammer and easily scratched with any knife blade. Like the shale that is interbedded with it, the limestone is very fine grained. Through a microscope, the limestone is seen to be composed mainly of tiny grains of calcite surrounded by the same materials that are common in the dark shale—clay, mica, quartz, and organic debris (fig. 30*C*). (The limestone specimen in fig. 30*C* is very impure; other parts of the same layer are practically pure calcite in tightly packed crystals and pellets.) Here and there, as in the shale, are fossilized remains of oysters, clams, snails, and ammonites.

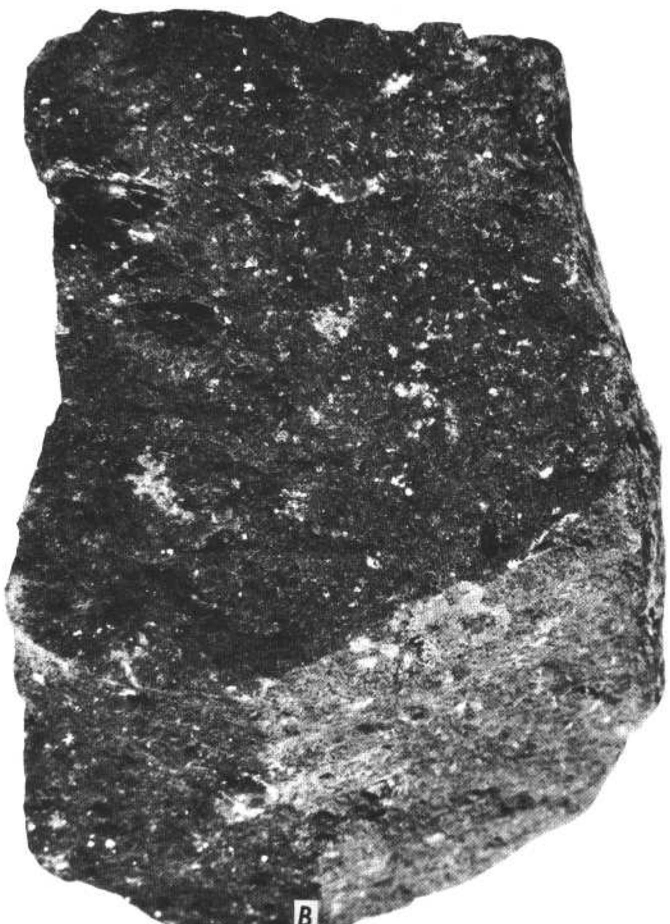
The limestone must have formed in somewhat the same way as did the shale—that is, as a sediment on the sea floor. But the calcite, unlike the clay, mica, and quartz, is not bits of older rocks washed in from the land. Calcite (calcium carbonate) is soft and is much more soluble than other common minerals in ordinary surface water (dissolved calcite is the main cause of "hard" water). Limestone does not, therefore, survive much stream transport or wave washing. So the calcite particles must have formed by some sort of chemical action not far from where they are now. Where inflowing streams and the activity of marine life supplied more calcium carbonate than the sea water could keep dissolved, some of the calcium carbonate was precipitated as crystals or as droplike groups of minute crystals to make a kind of calcite mud. Part of the calcium carbonate also went into the bodies of plants and animals, and fragments of these also sank into the mud. Later, the mud was buried by other sediments and was dried and compressed by their weight into limestone.

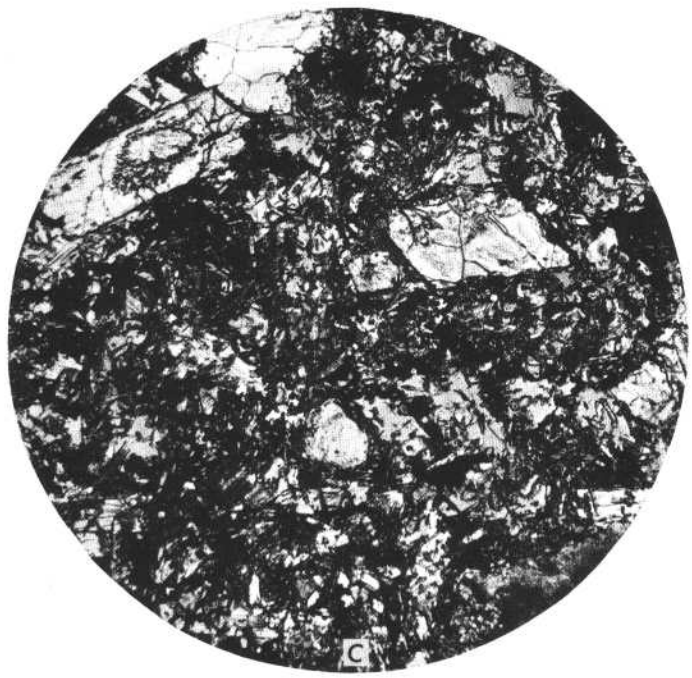
Limestone muds that may some day become rocks like these are forming in many parts of the ocean, where they are not diluted by too much debris from the lands—for example, in the shallow water on the Bahama banks, in the Pacific coral islands, and also at many places on the deeper ocean floor.

