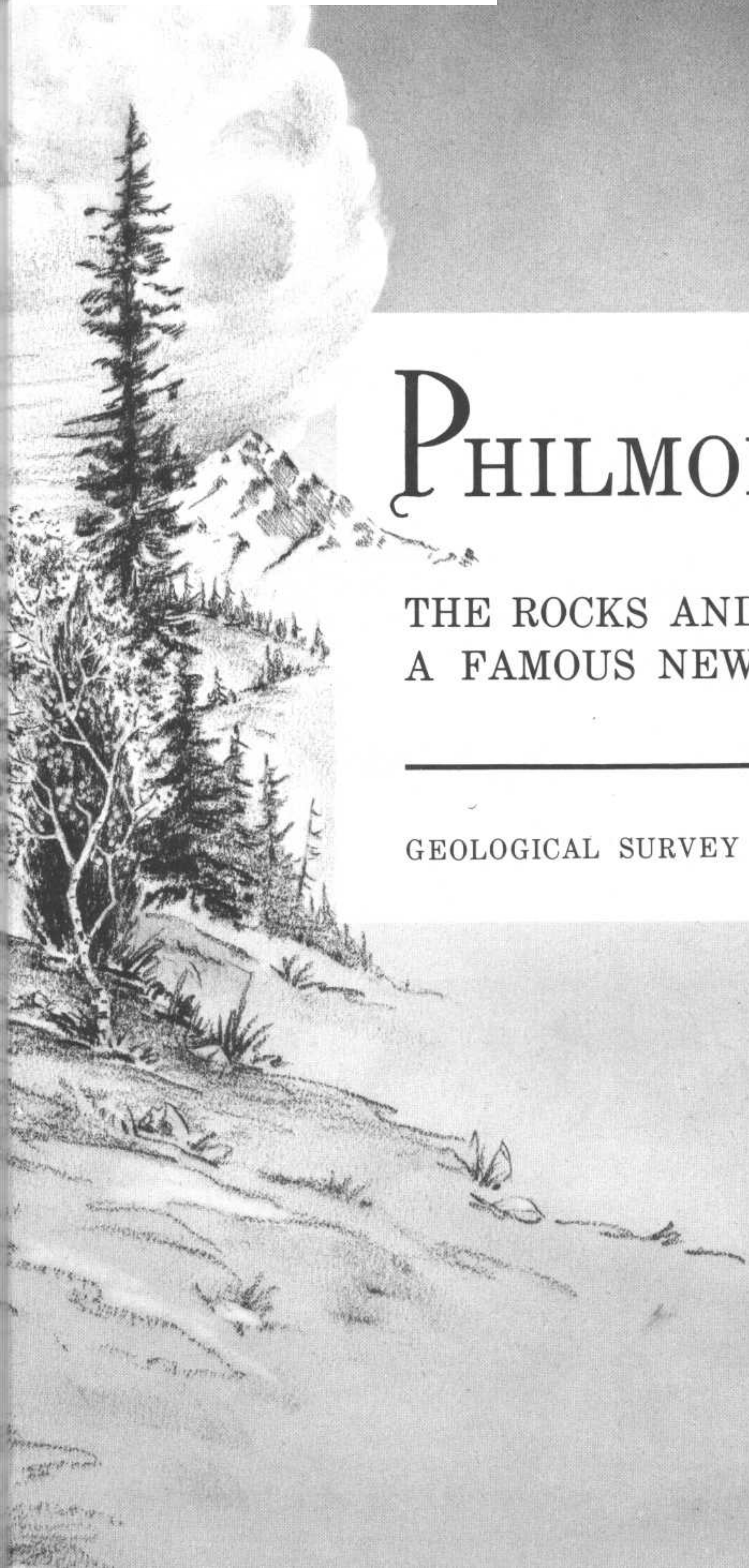

PHILMONT COUNTRY

THE ROCKS AND LANDSCAPE OF A FAMOUS NEW MEXICO RANCH

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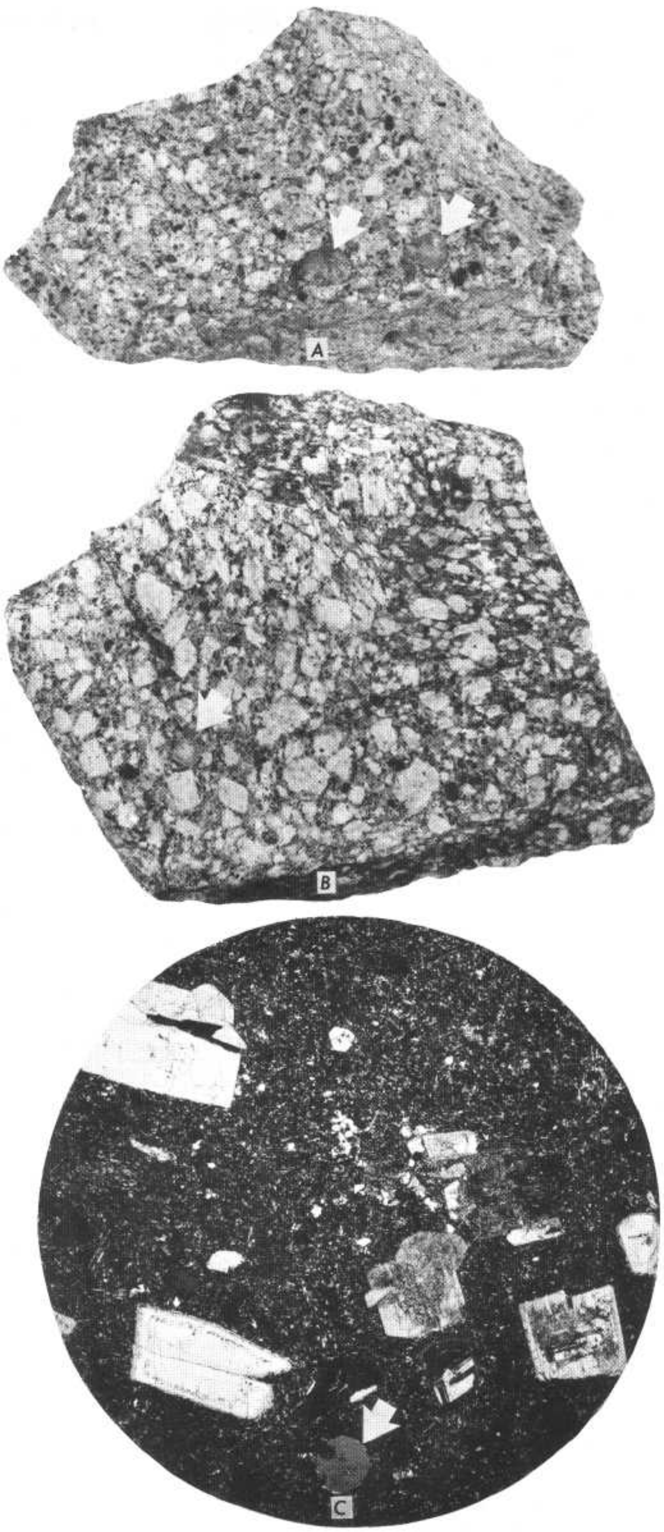
Early in the second stage, the melt attacked and corroded the quartz phenocrysts, rounding them, but freezing prevented the process from going very far. A reasonable guess is that the first stage of slow crystallization was at great depth, perhaps 10 miles or more. The second stage probably followed oozing of the partly solid mush into the cover of colder sedimentary rocks.

