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PRE-CAMBRIAN ROCKS OF GUNNISON RIVER COLORADO

BY

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ILLUSTRATIONS

PRE-CAMBRIAN ROCKS OF GUNNISON RIVER, COLORADO

By J. FRED HUNTER[1]

INTRODUCTION

PURPOSE AND EXTENT OF THE WORK

The purpose of this study is to present a more detailed description than is now extant of the distribution, nature, origin, and structure of the pre-Cambrian complex of metamorphic and igneous rocks that are exposed in a long, narrow area in Colorado, which extends from Saguache County west and north through Gunnison and Montrose counties into Delta County. The overlying formations are known and have been carefully studied in parts of the area; the present examination is confined to the more ancient rocks that wall the canyons of Gunnison River and its larger tributaries.

The exposures examined are represented in Figure 1. They extend almost without break for approximately 70 miles along Gunnison River, from a point 5 miles below the town of Gunnison down nearly to the mouth of Smiths Fork, along Lake Fork of Gunnison River for more than 13 miles, and along Cebolla Creek for 20 miles, making a total length of more than 100 miles. Below the confluence of Lake Fork with the Gunnison the area consists of a strip from 1 to 4 miles wide stretching along the Black Canyon of the Gunnison, with tongues running up side streams for short distances. East of Lake Fork the superjacent rocks have been partly removed for considerable distances south of Gunnison, leaving a belt of pre-Cambrian rocks, intricately patterned with overlying formations. This belt extends eastward for about 25 miles, as far as Cochetopa Creek, and averages about 14 miles in width, although Cebolla Creek has exposed the pre-Cambrian for 23 miles along its course. (See sketch map, fig. 1.) The rocks of this area west of the 107th meridian, in the Uncompahgre and Montrose quadrangles and beyond to the north end of Vernal Mesa, have been studied in detail, but those east

[1] Before this bulletin could be sent to the printer Mr. Hunter was drowned, May 23, 1917, while engaged in geologic field work in Georgia. The revision of the manuscript and proof has therefore necessarily fallen into the hands of others.

of that meridian and along the Black Canyon north of Vernal Mesa have been examined only in a reconnaissance way.

FIELD WORK AND ACKNOWLEDGMENTS

The field work for this report was begun in the fall of 1911, when the writer, who had been an assistant in the party of Whitman Cross since the summer of 1910, spent two months under somewhat unfav-

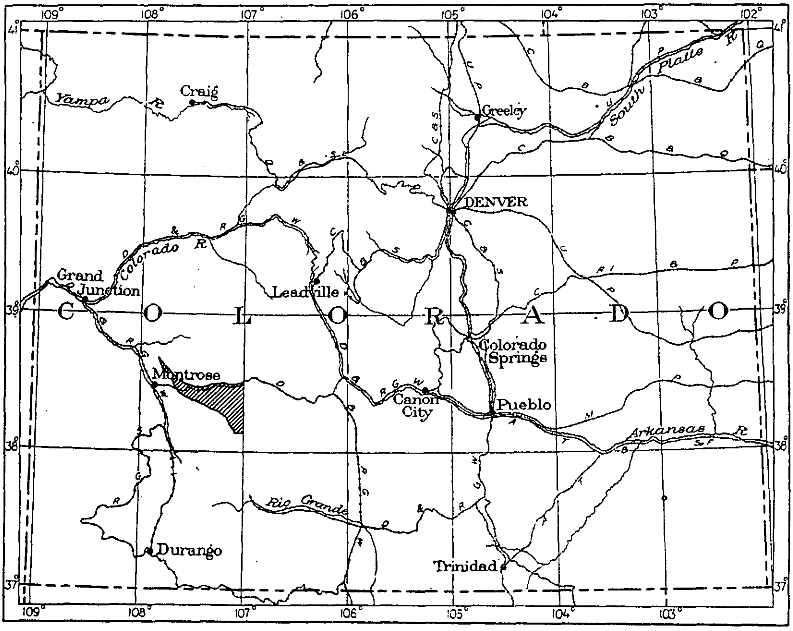


FIGURE 1.—Index map of Colorado showing location of area (shaded) described in this report

orable weather conditions in studying the Lake Fork and Black Canyon portions of the area. Two months of the summer of 1912 were spent in mapping the northeast quarter of the Uncompahgre quadrangle, and during a part of this time the writer was associated with E. S. Larsen, jr. In the field season of 1913 several localities were reexamined, and a reconnaissance of the area east of the 107th meridian was made incidentally to the work of the Cross party.

The bases used for the mapping were the Uncompahgre and Montrose topographic maps, a topographic map of the Uncompahgre Valley and adjacent territory made by the United States Geological Survey and the United States Reclamation Service to show the Uncompahgre Valley project, and for the area east of the 107th meridian, an enlargement of the Hayden map.

The writer wishes to express his appreciation to Messrs. Cross and Larsen for many suggestions both in the field and in the office. A preliminary report on this area was presented to the faculty of the

John Hopkins University in partial fulfilment of the requirements for the degree of doctor of philosophy. To Prof. Edward B. Mathews, who has been a sympathetic friend and teacher, the writer is indebted not only for helpful assistance in preparing the preliminary report but also for the patient and efficient instruction which rendered its accomplishment possible. Finally, grateful acknowledgment is made to Prof. William Bullock Clark and his associates in the geologic faculty of the university for their unfailing kindness and inspiration.