Dark mica-rich lamprophyre

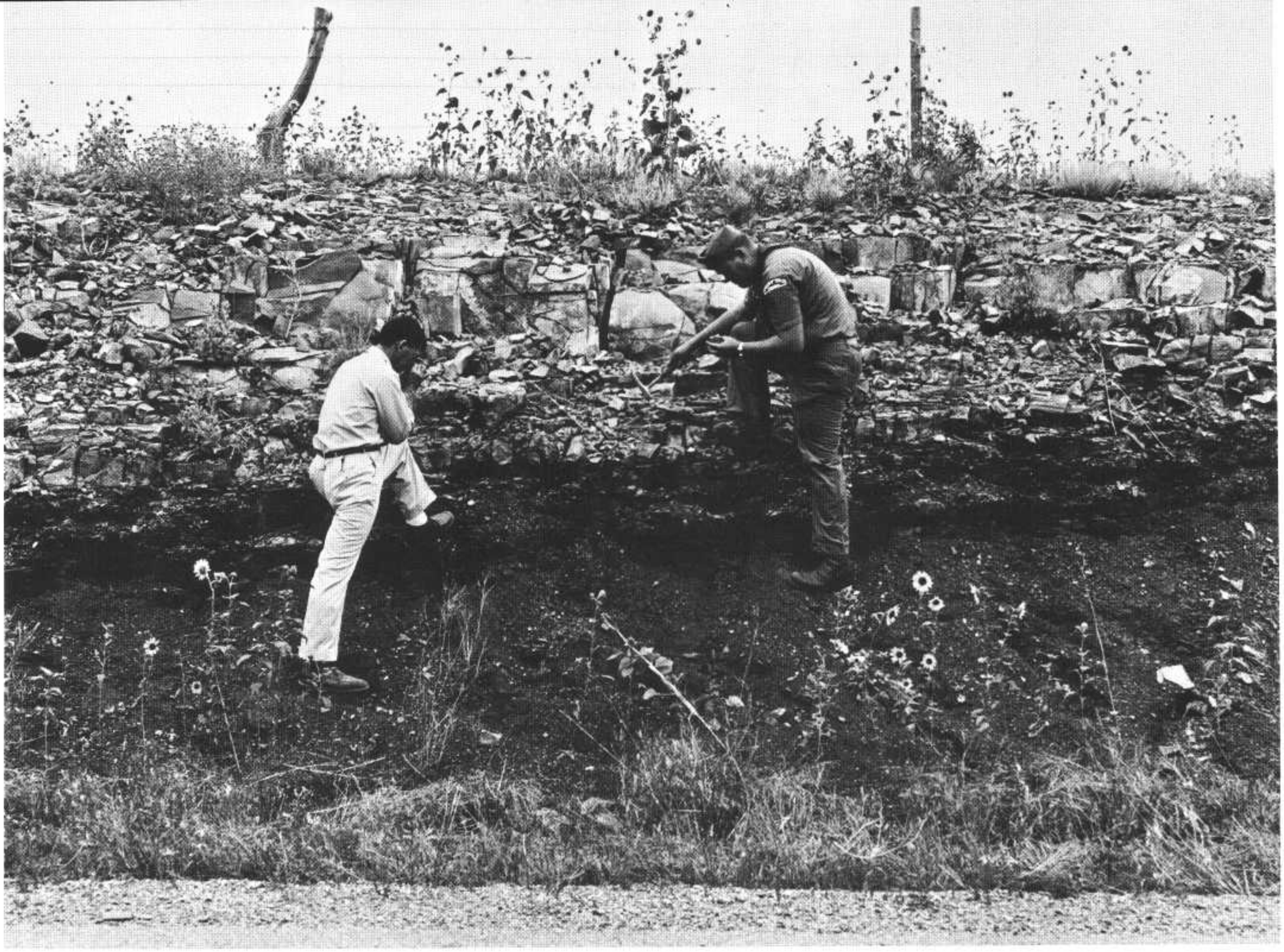
Lamprophyre, a rare rock the world over, is fairly common on the plains of Philmont. It is best seen at the southern edge of Horse Ridge, 1.2 miles northwest of Scout Ranch Headquarters on the north side of the trail to Cimarroncito Base Camp (fig. 31). The lamprophyre in Horse Ridge is a coarse-grained greenish- to brownish-black rock that looks like it is made wholly of closely packed flakes of glittering brown biotite mica (fig. 31). Through a microscope, however, it can be seen that the rock actually is less than half biotite—part of it in large crystals, and part in small crystals—and that the rest is mostly small crystals of green pyroxene intergrown with the biotite and with a little magnetite and calcite (fig. 31). The grains of these minerals are not rounded, as they would be if they had been washed in by water, but have the sharp corners and edges of crystals. Packed tightly together, they look as though they all grew at about the same time, although the large biotite crystals may have had a head start. Besides having crystals instead of rounded grains, this rock contains no quartz or clay or organic remains like the surrounding shale or the limestone does. Furthermore, it is not layered in the shale but is a vertical sheet 6 to 8 feet thick that cuts across the bedding (see figs. 110, 116).

The lamprophyre is not a sedimentary rock that settled out of running or standing water. Instead, it rose as a thick hot melt from inside the earth and oozed into fractures in the already solid shale. Upon cooling, it crystallized like fudge or sugar. The blocks that show so well in figure 31*A* are the result of shrinkage due to cooling. Rocks of this sort, which cooled from a melt, or magma, are called igneous rocks. A very large part of the rocks at Philmont formed from the freezing of rock melts, but most of them are very unlike the lamprophrye in appearance and in mineral content. Most of them, however, are like the lamprophyre in having two generations of minerals—an earlier formed set of large crystals, called phenocrysts, held in a later formed base of smaller crystals or of glass, which is molten rock that cooled so quickly that no crystals had time to form. An igneous