Striped gneiss and schist

Gneiss and schist are almost as abundant at Philmont as dacite porphyry, for the heart of the mountains, from upper Cimarron Canyon southeastward to Trail Peak, is made mainly of these rocks. Yet little can be said about them, for, as the timber warns from afar, they are rarely exposed. Scattered small outcrops reveal that these rocks, where unweathered, are fine to coarse grained, hard, and banded or layered (figs. 56, 57). Some bands are several feet thick; others are visible only under a microscope. Hard as they are, these rocks split easily and cleanly parallel to the layering. They are mainly composed of familiar minerals: clear quartz, dull white or pink plagioclase, shiny black biotite, silvery white muscovite, dark-green hornblende, and lighter green chlorite. The grains have sharp crystal outlines and are closely packed. The banding is due to varied proportions of the light- and dark-colored minerals. The grains do not lie at random; their long dimension, if they have one, is parallel to the layering, which, in crystalline rocks like this, is called foliation or schistosity, to distinguish it from the bedding in fragmental rocks like sandstone and shale. It is this alinement, especially of the flaky micas, that makes the rock split easily.



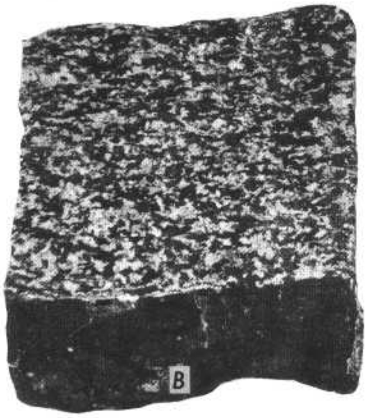
DACITE PORPHYRY: A CLOSER LOOK at two common varieties. A, Porphyry with medium-size phenocrysts of cloudy feldspar, dark biotite and hornblende, and larger egg-shaped grains of glassy quartz (white arrows). B, Porphyry with large phenocrysts of feldspar and smaller ones of biotite, hornblende, and quartz (white arrow). Natural size. C, Slice of dacite porphyry, magnified 8 times. Doubly polarized light. (Fig. 55)

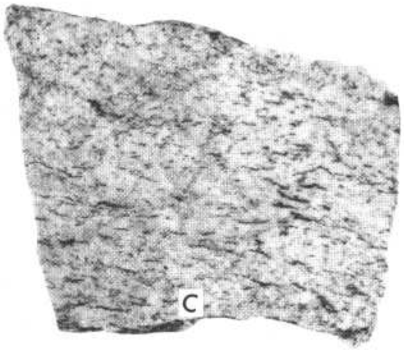
GNEISS—changed from sedimentary or igneous rocks by heating and squeezing deep within the earth's crust. Rare outcrop on Apache Creek. (Fig. 56)

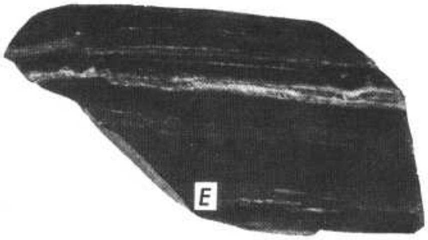
Those striped crystalline rocks that have rather rough and irregular banding and are made mainly of the light-colored blocky minerals, quartz and feldspar, are called gneiss; those that have more even banding and are made mostly of platy biotite, muscovite, and chlorite, or rodlike hornblende are called schist. All gradations between gneiss and schist exist and in some places can be seen in a single outcrop, so we talk about them together. Most of the gneiss and schist is rather coarse grained, but fine-grained gneiss and schist, like that shown in figure 57*E*, can be seen at several places along the east side of the mountain core, such as near the head of South Fork Urraca Creek and in Cimarron Canyon upstream from Clear Creek Store.

The striped gneiss and schist have some things in common with both sedimentary rocks and igneous rocks, but they are different enough to convince us that they formed in a different way. They resemble waterlaid sandstone and shale in their general mineral content, their rapid changes in composition and grain size, and their layering. Their grains, however, are not rounded but have smooth crystal surfaces with sharp edges and are closely packed. In this they are something like the coarse-grained igneous rocks, but the drawn-out texture and delicate mineral layering of the gneiss and schist are quite unlike anything we have seen in the igneous rocks.