GEOGRAPHY

The first authentic information concerning the Gunnison Valley is contained in the reports of the explorations of Capt. J. W. Gunnison, who was in command of one of the many parties sent by the United States Government in search of a route for a Pacific railroad.[1] The Gunnison party entered the basin of Gunnison River by way of Cochetopa Pass in August, 1853, and traveled down Cochetopa Creek to the river which was at first called the Grand but was later renamed Gunnison in honor of its explorer. Gunnison followed the river down to the site of the present town of Sapinero, where, finding further progress impossible for so large a party, he crossed Lake Fork with great difficulty and traversed the high mesas south of Black Canyon to the head of Cedar Creek, a small tributary of Uncompahgre River. He did not visit the lower part of the Gunnison Canyon, which was reported to him to be inaccessible to men, but continued down the Uncompahgre to the point where the town of Delta now stands. A few weeks later, on October 26, 1853, Gunnison and others of his party were massacred by the Paiute Indians, but the expedition was continued under the command of Lieut. E. G. Beckwith, who wrote the official report.

In 1873 and 1874 the region was mapped by the parties of F. V. Hayden,[2] and the name "Grand Canyon of the Gunnison River" was given to that part of the stream from the mouth of Lake Fork to the mouth of North Fork of Gunnison River. The name Black Canyon is now applied to this stretch of the river.

The explorations of the Hayden parties were made along the rims of the canyon. The first known attempt to explore the bottom of the canyon was made in the winter of 1882–83 by a surveying party of the Denver & Rio Grande Railroad, in charge of B. H. Bryant. The men climbed down into the canyon every morning, worked for two hours, for the most part on ice, and then climbed out again. They proceeded in this manner downstream, but near the mouth of Grizzle

[1] Beckwith, E. G., Report of explorations for a route for the Pacific railroad: U. S. Pacific R. R. Expl vol. 2, pp. 50–58, 1854.

[2] Hayden, F. V., Atlas of Colorado, sheets 8 and 14, U. S. Geol. and Geog. Survey Terr., 1881.

Gulch a gorge with open water halted them and caused them to go to Delta and make a new start up the river. Early in the spring of 1883 connection was made with the point previously reached, and the data for a profile and topographic survey of the gorge were completed.

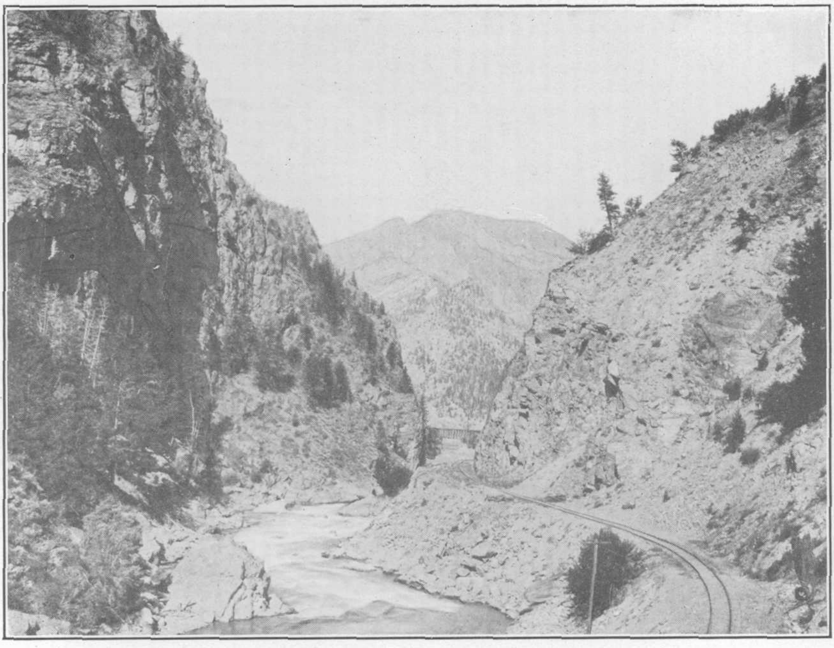
An even more daring exploit was that of A. L. Fellows, of the United States Reclamation Service, who, with W. W. Torrence, descended the river from the mouth of Cimarron Creek, starting on August 12, 1901, and reaching a point opposite the mouth of Smiths Fork 10 days later. The data obtained were used in planning the Uncompahgre irrigation project.

Gunnison River is one of the chief upper tributaries of Colorado River and flows west and northwest through the great valley between the San Juan Mountains on the south and the Elk and West Elk mountains on the north. Swinging to the northwest around the southwest base of the West Elk Mountains, it cuts a mighty trough across the eastern border of the Uncompahgre Valley, but the general altitude of its floor is notably higher than that of the corresponding part of Uncompahgre River.

From Hierro to the mouth of Lake Fork the river runs through a series of narrow gorges of hard pre-Cambrian rock only a few hundred feet in depth, interrupted by three more open valleys at Iola, Cebolla, and Sapinero, where the softer overlying rocks come well down to the valley floor. A short distance west of Sapinero the river plunges into the wild and picturesque Black Canyon, so named from the dark colors of its metamorphic rocks. This canyon has long been famed for its scenic wonders, especially since a portion of it was made accessible to the public by the Denver & Rio Grande Railroad. The walls are in places unusually sheer and precipitous, as in the granite area west of Curecanti Needle, where they rise almost vertically for nearly 1,200 feet. (See Pl. II.) For 9 or 10 miles below Crystal Creek the sides of the canyon are extremely steep and the gorge is correspondingly narrow, as is well shown in Plate III. Where the direction of the river cuts the vertical joint planes and structure lines obliquely, curious spirelike rocky forms are developed. (See Pl. IV.) This rock carving is probably best shown near the mouth of Crystal Creek, and the famous Curecanti Needle, at the mouth of Blue Creek, is an example of this phenomenon on a larger scale. (See Pl. II, *A*.)