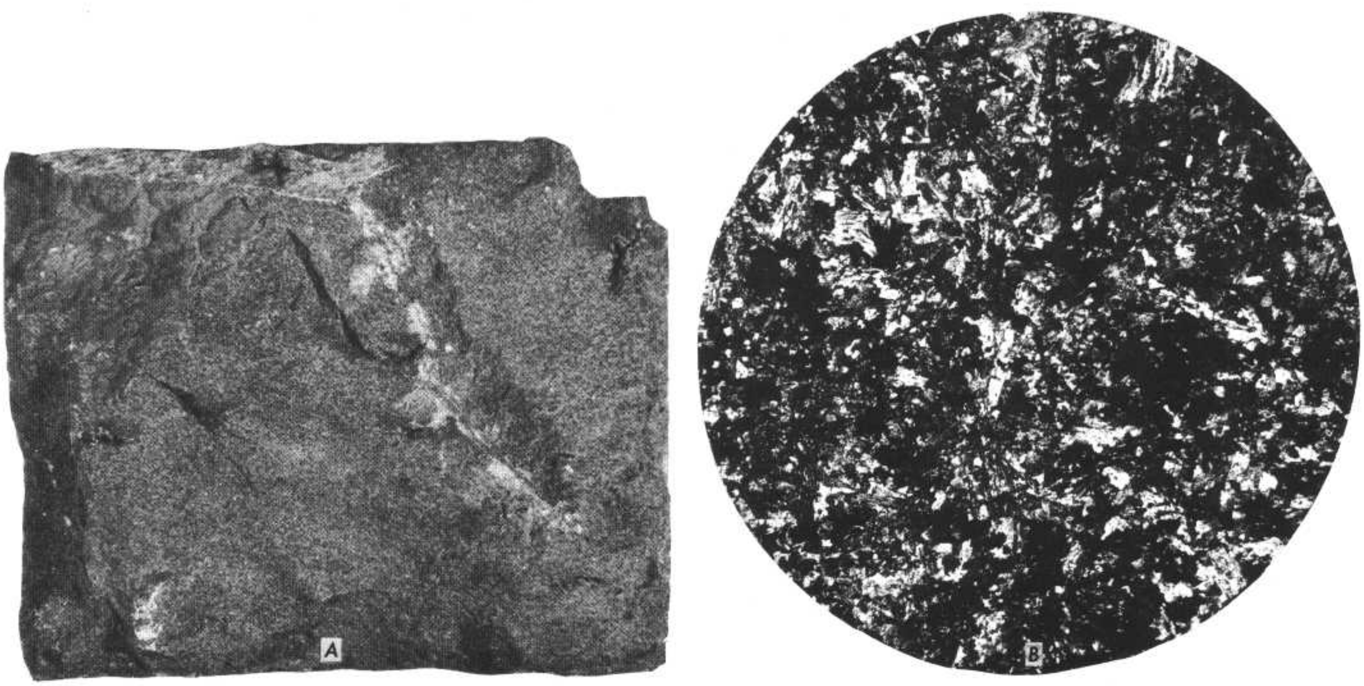




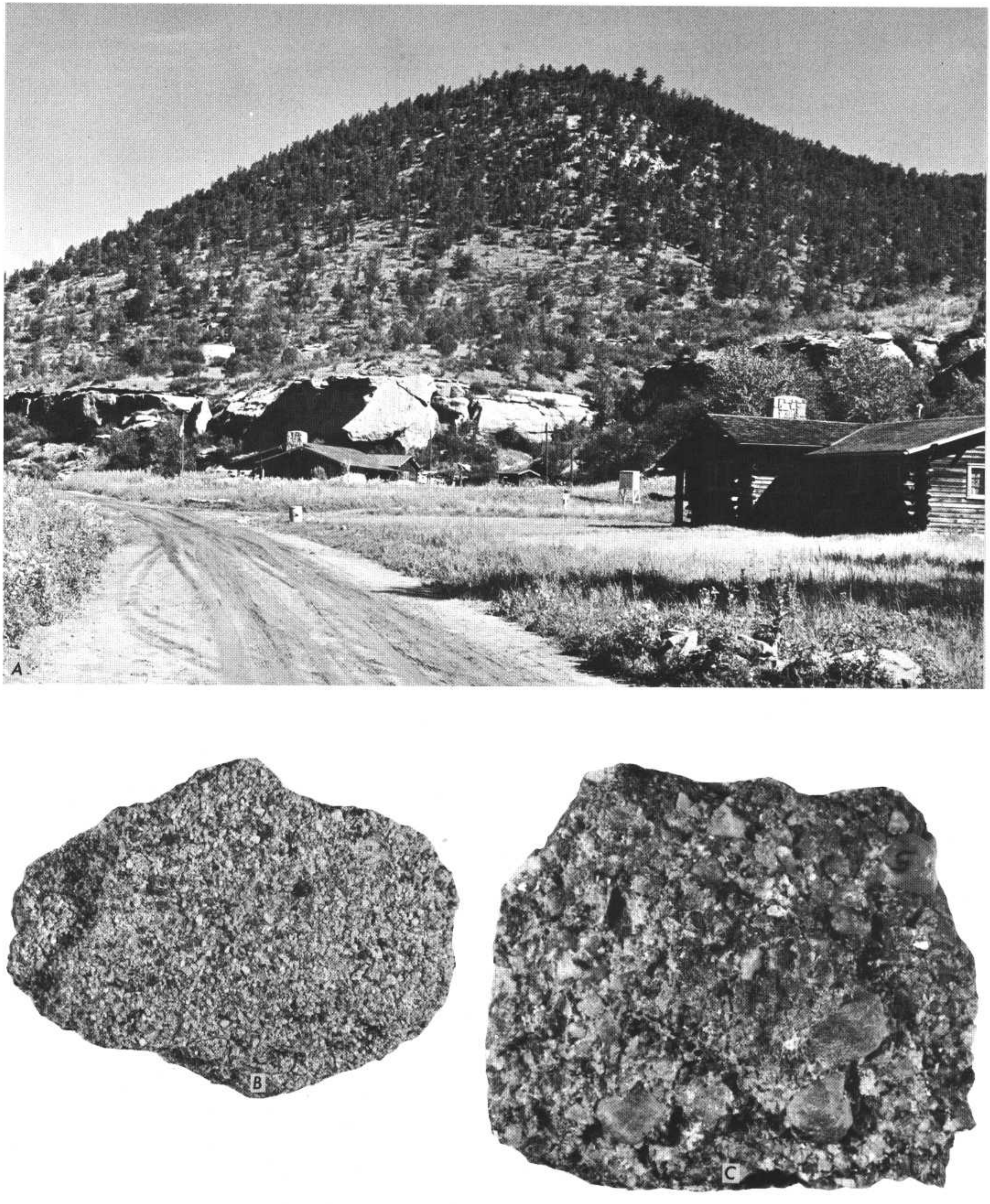
LAMPROPHYRE. Molten material—magma—from within the earth rose in cracks and froze slowly to make this rare biotite-pyroxene rock. A, Ridge of lamprophyre at Horse Ridge. B, Piece of lamprophyre, natural size. C, Slice of lamprophyre, magnified 24 times. Large crystals of biotite surrounded by intergrown small rods of pyroxene and bright flakes of biotite, and scattered light patches of calcite and black grains of magnetite. (Fig. 31)