The drawn-out or stretched look in the outcrop exists at a microscopic scale (fig. 58). The rock looks as though it has been squeezed and mashed so powerfully that its grains have been forced into parallel alinement. Some of the platy grains, like the biotite, and the rodlike ones, like the hornblende, seem to have been



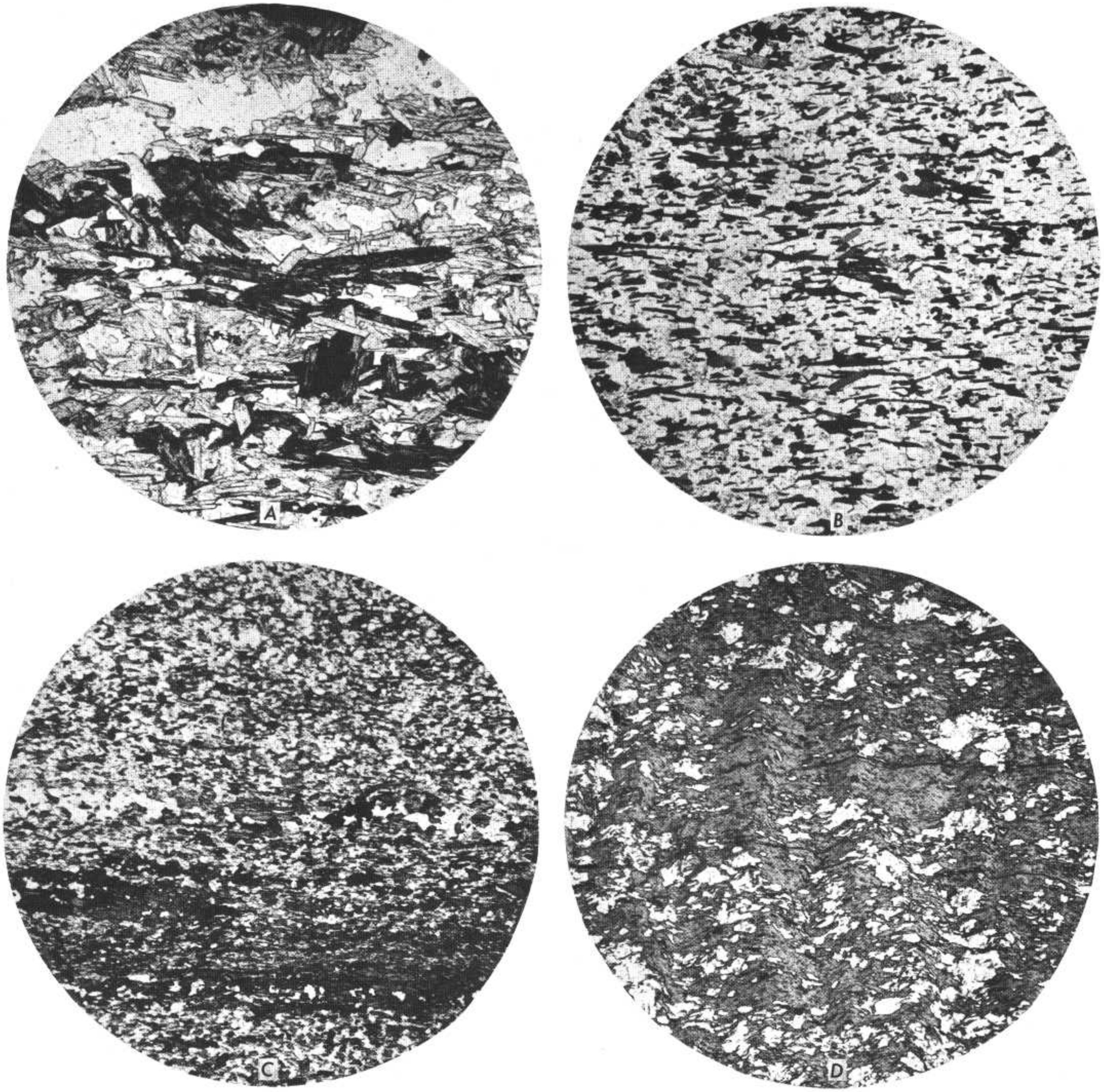




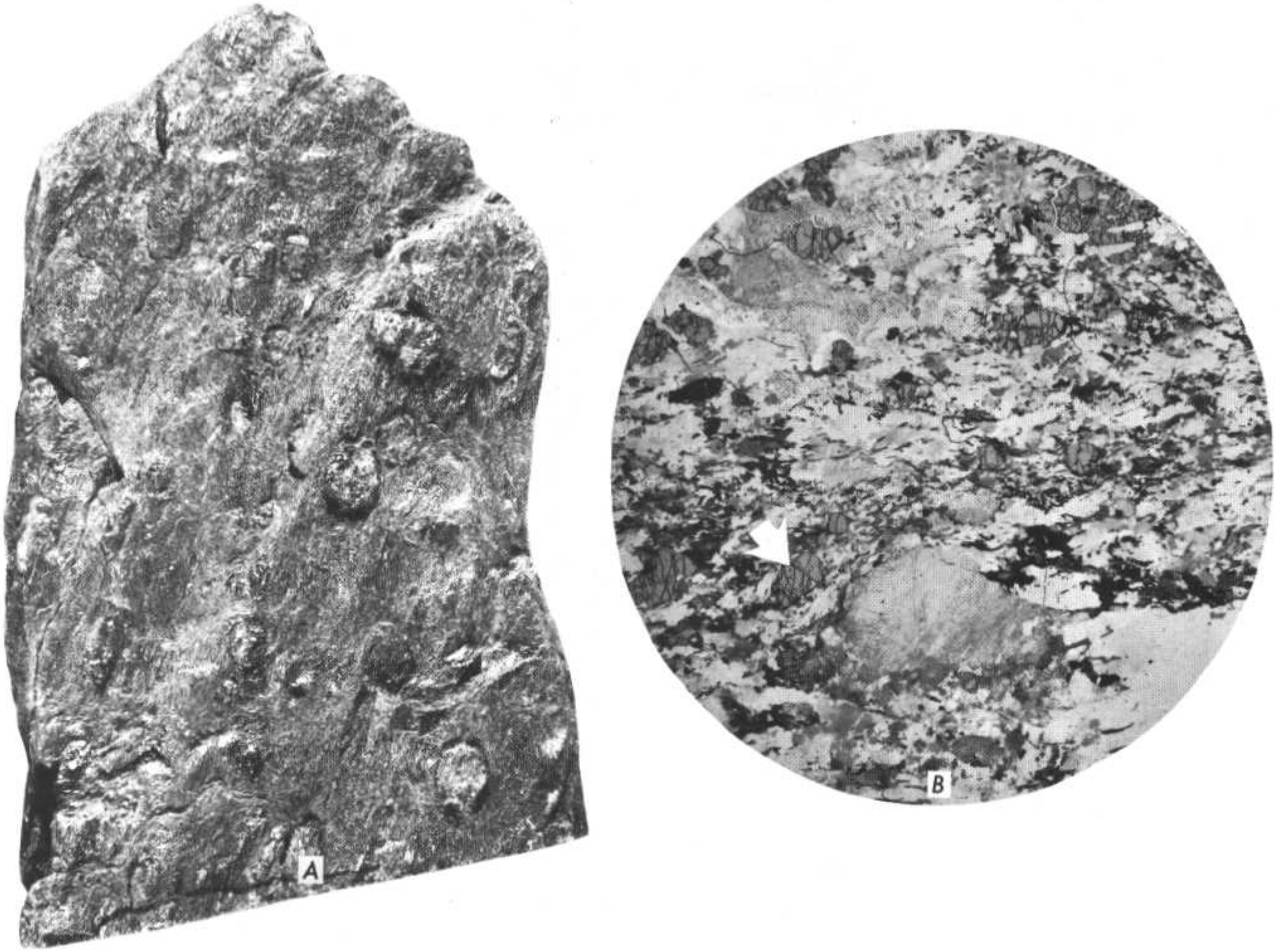
GNEISS AND SCHIST. A, Roadcut in schist at head of South Fork Urraca Creek. B, C, and D, Common varieties of coarse gneiss. Light-colored grains are quartz and feldspar; dark-colored ones are biotite and hornblende. E, Fine-grained schist from head of South Fork Urraca Creek. (Fig. 57)

rotated bodily by pressure. Other grains, like the quartz, which is in pods made of many small grains, seem to have responded to pressure by dissolving at points of greater stress and refreezing or recrystallizing at points of lesser stress. The fact that the rotation or recrystallization has produced parallel alinement tells us that the squeezing was not all-sided, as in a swimming pool, but directional, as in a vise. The distinctive shapes and