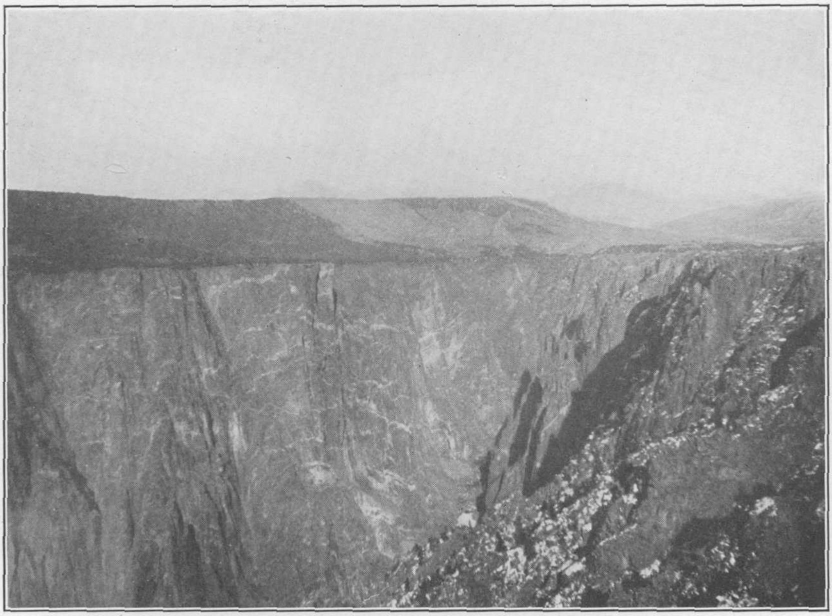
At 4½ miles below the mouth of Crystal Creek is the river portal of the celebrated Gunnison tunnel, which was driven under Vernal Mesa for more than 6 miles to divert water from Gunnison River for irrigating the Uncompahgre Valley. On the north side of the canyon about 6 miles below River Portal is a famous scenic vantage point,

A. BLACK CANYON AND CURECANTI NEEDLE



B. BLACK CANYON EAST OF THE MOUTH OF CIMARRON CREEK

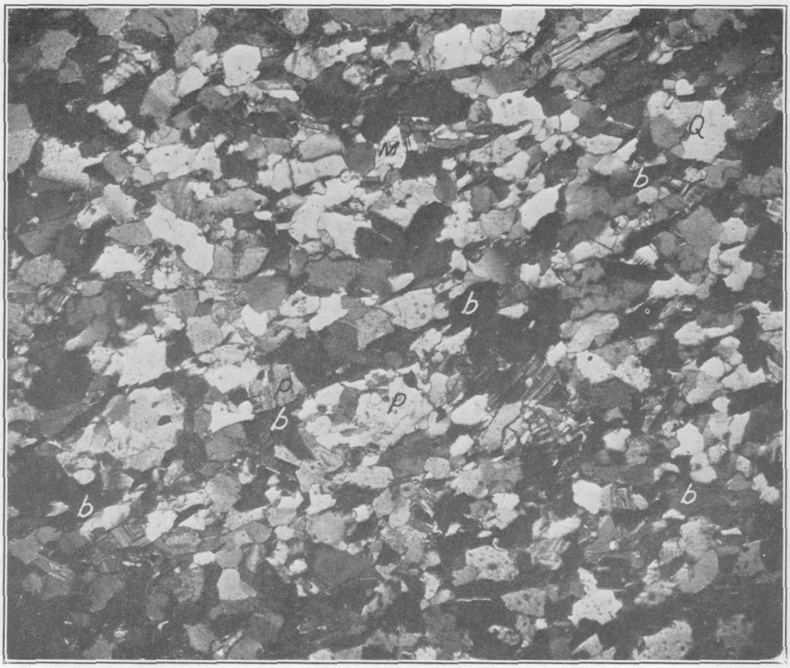
BLACK CANYON BELOW THE MOUTH OF CIMARRON CREEK



A. VIEW ACROSS THE GUNNISON CANYON FROM THE NORTHWEST END OF BOSTWICK PARK

B. VIEW DOWN THE LOWER PORTION OF THE GUNNISON CANYON FROM THE NORTHWEST END OF VERNAL MESA

A. BANDED BIOTITE SCHIST OF THE BLACK CANYON SCHIST



B. PHOTOMICROGRAPH OF BIOTITE SCHIST

Q, Quartz; *b*, biotite; *M*, muscovite; *p*, plagioclase. Enlarged 26 diameters from which views up and down the canyon for many miles can be obtained. The walls in this vicinity are very steep, rising in places almost vertically for more than 1,000 feet, as is well shown in Plate IV, *A*.

The history of the cutting of the Gunnison, which took place during Pleistocene and Recent time, has been worked out by W. W. Atwood[3] in connection with his physiographic study of the San Juan Mountains. It will suffice here to note that within the Uncompahgre quadrangle the river valley is flanked by high lava-capped mesas, the structure of which is flat or gently synclinal with an axis following the line of the river, whereas below Crystal Creek the canyon is approximately in the crest of an anticline of Triassic "Red Beds" and later sediments. The most curious feature of the physiography is that the river failed to avail itself of the path of apparent least resistance west from the mouth of Cimarron Creek through a scant mile of crystalline rock to the soft Cretaceous shale but instead turned northwestward, thereby being obliged to cut its way in hard pre-Cambrian rocks for many miles.