LIGHT-COLORED ANDESITE IN DARK SHALE (Pierre Shale) on State Highway 21. (Fig. 32)



A CLOSER LOOK AT ANDESITE. A, Piece of andesite, natural size. B, Slice of andesite, magnified 24 times. The rock is made mainly of microscopic lath-shaped crystals of glassy plagioclase feldspar and flakes of brown biotite but contains many grains of transparent calcite and a little black magnetite. (Fig. 33)



YELLOW SANDSTONE AND CONGLOMERATE (Poison Canyon Formation), deposited by ancient streams. A, Outcrops at Ponil Base Camp. B, Piece of yellow sandstone. C, Piece of yellow conglomerate. (Fig. 34) rock that is more than half phenocrysts is called a porphyry; if phenocrysts are common but less than half, the rock is merely porphyritic. The lamprophyre is, therefore, porphyritic, though at first glance it seems to be a porphyry.

Other sheets of lamprophyre, some cutting across the bedding, some parallel to it, makes less striking outcrops in the terraces 2 miles east of Ranch Headquarters. In some of these the rock is much finer grained than the rock at Horse Ridge and looks like limestone, except for the glitter of tiny biotite flakes; some even reacts to hydrochloric acid like limestone, by fizzing vigorously, because it contains much calcite.

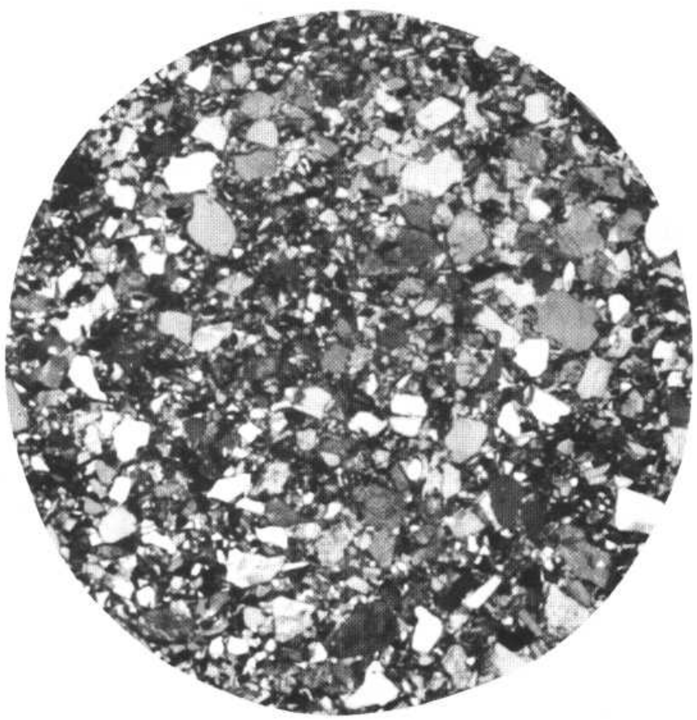
Brown andesite

Andesite, though rare in the lowland plains, is worth mentioning because it is easy to see on State Highway 21 at the rise 0.8 mile north of Ranch Headquarters (figs. 32, 33). Here it makes a sheet about 10 feet thick parallel to the bedding of black shale. The shale is hardened and splintery for several inches above and below the andesite sheet.

The andesite is a dense hard fine-grained rusty-brown rock containing scattered pale-blue spots and streaks (fig. 33*A*). The rock is made mainly of microscopic lath-shaped crystals of glassy plagioclase feldspar and flakes of brown biotite but contains many grains of transparent calcite and a little black magnetite (fig. 33*B*). The blue material is opal. In weathering, the black magnetite rusts to brown hematite, which gives the rock its color.

Like the lamprophyre, the andesite rose from below as a melt and froze in the shale. The heat released by the cooling andesite dried and baked the shale, making it brittle along the contact. The shale for a foot or so both above and below the andesite sheet is baked and brittle (the sheet must be followed eastward to learn this, for its top is not exposed in the roadcut), proving that the andesite actually squeezed between the shale layers instead of flowing on the surface like lava. A surface flow would alter the rocks it flows over but could not affect layers not yet deposited on its top.

The molten andesite was certainly hot enough to do a lot of baking. Laboratory experiments with rocks like andesite show that they melt completely at about 2000° F at near-surface pressure (so does ordinary window glass) and are completely crystallized by the time they cool to 1800° F. The lamprophyre melt, having more water to keep it fluid, may not have been quite so hot.



SLICE OF YELLOW SANDSTONE, magnified 16 times. Grains are mostly quartz and feldspar. (Fig. 35)

Rocks of the benchlands

The rocks that underlie the benchlands are not much like those beneath the plains, but the rocks of the two areas have two things in common—they are mostly made of fragments of older rocks deposited by streams or in the ocean, and they lie for the most part in nearly horizontal layers, roughly parallel to the bench surfaces. The benchlands also have some igneous rocks, but these rocks are mostly very different from the igneous rocks of the plains.