arrangement of the grains also reveal that these rocks grew as they are with little or no melting. If they had been hot enough to melt, except perhaps around the edges of grains, these rocks would have textures like igneous rocks. The original shape, not only of the rock mass as a whole but of each small grain, has changed under directed pressure without much melting. Such rocks that were transformed while solid are called metamorphic rocks, a term derived from the Greek for "change shape" or "transform."

What sort of rocks were transformed to the gneiss and schist of Philmont? In some regions this question can be answered directly by tracing metamorphosed rocks away from areas of compression to places where they are not much changed. This is not possible at Philmont, however, for the gneiss and schist do not grade into less metamorphosed rocks.

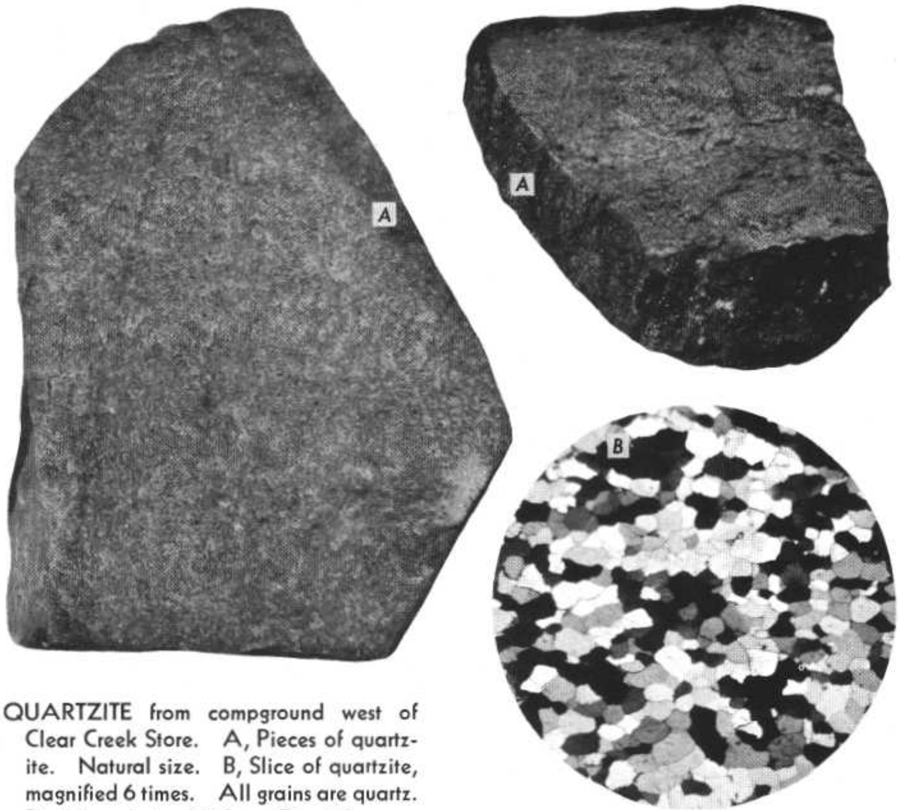


GNEISS AND SCHIST under the microscope. A, B, and C, Three common kinds of gneiss. D, Chlorite schist. These views, all magnified 24 times, show the tight packing and parallel alinement of grains that mark most metamorphic rocks. (Fig. 58)