The canyon of Lake Fork of the Gunnison from Madeira siding to its mouth, a distance of 13 miles, is only slightly less noteworthy than that of the major stream. The wildest portions of this gorge between the abandoned railroad stations of Vanguard and Marion, are comparable in every way to the Black Canyon. Cebolla Canyon is less steeply walled (see Pl. XV, *A*), although in places its sides are extremely precipitous. The wide and fertile meadows on Cebolla Creek near Powderhorn provide sites for prosperous ranches, and even its canyon in many places affords sufficiently wide alluvial floors for cultivation. Both these streams head far up in the San Juan Mountains and flow north-northwest through the area under discussion to the Gunnison.

The pre-Cambrian country south of the Gunnison in the Uncompahgre quadrangle and farther east is characterized for the most part by high, nearly flat mesas of sandstone or lava, whose fronts slope steeply down to the older crystalline rocks. These mesas run back with a slight rise to the distant mountains, and they finger out between the side streams toward the main river. Where the overlying formations have been removed by erosion the surface of the pre-Cambrian complex is in many places undulating and physiographically mature. (See Pl. XV, *A*.)

Most of the region studied is easily accessible. The Denver & Rio Grande Western Railroad follows Gunnison River as far as Cimarron

[3] Atwood, W. W., Geographic history of the San Juan Mountains since the close of the Mesozoic era (read before the Geologic Society of America Dec. 29, 1915).

Creek, and the Lake City branch of the same line runs through the Lake Fork canyon. In the Cebolla Valley and along the Gunnison above Sapinero ranches and small settlements are not infrequent. There are scarcely any houses near the rims of the Black Canyon, but at some distance back from the river houses stand along the larger tributary streams. Ranches on Cimarron and Crystal creeks and in Red Canyon are the most convenient points from which to explore the canyon. Most parts of Vernal Mesa may be reached from Bostwick Park, which lies southwest of it and is extensively settled.

LITERATURE

The first mention of the pre-Cambrian rocks of Gunnison River was made in 1855 by James Schiel.[4] He did no more than to recognize the presence of a complex of "feldspathic granite, gneiss, a rough siliceous shale, and fine mica slate, the latter dissolving only under a powerful lens into a mixture of quartz and mica."

J. J. Stevenson[5] in 1875 referred to the rocks of this area as schist and gneiss but added no data of present value.

A. C. Peale[6] in 1876 recognized the pre-Cambrian age of the complex. He noted the manner of occurrence of the rocks in canyons as well as their schistose and metamorphic character. In describing this belt of gneiss and schist, he spoke of it as "narrow for the most part, extending but a short distance from the edge of the river except on the lateral branches, where the metamorphic rocks are exposed some distance from the Gunnison, forming long tonguelike areas."[7]

A summary of the knowledge of the pre-Cambrian rocks of this and neighboring regions has been prepared by C. R. Van Hise and C. K. Leith.[8] Except in the generalized mapping of the early reconnaissance surveys of Wheeler and Hayden, no study has been made of the Gunnison River region.

ADJACENT PRE-CAMBRIAN AREAS

The pre-Cambrian metamorphic complex together with the igneous materials that have been intruded into it constitute the basement upon which all the later formations and lava flows have been spread. Only where great elevations of the terranes have occurred or where the streams have cut far down into mountain or plateau masses have the older rocks been exposed.

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[4] U. S. Pacific R. R. Expl., vol. 2, pp. 96–107, 1855.

[5] U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 303–501, with atlas sheets, 1875.

[6] Report upon the Eagle, Grand, and Gunnison rivers: U. S. Geog. and Geol. Survey Terr. Eighth Ann. Rept., pp. 94–105, 107–109, 425, 1876.

[7] Geological report on the Grand River district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., pp. 29–101, with atlas sheets, 1877.

[8] Pre-Cambrian geology of North America: U. S. Geol. Survey Bull. 360, pp. 800–833, 1909.

The largest area of pre-Cambrian rocks in the San Juan region lies in and on the south side of the Needle Mountains. This great massif forms part of the Continental Divide and has been exposed by Animas River and its tributaries. A study of these formations by Cross and Howe, cited by Van Hise and Leith,[9] showed that the rocks are divisible into the following units in ascending order:

1. The Archean gneisses and schists.
2. A group of greenstones with derived gneisses and intimately associated with very subordinate quartzites.
3. A group of conglomerates, quartzites, and shales or slates, called the Needle Mountains group.
4. Intrusive and still massive granite and gabbro bodies of large size with many smaller dikes.

The Sawatch Mountains, forming the part of the Continental Divide east of the Gunnison area, are composed mainly of pre-Cambrian granite, gneiss, and schist. They have been little studied and have not been divided into lithologic or structural groups. However, abundant quartzites, interbedded with schistose acidic porphyries and diorites, were observed by Van Hise and Leith in the Salida area. A series of hornblendic, micaceous, and chloritic schists occurs near Salida, Marshall Pass, and Tincup Pass and is believed by Cross to be a series of metamorphosed Algonkian lavas.[10]

The pre-Cambrian rocks of the Gunnison area are connected with those of the Sawatch Range by exposures north of Tomichi Creek, and it may be assumed that the rocks exposed in the lateral canyons of the Gunnison represent the character of much of the old substructure of the West Elk and San Juan mountains.