Yellow sandstone and conglomerate

In the striped benchlands that make up most of the north half of Philmont, the light-colored stripes are mainly yellow sandstone and conglomerate. These rocks cap the benches on both sides of Cimarron Creek. Dipping gently northward, they come to creek level in the northern part of the area, as in the outcrops near Ponil Base Camp (fig. 34). The sandstone is made mostly of poorly rounded grains of glassy quartz and cloudy feldspar but contains angular bits of biotite, hornblende, and dark shale (fig. 35). The grains, which vary widely in size, are loosely held together by a little clay and calcite cement. Open spaces between grains amount to as much as a fourth of the total volume of the rock.

Except for the cement, this rock is just like the sand on the banks of the present creeks and no doubt started out in much the same way. As do the streams of today, the streams that deposited the sediments which made these rocks dried up sometimes and also shifted their courses often, leaving the soft wet sand to dry in the sun. Cracks caused by drying are still preserved on the surfaces of some sandstone beds at Philmont, as figure 36 shows. The slab pictured, more than 20 feet long, fell off a hill. The cracked surface, now vertical, was originally flat and was the bottom of a layer that was deposited on top of a layer that had dried, cracked, and hardened. It is, then, a print or mold of a sun-cracked surface rather than the surface itself. The shape of the plates between the cracks shows why: mud-dried plates curl up at the edges and are cup-shaped, but the plates on the sandstone surface are higher in the center—dome shaped—so they are molds.

Another result of shifting stream courses is crude crossbedding, shown in figure 37. The beds from creek level to twice as high as the man's head dip gently to the right. Above this level they are cut off by flatter beds. The lower beds once extended farther but were planed off by a flood. Then, the receding flood waters, or a later flood, dropped new sand on the scoured surface.

Trapped with the sand were fragments of trees and other plants that have been preserved as fossils (fig. 38). (The fossils in the photographs come from elsewhere, but similar ones have been found at Philmont.) Plants like this grow only on land; so rocks containing abundant remains of land plants and no recognizable signs of ocean life surely were deposited on land. Later, the sand was covered by other rocks and was cemented with material deposited in part from water buried with the sand and in part from new water that percolated down.

Yellow conglomerate (fig. 39) made of pebbles and larger chunks of older rocks cemented together crops out near the yellow sandstone. The sandstone and conglomerate grade into each other and are interbedded (fig. 40): the conglomerate is simply a king-size sandstone. Older rocks that could have supplied the fragments in the sandstone crop out, as we shall see, only in the core of the Cimarron Range to the southwest and in the Sangre de Cristo Mountains still farther west. If the sandstone is cemented river sand, the conglomerate is cemented river gravel. Both were probably deposited by streams that flowed from the west, like those of today.

Light-gray sandstone

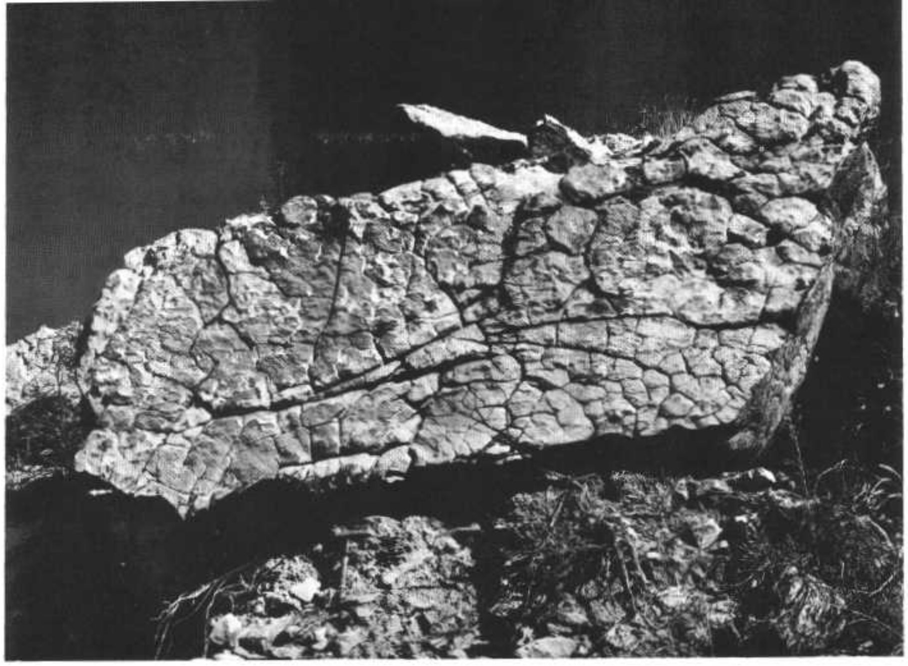
A different kind of sandstone crops out in sheer low cliffs near the base of the benches flanking lower Cimarron Creek and lower Ponil Creek (fig. 41). This sandstone, which is broken into huge blocks by widely spaced joints, is light gray and is made up mostly of quartz grains and only a very small amount of feldspar, biotite, and hornblende (fig. 42). Unlike the yellow sandstone, its grains are nearly all about the same size, the quartz and feldspar grains are somewhat rounded, and there are no shale chips (fig. 42*B*). Like the yellow sandstone, this rock contains a few plant fossils (fig. 43) and also some odd knobby tubular masses, called *Halymenites*, made by some sort of burrowing animal or branching plant that once lived there (fig. 44). (The plants and tubes in the photographs were collected from this sandstone northeast of Philmont.) These masses used to be called fossil seaweed, but now we are not so sure just what kind of organism they represent. They look very much like the burrows of living crabs in Atlantic coast sand beaches.

This rock was probably deposited on an ocean beach. Its sand must have been washed and rewashed many times to produce the even size and slight rounding of the grains. This kind of working over is common on ocean beaches, as are burrows and also leaves, blown from near-shore trees.