GARNET SCHIST. A, Specimen of garnet schist. The round lumps are garnets, surrounded by chlorite. Natural size. B, Slice of garnet schist, magnified 3 times. Arrow points to one of the many garnet crystals. (Fig. 59)

Work in other regions of metamorphic rocks, such as in New England, the Canadian Shield, and the Scandinavian countries, shows that gneiss and schist like that at Philmont may be transformed either from ordinary sandstone and shale or from common types of igneous rocks. The transformation, however, is not direct, as the rock passes through a long series of changes before reaching the gneiss or schist stage; shale, for example, under mild metamorphism becomes the familiar roofing and blackboard material, slate. The minerals of the new rock may or may not be the same as those of the old rock, as the high pressures and fairly high temperatures of metamorphism may lead not only to rotation and recrystallization of minerals that already exist but also to the growth in place of new minerals better suited to high temperature and pressure, without any additions of matter. For example, part of the clay so common in sedimentary rocks has about the chemical composition of feldspar plus water; the heat of metamorphism may drive off the water of this clay, and new feldspar may form. Chlorite, another component of common sedimentary clay, has a chemical composition similar to that of biotite plus water; it may recrystallize to biotite when the water is driven off. If calcite (calcium carbonate) is present, as it often is, its calcium may combine, during metamorphic heating, with chlorite to form hornblende, and the carbonate may escape as carbonic acid. Of course, if anything besides heat and pressure is added during metamorphism, all sorts of new minerals may form. And, if the rock gets hot enough, it may partly melt and later freeze as an igneous rock.



QUARTZITE from compground west of Clear Creek Store. A, Pieces of quartzite. Natural size. B, Slice of quartzite, magnified 6 times. All grains are quartz. Doubly polarized light (Fig. 60)

Garnet schist

An especially interesting kind of schist exposed at Philmont is garnet schist, which is visible on the trail above the head of South Fork Urraca Creek. Here, scattered in fine-grained hornblende-biotite schist near the outcrop shown in figure 57*A*, are small pink garnets about one-eighth to one-quarter inch across (fig. 59). Garnet is a mineral that is common only in metamorphic rocks. It does not appear in any of the igneous rocks at Philmont, and it is rare in igneous rocks elsewhere. Occasionally, crystals of garnet are found in sandstone, but the edges are always rounded off, showing that the garnet did not grow in the sandstone but was washed in. The garnet crystals at Philmont have grown in the schist as brand-new minerals, as a magnified slice shows (fig. 59*B*). Pink garnets require a lot of calcium, much more than ordinary igneous rocks have; perhaps this schist was once a calcite-rich shale or a shaly limestone.

Quartzite

Here and there, especially along the east side of the mountain core, layers of a hard rock made almost wholly of tiny grains of quartz are sandwiched between the layers of gneiss and schist. The grains are tightly cemented by quartz, and the rock is called quartzite. Most of the quartzite layers are only a few inches thick, but some are many feet thick. The thickest and best exposed are in Cimarron Canyon at the west end of the campground half a mile west of Clear Creek Store. The outcrops of quartzite weather to dark colors, but the freshly broken rock is a glassy medium gray and contains scattered hairline streaks of pale green (fig. 60). The green streaks, though hard to see, are parallel to each other and to the layering in the neighboring gneiss and schist. Magnified (fig. 60), the rock turns our to be made almost entirely of tiny irregular grains of quartz. The rock also contains scattered flakes, and bundles of flakes, of white mica and green chlorite that do not appear in figure 60. The grains fit tightly together, as in a mosaic, and the rock has no pore spaces.

This quartzite is just as much a metamorphic rock as is the neighboring gneiss and schist, but a microscope is needed to show that it is, by the shape and arrangement of the quartz grains. If the rock had more platy minerals, it might even be called gneiss. Though it is uncertain whether the common gneiss and schist of the mountains were transformed from sedimentary or from igneous rocks, there is no such hesitation about the parent rock of the quartzite: it was quartz mudstone or sandstone. Sedimentary rocks made almost wholly of small grains of quartz are common, but igneous rocks of such composition and texture are unknown.

Diorite porphyry

Near the head of South Fork Urraca Creek is a single large outcrop of a remarkable rock consisting of giant pale-gray crystals of plagioclase feldspar as much as 2 inches long surrounded by small interlocking grains of hornblende and feldspar (fig. 61). This rock is diorite porphyry. It looks a little like the common dacite porphyry of the mountains, but it is really very different. For one thing, it is a much simpler rock, lacking three minerals abundant in the dacite porphyry—orthoclase, biotite, and quartz.

DIORITE PORPHYRY from South Fork Urraca Creek. Giant crystals of feldspar surrounded by small ones of black hornblende and clear feldspar. Natural size. (Fig. 61)

For another, it has a smeary, fuzzy look. This is because the rock has been partly shattered, dragged apart, and then recrystallized, so that the phenocrysts have jagged rather than smooth edges. This rock seems to have started out as an igeneous rock but to have been changed a little by pressure. In a sense it is a metamorphic rock, but it has not been changed nearly as much as the neighboring gneiss and schist.

Anyone walking up the bed of the South Fork soon becomes aware that this distinctive rock must crop out somewhere upstream, for pebbles and cobbles of it are noticeable for many miles downstream. As similar stones do not appear in any other creek bed, it seems safe to conclude that this outcrop is the only one in the Philmont area.