RELATIONS TO THE OVERLYING FORMATIONS

Above the pre-Cambrian rocks in the Gunnison area is a profound unconformity which is both erosional and structural. Except for a small body of limestone, which is itself probably of pre-Cambrian age, on the west side of the Cebolla Valley near Powderhorn, the oldest formations known to be in contact with these rocks are the Triassic "Red Beds." Over a large part of the area the pre-Cambrian rocks are overlain by what is thought to be La Plata sandstone, of Jurassic age, and at many points they are in immediate contact with Tertiary volcanic rocks. On the southwest, from Lake Fork to a point near the south end of Bostwick Park, the complex is in fault contact with younger sediments. The contact between the metamorphic rocks and the Mesozoic formations is everywhere, unless disturbed by faulting, very regular. This is well shown along the north rim of

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[9] Op. cit., p. 830. See also Cross, Whitman, and others; U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), Needle Mountains folio (No. 131), Ouray folio (No. 153), and Engineer Mountain folio (No. 171).

[10] Van Hise, C. R., and Leith, C. K., op. cit., p. 829.

the Black Canyon, where the contact is remarkably sharp and straight and in general dips gently to the northeast. (See Pl. XI, *A*.) This regularity of contacts indicates a peneplanation accomplished since pre-Cambrian time. Where the sedimentary section has been removed and the later volcanic rocks rest directly on the crystalline rocks the contact is as a rule less regular. Notable irregularity is seen in the eastern part of the Uncompahgre quadrangle, especially around Powderhorn and in the Milkranch Basin.

OUTLINE OF THE PRE-CAMBRIAN GEOLOGY

The pre-Cambrian of the Gunnison area is composed mainly of a metamorphic complex of mica and amphibole schists and gneisses, to the major portion of which the name Black Canyon schist is here applied, and which, save for two unique bodies of schist and amphibolitic rocks, called here the River Portal mica schist and the Dubois greenstone, is of fairly uniform character throughout the region. This complex has been extensively intruded by granite, granite porphyry, syenite, aplite, and pegmatite and to a less degree by a variety of more basic rocks, ranging from quartz diorite and diorite to diabase and gabbro. In addition, in the vicinity of Iron Hill, near Powderhorn,is an area of highly sodic and nephelinitoid rock, ranging from soda and cancrinite syenite, ijolite, and nepheline gabbro to pyroxenite with many curious and interesting associated apatite, analcite, and melilite rocks. In this area there is also a body of limestone considerably more than a square mile in extent, making Iron Hill, which rises 1,000 feet above the floor of the adjacent Cebolla Valley.

METAMORPHIC COMPLEX

The fundamental group of rocks of this area is the metamorphic complex of mica schist, granite gneiss, amphibole schist, and amphibolite. The entire pre-Cambrian mass is made up of these materials save where later igneous bodies have intruded it. These rocks have been profoundly metamorphosed by compression, mashing, and folding, and definite foliation has been almost everywhere developed in them and indicates by its present attitude the nature and direction of the tectonic forces that have acted upon the mass.

AGE AND CORRELATION

The metamorphic complex of schists and gneisses in the Gunnison area has been regarded as of pre-Cambrian age ever since it was first mapped by A. C. Peale in the course of the Hayden survey of Colorado. Consideration of the relations and character of these schists and gneisses and a comparison of them with other pre-Cambrian rocks of the Rocky Mountains lead to the belief that they are of Archean age. It is not conceivable that the rocks composing the complex acquired their present character elsewhere than at great depths beneath the earth's surface, and the alteration probably took place in that zone which has been called by Van Hise "the zone of flowage." As the structure of neither the overlying beds nor the Paleozoic formations found in the San Juan Mountains shows a comparable degree of folding and metamorphism, it is manifest that these rocks of the metamorphic complex are much more ancient than the Cambrian. They are separated from the rocks overlying them by a profound erosional and structural unconformity, and indeed great periods of erosion subsequent to the great deformative movements had necessarily elapsed before the Cambrian beds were laid down.

A strong probability that most of the metamorphic rocks are pre-Algonkian is found on comparison with the pre-Cambrian exposures elsewhere throughout the Rocky Mountains and more particularly in the San Juan Mountains on the south. In texture, composition, structure, and degree of metamorphism they resemble most closely the metamorphic rocks in the Silverton, Needle Mountains, and Engineer Mountain quadrangles, described by Cross, which are overlain by a group of conglomerates, quartzites, and shales or slates called the Needle Mountains group and thought to be of Algonkian age. In regard to these rocks Van Hise and Leith[11] concluded that:

> The ancient granites, gneisses, and schists constituting the oldest basal rocks of the mountains (division 1 of Cross) are referred to the Archean. [See p. 7.] They are simil rain lithology and complexity to the Laurentian rocks of Canada and the Lake Superior region, using the term in its restricted sense.

The complex of the Gunnison area does not differ greatly from the ancient metamorphic crystalline rocks occurring at many localities throughout the Cordilleran system and held to be of probable Archean age. On the other hand, it is very different from any rocks of that region that are thought to be post-Archean. It corresponds most closely with the Archean Vishnu schist of the Grand Canyon section,[12] collections from which the writer has recently studied.

DIVISIONS OF THE COMPLEX

Although the many varieties of metamorphic rocks that make up the complex are intimately and in places rather intricately associated, certain major bodies or zones have been distinguished and will be mapped and described as separate units. These are, in the order in which they will be described, (1) the Black Canyon schist, composed

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[11] Op. cit., p. 833.