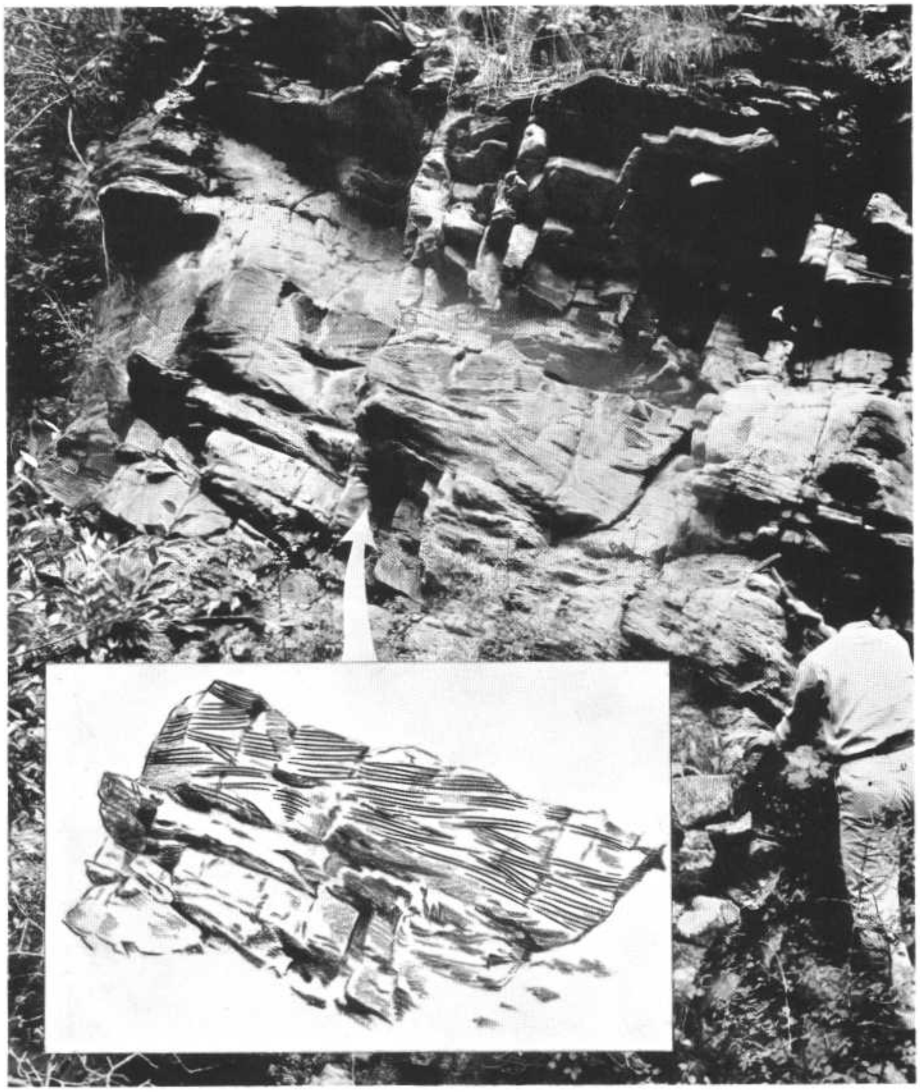
Shale

Black marine shale like that beneath the plains is also a major rock type in the lower parts of the benchlands. The soft shale rarely makes ledges itself, but it can be seen in many places where it is protected by overlying ledges of sandstone, as along the north side of Highway 64 west of Cimarron town from Slate Hill to Turkey Creek (see right edge of fig. 3) and at the heads of a few streams on the flanks of Urraca Mesa (fig. 45).

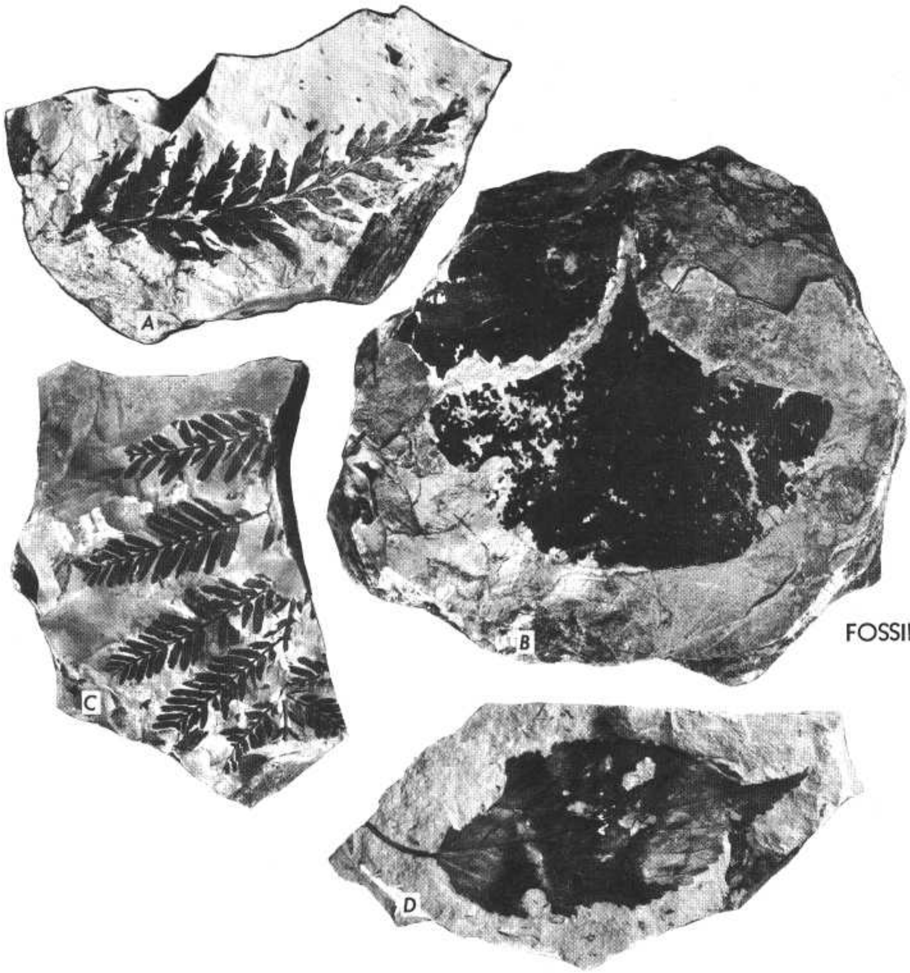
Shale that is lighter colored and sandier than the black shale makes most of the dark stripes in the striped benchlands. Like the black shale, it rarely crops out but is covered with soil and slide rock. The sand in this shale is just like that in the yellow sandstone and conglomerate, and so