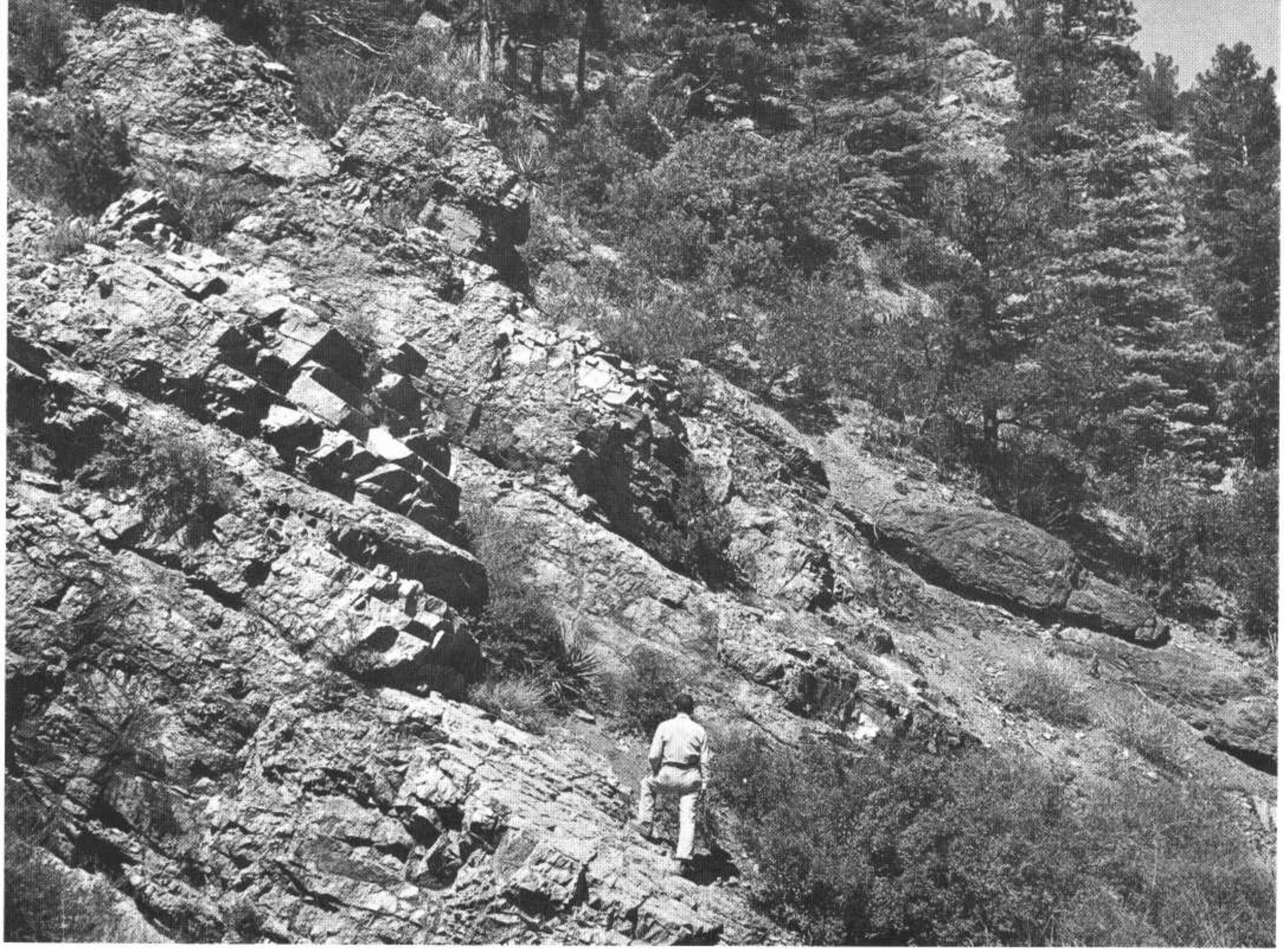
Outcrops of other rock types can, of course, be predicted in the same way—the diorite porphyry, being both unusual and gaudy, just offers an especially easy spoor to follow. A challenging game is to pick out the different rock varieties in a stream gravel and see how many can be tracked to their outcrops upstream. This is not entirely a game for this is the way many gold and other ore deposits have been found.

Pink granodiorite

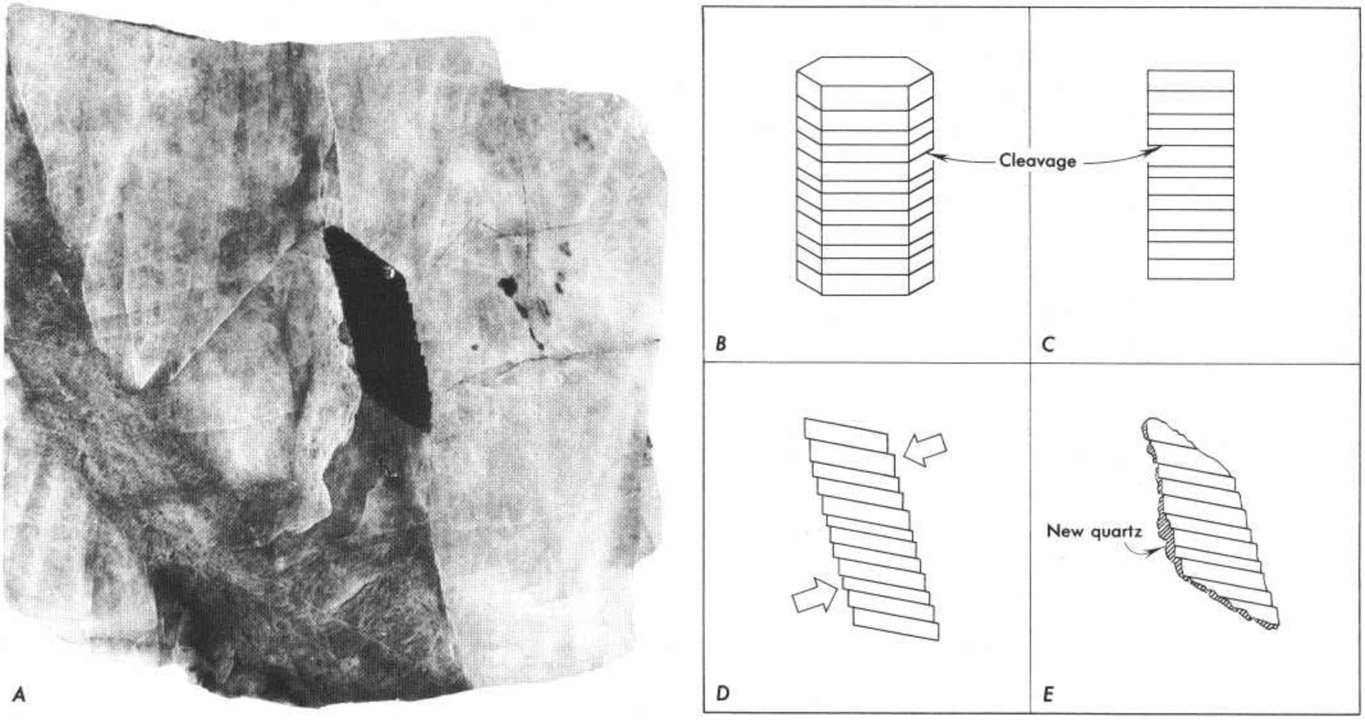
Scattered throughout the areas of gneiss and schist, but not elsewhere, are irregular masses of pink granodiorite and similar granitelike rocks. Most of the masses are small and are deeply weathered. A large and well-exposed body of coarse-grained granodiorite, however, is on Highway 64 near Clear Creek Store (fig. 62). The rock is so coarse (fig. 64) that the individual minerals can be identified on sight—they are clear quartz, deep-pink orthoclase, pale-gray plagioclase, and brownish-green biotite.