[12] Walcott, C. D., Algonkian rocks of the Grand Canyon of the Colorado: Jour. Geology, vol. 3, pp. 312–330, 1895; U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 497–524, 1894. Ransome, F. L., A comparison of some Paleozoic and pre-Cambrian sections in Arizona: Science, new ser., vol. 27, pp. 68–89, 1908. Noble, L. F., and Hunter, J. F., A reconnaissance of the Archean complex of the Granite Gorge, Grand Canyon, Ariz.: U. S. Geol. Survey Prof. Paper 98, pp. 95–113, 1917.

chiefly of biotite schist with many narrow bands of quartz-mica schist, granite gneiss, amphibole schist, chlorite schist, and ultrabasic rocks and representing the most widespread and possibly the oldest and most fundamental class of rocks of the region; (2) the River Portal mica schist, a large well-defined body somewhat similar in character to the Black Canyon schist but differing markedly in texture and to a less degree in composition; (3) the Dubois greenstone, representing a broad zone parallel to the schistosity of the other rocks and somewhat similar to certain smaller zones found throughout the area.

BLACK CANYON SCHIST

OCCURRENCE

The most widespread group of the metamorphic complex, the Black Canyon schist occurs throughout the area, with many interruptions, from Cochetopa Creek, at the extreme eastern end of the area, down the Gunnison nearly to the mouth of Smiths Fork, the most northern and western point of the area. Save for the many bodies of igneous rocks that have invaded it and the River Portal schist, which might be regarded as a part of it and which extends from a point east of Cimarron to the north end of Vernal Mesa, the pre-Cambrian area adjacent to Gunnison River is composed almost entirely of the Black Canyon schist. The name Black Canyon schist is here introduced in the belief that it will serve clearness of discussion and ready reference even if not used for correlation by workers in other pre-Cambrian areas.

From Lake Fork eastward the Black Canyon schist is bounded on the south by the Dubois greenstone, also a closely related mass, the contact with which is for most of its extent a sharp line running nearly due east through the old mining town of Spencer and a mile north of Dubois and Vulcan. South of this line there are a few minor occurrences of mica schists, which are thought to be inclusions in later rocks, and suggest the persistence of these rocks under the great volcanic mass of the San Juan Mountains on the south. Elsewhere the complex is delineated by overlying formations. North and northeast of the river the old peneplain surface at the top of the crystalline rocks dips northeast and rapidly disappears under Mesozoic sediments or Tertiary volcanic rocks. North of the Vernal Mesa the river flows in general northward and has exposed the schist along its inner gorge in a long, narrow strip extending to the vicinity of the mouth of Smiths Fork, where it finally plunges under later formations.

The best and most accessible exposures of the schist are in the walls of the Black Canyon from Sapinero to the Curecanti granite and up Lake Fork Canyon to the granite mass 1 mile above Vanguard. Other good exposures occur along Gunnison River between Sapinero and Hierro and in the canyon below the Vernal Mesa granite body. Abundant outcrops of these rocks occur also along the Cebolla and adjoining mesas as far south as the Dubois greenstone.

GENERAL CHARACTER

The schists and gneisses of this group of the metamorphic complex differ greatly in appearance from place to place in the canyon walls and through the area. In many of their outcrops they range from black to gray, and show banding even at some distance. Weathering may give them brownish or yellowish tones, and an abundance of microcline may add a slight pinkish tint. Where there has been extensive injection of granitic material gray or flesh-colored bands, streaks, or blotches are added to the darker shades. The rocks of this group show great diversity in both composition and texture, including all gradations from biotite schist, quartz-muscovite schist, and granite gneiss to chlorite and amphibole schists and even to amphibolite. The commonest and fundamental rock of the complex is biotite schist in which the other rocks of the group occur as relatively narrow zones, many of which are indefinitely bounded.

Most of the rocks of the Black Canyon schist are well laminated, showing glistening biotite or hornblende on surfaces parallel to the schistosity, and where free from injections they have a moderately fine and even texture. The strike of the schistosity is remarkably persistent over large areas, although locally there may be variations or aberrant structural features, some of them traceable to faulting or to igneous intrusion. Along Cebolla Creek, Lake Fork, and Gunnison River as far as Nelson Gulch, 2 miles west of Curecanti Creek, a west-northwest to west strike and various though steep dips are maintained with but few notable irregularities. At Nelson Gulch there is a pronounced pre-La Plata fault, beyond which the structure is of different type, and the strike of the schistosity is dominantly north to north-northeast.

The metamorphic rocks have been extensively injected with granitic materials, and the resulting rock is of still more varied character. In many places the injection has been so fine and the mixture with the invaded material so intimate that the rocks have become injection gneisses. Some of these injections were parallel to the schistosity and resulted in definite banding; elsewhere the granitic material intruded the schist as dikelets, dikes, sill-like lenticles, or irregular bodies. Probably the best examples of these minor and intimate injections are in the Black Canyon near the mouth of Lake Fork.

Areas in which the intruding granites and pegmatites are so numerous and extensive as to approach or equal in quantity the invaded schist have been outlined in a generalized way on the map. Such areas occur in the eastern part of the Uncompahgre quadrangle, west and south of the Curecanti granite mass lying along the Black Canyon and Blue Creek, and on the Vernal Mesa contiguous to the Vernal Mesa granite body. In these localities the invaded rocks were originally the same schists that are found elsewhere, but they have been so thoroughly invaded by granitic material, most of it similar in character to the adjacent larger granite masses, that the mapping of the individual bodies would be a hopeless task.

A few zones of amphibole schists have been outlined somewhat diagrammatically and will be mentioned in the discussion of the various types. The differences in composition and appearance among the rocks of this group, although considerable, are not sufficiently great or persistent to make practical or even desirable any more detailed recognition by cartographic units.