YELLOW SANDSTONE (Raton Formation) that has fossil sun cracks, Ponil Creek. (Fig. 36)

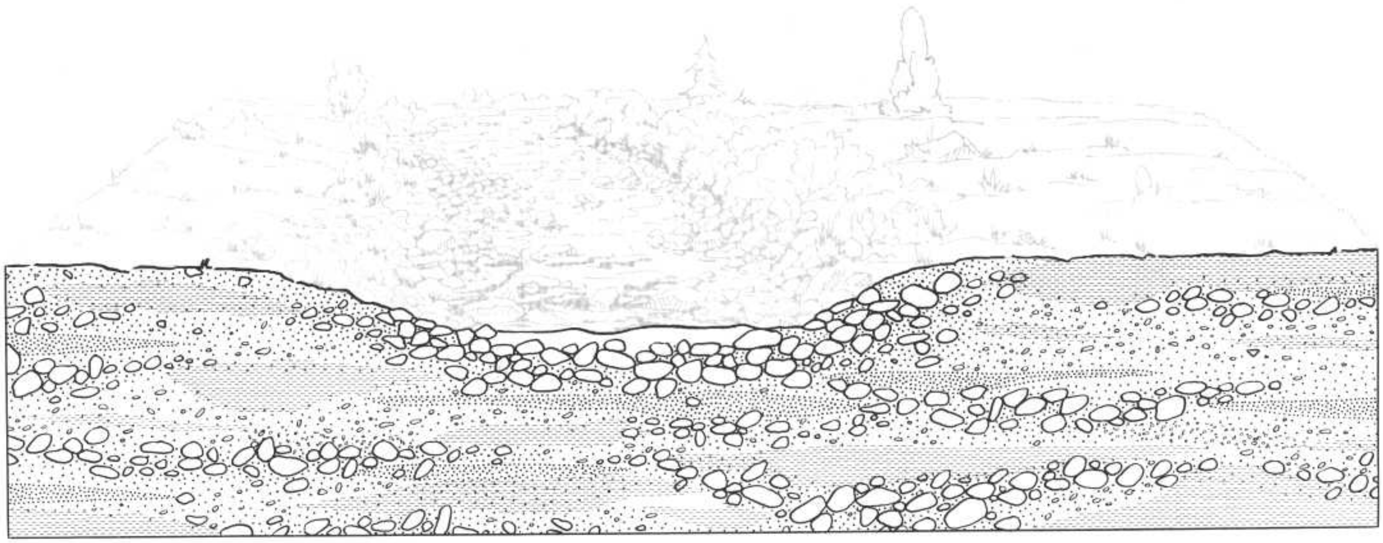


CROSSBEDDING in yellow sandstone (Raton Formation), Ponil Creek. A result of shifting stream channels. (Fig. 37)



FOSSIL PLANTS from ancient stream beds. (Fig. 38)

YELLOW CONGLOMERATE (Poison Canyon Formation) in high benchlands north of Baldy Mountatn. (Fig. 39)



SANDSTONE, CONGLOMERATE, AND SHALE in old stream deposits, showing grading (gradual change) and bedding (sharp change). (Fig. 40)

LIGHT-GRAY SANDSTONE (Trinidad Sandstone)—relic of a vanished ocean beach. Outcrop on lower Ponil Creek. (Fig. 41)

are the fossils—bits of land plants. Also, in places the shale grades into yellow sandstone in the same way that the sandstone grades into conglomerate (see fig. 41). This shale was not deposited in the sea, like the black shale, but by streams on land, like the yellow sandstone and conglomerate. When the streams flooded, they left sand and gravel in their channels but carried mud as far as the water spread, finally dumping it on the flood plain, where it was mixed with debris from plants that had lived and died there. Eventually this soupy mixture was buried by deposits from later floods, the water was mostly squeezed out, and it became rock.

Dark basalt

Basalt, in dark hues of gray and green, caps the mesas in the southwestern part of Philmont. The best exposures are at the mesa edges (see fig. 45); elsewhere, the basalt is concealed by a thin but continuous cover of soil and rubble. From a distance the basalt seems to be broken into neat vertical pencil-like columns, but close up this pattern disappears (fig. 46); for the rock has many fractures besides the vertical joints that make the columns, and it tends to break down into piles of jagged rubble. Most of the rock is dense and glassy, but it has a few green-brown greasy-looking phenocrysts of olivine and scattered football-shaped holes (fig. 47*A*). In places the rock has many of these holes and approaches pumice. Some of the holes are filled with white calcite, and a few others with white fibers of zeolite (fig. 47*B*). Using a microscope, we see that the large olivine phenocrysts "float" in a mixture of brown glass and tiny crystals of colorless feldspar, green pyroxene, and golden olivine (fig. 47*C*).