Similar rocks elsewhere at Philmont are mostly finer grained and contain different proportions of the same minerals; some also contain hornblende. Properly, they should have other names, like granite and quartz monzonite, but we will include them with the granodiorite. In some places the granitelike rock is even coarser than that near Clear Creek Store, in such places it has sheets of mica as much as a foot across and crystals of quartz and feldspar to match. Such aggregates of giant crystals are called pegmatites; those at Philmont have less feldspar than the ordinary granodiorite, more quartz and biotite, and also much silvery muscovite. A piece of pegmatite is shown natural size in figure 63. The crystals are so large that we see all of only one—the dark distorted column of biotite; the rest of the view shows parts of several intergrown crystals of quartz.

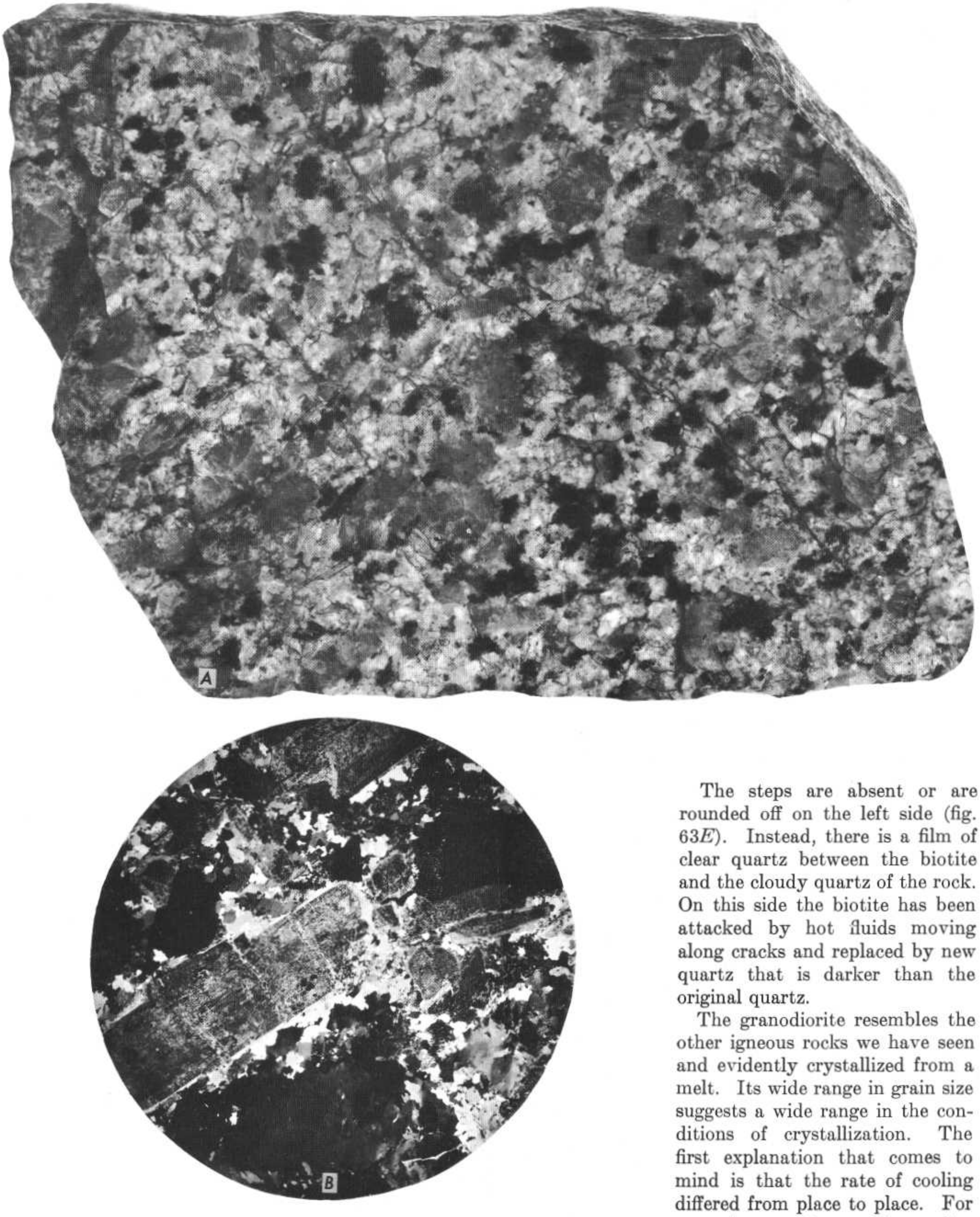
The pegmatite is not layered like the gneiss and schist, but it has been somewhat distorted by pressure, as figure 63 dramatically reveals. Normally, biotite crystals form in six-sided columns (fig. 63*B*). The flaking or cleavage that is so characteristic of mica is parallel to the base of these columns. A normal crystal of biotite cut like that in figure 63 would have the shape of a rectangle (fig. 63*C*). The biotite in the photograph has been distorted (fig. 63*D*). The tiny steps on the right-hand edge are places where bundles of cleavage plates have shifted as units in response to deforming stress.