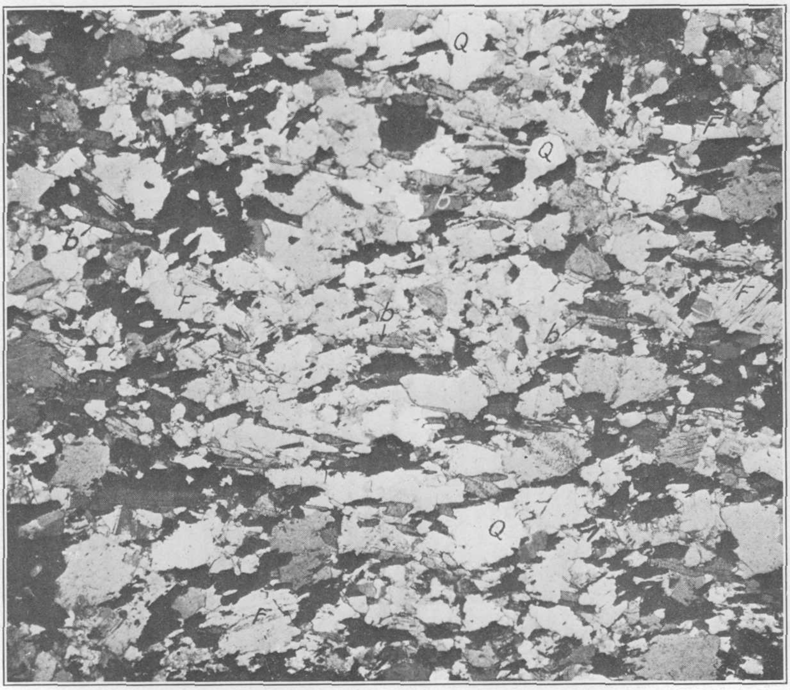
BIOTITE SCHIST

General features.—Rocks of the biotite schist type occupy as much as if not more than half of the total exposed pre-Cambrian area of the region and commonly show the most intense metamorphism. They have been subjected to great pressure, mashed, foliated, and completely recrystallized and are in consequence very schistose, breaking easily along the planes of lamellation; their content of mica is therefore likely to be overemphasized. On surfaces at right angles to the foliation quartz and feldspar, the other essential constituents of the rock, are almost invariably seen in greater amount than the mica. (See Pl. V, *A*.) Most of these rocks are gray to black, but they show rusty pink shades where abundant microcline is present, and they weather to dark brown and reddish yellow. They are of moderately fine grain and of uniform texture unless injected by granitic or other igneous material. (See Pl. VI, *A*.)

The biotite schists form the fundamental class of rocks in which the other rocks of the group occur as relatively narrow and more or less indefinite bodies. They are finely exposed in the Black Canyon, east of the Curecanti granite mass, and below Red Rock Canyon, as well as in the Lake Fork and Cebolla gorges. A very fine and compact phase of this type is common and forms the greater part of the walls of Lake Fork canyon from the mouth of Willow Creek to Vanguard.

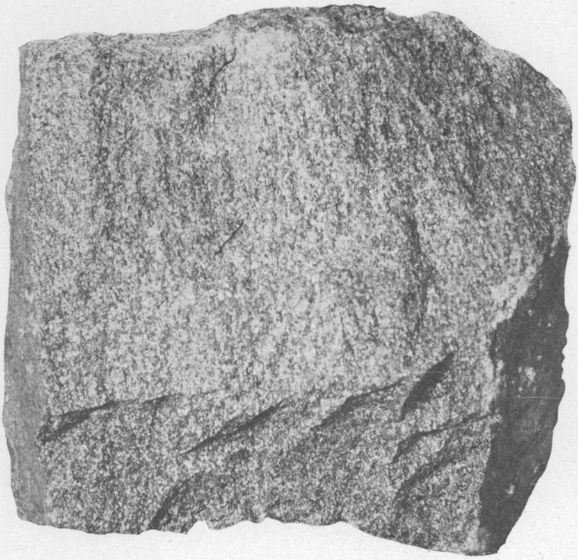
Petrography.—Under the microscope the biotite schists are found to be holocrystalline and allotriomorphic and to possess an equiangular to seriate fabric, commonly showing elongation of the minerals in