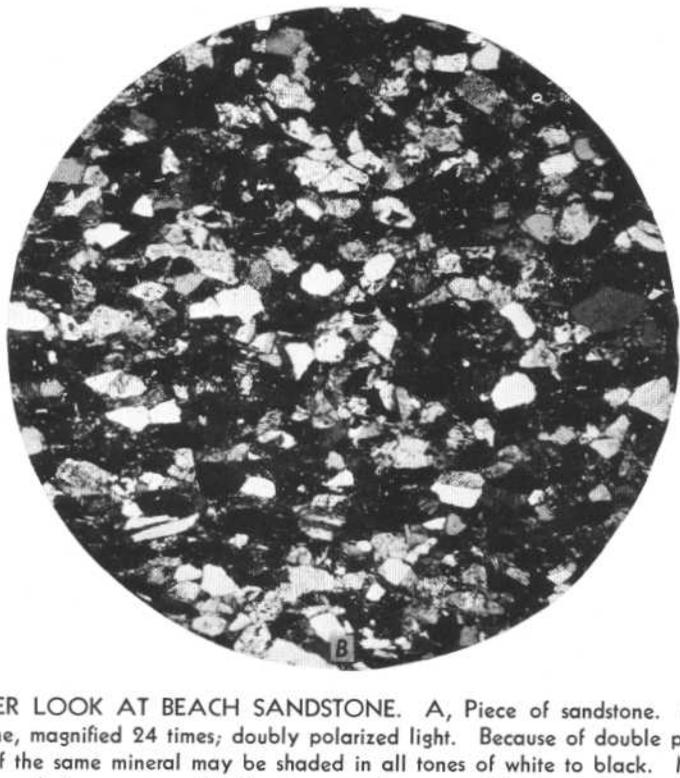
This rock flowed out on the surface as a thick glowing-hot paste. It is in every way like the lavas that are erupted every few years by Mauna Loa and Kilauea volcanoes on Hawaii. The large crystals probably formed while the melt was still deep within the earth, and the smaller ones as it was rising through fissures, or perhaps even as the lava cooled on the surface. Most of the rock cooled so rapidly at the low temperature and pressure of the atmosphere that no crystals formed, only glass. Most of it, too, had little gas and cooled to a dense rock like that in figure 47*A*. The basalt that now has bubble holes originated miles below the earth's surface, and there it contained several percent of dissolved gases—mostly water vapor—which were kept dissolved by the pressure of the overlying rocks. As the basalt rose and the rock pressure grew less, the gases expanded and formed bubbles. If the gas in a bubble escaped while the lava was still hot enough to flow, the hole simply closed up; but if the rock was fairly hard before the gas escaped, the walls of the bubble remained. Later, hot water related to the eruption, or cold water percolating from the surface, deposited white calcite and zeolite minerals in these open spaces and completed the formation of rocks like that in figure 47*B*.

As the basalt cooled, it cracked and shrank, and vertical joint columns and cross cracks were formed. The basalt, to judge by what we know happens at Hawaii, emerged from the volcano white-hot at a temperature of nearly 2000° F. Most of the basalt at Philmont seems to have come from volcanoes to the south, but the lava on Fowler and Urraca Mesas probably came from a vent at the mountain front, near Crater Peak.

Dacite porphyry

Dacite porphyry, though rare in the benchlands compared to sandstone, shale, and basalt, makes some striking light-colored outcrops in the northwestern part of Philmont. It caps Wilson Mesa, on South Ponil Creek, and makes ledges near the rims of the benches bordering Middle Ponil Creek and its tributaries above Ponil Base Camp (fig. 48). These exposures are all parts of a single nearly flat sheet no more than 100 feet thick but at least 5 miles long, that lies parallel to the bedding of the surrounding sandstones and conglomerate. The sandstone above has been eroded in many places, leaving the resistant dacite porphyry as the bench capping, as in figure 48*A*. In other places, such as in Bonita Canyon, the sheet is sandwiched between beds of sandstone. The dacite outcrops are about the same color as the sandstone but have vertical jointing like the basalt; thus, they are easy to identify, even from a distance.

The dacite, though different from the lamprophyre and basalt in many ways, is made of interlocking crystals (fig. 48*B*) and, like them, is an igneous rock. The dacite is a porphyry because it has many large crystals in a mosaic of tiny ones. As dacite porphyry is rather rare in the benchlands but is the most prominent ledge maker in the mountains, we will say more about its composition and origin later. The dacite has slightly baked and discolored the sandstone both below and above, showing that it was squeezed in between the sandstone beds, like the andesite near Highway 21, and did not flow out on the ground, like the basalt.



A CLOSER LOOK AT BEACH SANDSTONE. A, Piece of sandstone. B, Slice of sandstone, magnified 24 times; doubly polarized light. Because of double polarization, grains of the same mineral may be shaded in all tones of white to black. Most of the grains are of clear quartz; a few lined or striped ones are feldspar, biotite, or hornblende. Bright rims on some grains are clay and calcite. (Fig. 42)

Andesite

Some thin sheets of salt-and-pepper andesite and andesite porphyry (andesite that has many large crystals of feldspar) make striking ridges that can be traced for miles in the northwest corner of Philmont. Nearly all are vertical, like the lamprophyre of Horse Ridge, but a few are nearly flat, like the dacite porphyry of Wilson Mesa. Because all the andesite sheets in the benchlands are hard to reach or are in mining areas closed to visitors, no more will be said of them.

Coal

Shiny-black coal is a fairly common rock along the southern edge of the northern benchlands, from the north side of Cimarron Creek, below Ute Valley, to the north side of Ponil Creek, below Chase Canyon. Beds of coal as much as 4 feet thick are interlayered with shale and sandstone. The coal, however, rarely crops out, because it falls to pieces on exposure to air. A little coal was once mined here, and countless chips of disintegrated coal can be seen on waste-rock dumps at the openings of abandoned mines on the slopes of Slate Hill (see fig. 79) and on lower Ponil Creek (fig. 49). It is interesting to see the coal and other rock debris on the dumps, but it is unwise to enter the mines. They were dangerous when mining was still going on and are much more so now, after decades of neglect.

Coal, when magnified enough (fig. 50), is seen to be made mostly of altered and compressed plant fragments. Such material accumulates in swamps and becomes peat, an early stage product in the coal-forming process. There are many present-day peat bogs. Plants are made almost wholly of compounds of carbon, oxygen, and

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