COARSE-GRAINED PINK GRANODIORITE one-fourth mile downstream from Clear Creek Store. (Fig. 62)



PEGMATITE—a granitelike rock made of giant crystals—from near Clear Creek Store. A, Pegmatite containing distorted biotite crystal. Natural size. This specimen contains quartz and biotite only. The large pod of pegmatite from which it came also displays giant crystals of feldspar and of muscovite. B, C, D, and E, Steps in the distortion of a biotite crystal. (Fig. 63)



CLOSE-UPS OF GRANODIORITE. A, Slab, natural size. B, Slice, magnified 5 times. Doubly polarized light. (Fig. 64)

The steps are absent or are rounded off on the left side (fig. 63*E*). Instead, there is a film of clear quartz between the biotite and the cloudy quartz of the rock. On this side the biotite has been attacked by hot fluids moving along cracks and replaced by new quartz that is darker than the original quartz.

The granodiorite resembles the other igneous rocks we have seen and evidently crystallized from a melt. Its wide range in grain size suggests a wide range in the conditions of crystallization. The first explanation that comes to mind is that the rate of cooling differed from place to place. For example, a small mass of granodiorite magma intruded into solid cold rocks would be expected to cool more quickly and be finer grained than a large mass. If the intruded rocks were almost as hot as the magma, however, even a small amount of magma would cool slowly and end as a coarse-grained rock.

But more than the rate of cooling is involved, for the same small mass may grade in a few inches from fine-grained granodiorite to pegmatite. Understanding begins when we realize that besides being coarser grained than the granodiorite, the pegmatite contains much more water: it is richer in biotite and muscovite, which contain much water, and poorer in feldspar, which contains none. Probably the pegmatite is coarser grained because it crystallized from a part of the magma kept fluid by dissolved water vapor; molecules were able to migrate more easily through it than through the stickier, water-poor parts of the magma, so that larger crystals could grow there during the same time that smaller ones were growing nearby.

Where did the granodiorite magma come from? Granodiorite occurs only in the metamorphic rocks and has the same minerals as the metamorphic rocks, but it differs in texture. A reasonable idea is that the granodiorite represents bands of gneiss that were heated a little more than others, perhaps because they were more deeply buried, and consequently melted enough to flow a short distance and to crystallize with igneous texture. The temperature at which this might happen would vary with the weight of overlying rock and the amount of free water in the gneiss. Laboratory experiments suggest that a granodiorite magma might form at temperatures as low as 1000°F under 10 miles or more of rock cover.

Yellow and gray quartz sandstone

Many prominent light-colored bare ridges in the mountains are made not of dacite porphyry but of sandstone. From a distance it may be hard to tell which is which, but there is no doubt whatever at the outcrop.

At the eastern mountain front, the first bare ridge that is not dacite porphyry is pale-yellow or gray sandstone, as in the upper canyon of Cimarron Creek where it opens into Ute Valley (fig. 65*A*). Good exposures can also be found farther back in the mountains, especially in the wilderness country at the west boundary of the Scout Ranch, west of Cimarroncito Peak, and north of Comanche Peak. One of the best places to see this rock easily is on the trail along South Fork Urraca Creek (fig. 66). The rock is in beds many feet thick, but weathers into thin plates or slabs. In some places the sandstone is crossbedded like the sandstone of the northern benchlands (see fig. 37).

This sandstone is made almost entirely of quartz; and the grains, many of which have a frosted look, are somewhat rounded, rather uniform in size, and tightly cemented (fig. 65*C*). To distinguish it from sandstone rich in other minerals as well as quartz, we will refer to it as quartz sandstone. The yellow variety is mainly cemented with silica; the gray, with calcite and clay. The rock is broken by irregular fractures which are healed with chalky white calcite or clear quartz. In photographs, the rock looks rather like the quartzite of the mountain country (compare fig. 60), but there is no mistaking the rocks themselves: the sandstone, though hard, breaks around the grains and therefore has lumpy dull surfaces; the quartzite breaks across the grains and has smooth, shiny surfaces.

Most of this sandstone was probably laid down by ocean currents on beaches, as was the gray sandstone of the benchlands, which it somewhat resembles; but the quartz sandstone must have been worked over a great deal more. The crossbedded parts may, however, have been laid down by beach winds rather than by beach waters: they may be fossil dunes. Their crossbedding and texture are like those of existing dunes that are piled up by prevailing winds where there is an abundant supply of sand unprotected by soil and vegetation (fig. 67). Dunes are usually thought of as features of deserts, either far inland, as in Death Valley in California, or along dry hot coasts, as in the Sahara. But there are many dune fields in cool wet climates along open coasts, as on the shores of Lake Michigan or of the Baltic Sea. If most of the quartz sandstone is an ocean-beach deposit, then the crossbedded part no doubt represents coastal dunes. Fossils might help confirm this and also help decide whether the windy beaches were on a hot dry coast or on a cold wet coast, but no fossils have been found in these rocks.

Red sandstone and conglomerate

Low ledges of dark-red or reddish-brown coarse-grained sandstone and conglomerate flank many parts of the mountain core. The only large body of such rocks is on Rayado Creek, where they underlie almost a square mile of canyon land southeast of Rayado Peak. There are good but small exposures along Cimarroncito Creek (figs. 68, 69) and in the northeast slopes of Bear Mountain.