A. BIOTITE SCHIST OF THE BLACK CANYON SCHIST

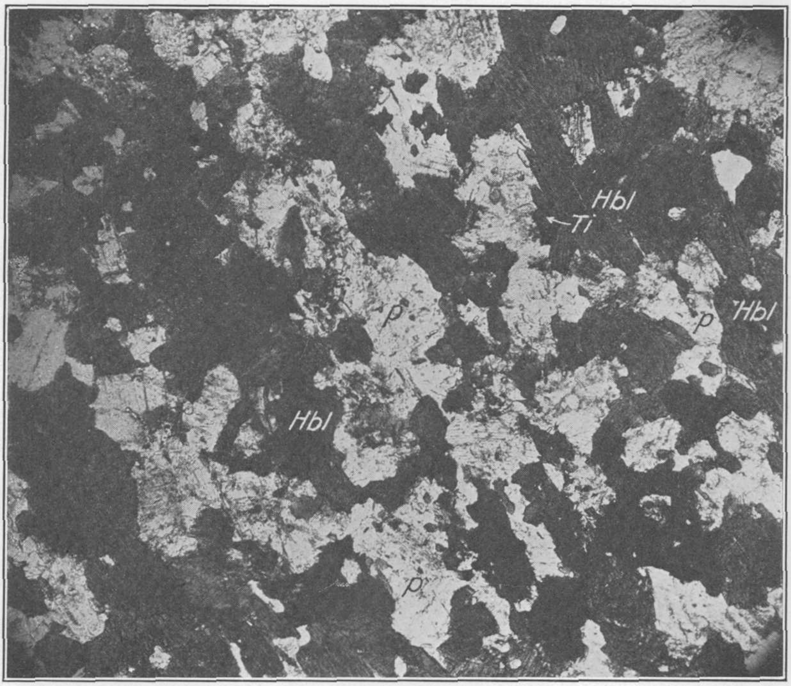


B. PHOTOMICROGRAPH OF BIOTITE SCHIST

Q, Quartz; *b*, biotite; *F*, feldspar. Enlarged 26 diameters

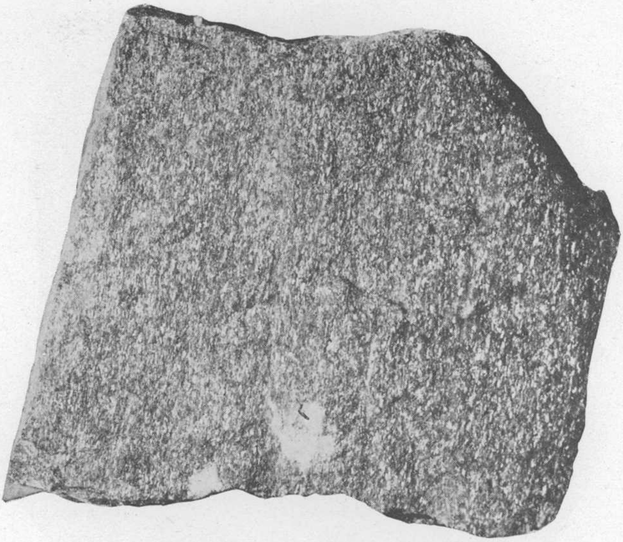


A. AMPHIBOLE SCHIST OF THE BLACK CANYON SCHIST

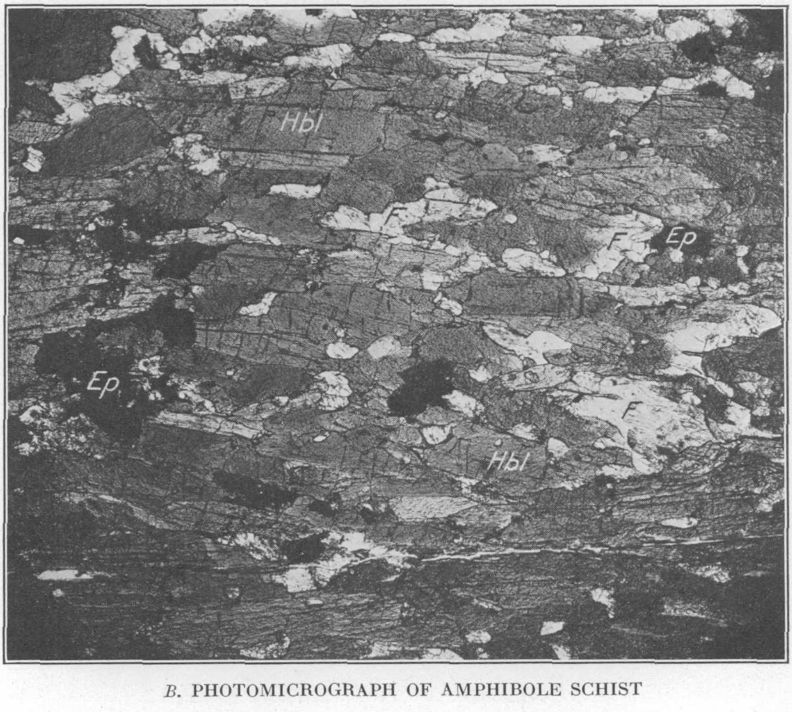


B. PHOTOMICROGRAPH OF AMPHIBOLE SCHIST

Hbl, Hornblende; *Ti*, titanite; *p*, plagioclase. Enlarged 26 diameters

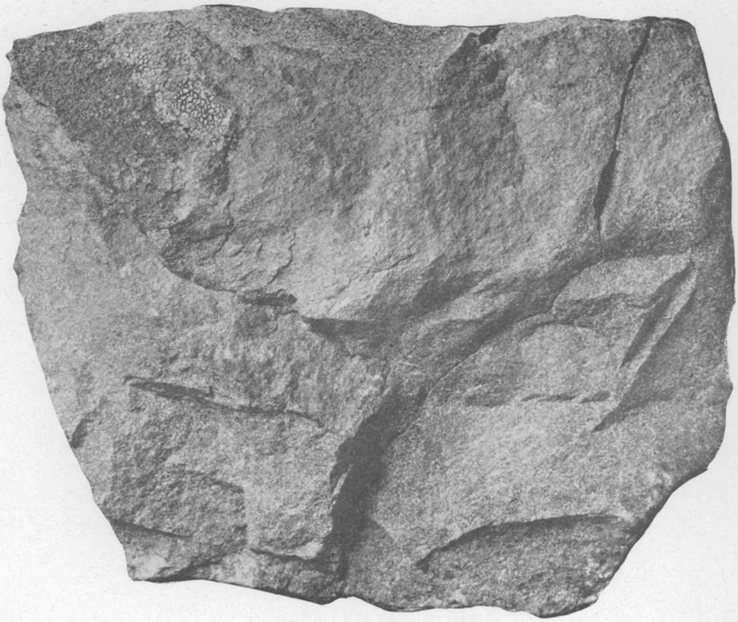


A. AMPHIBOLE SCHIST OF THE BLACK CANYON SCHIST

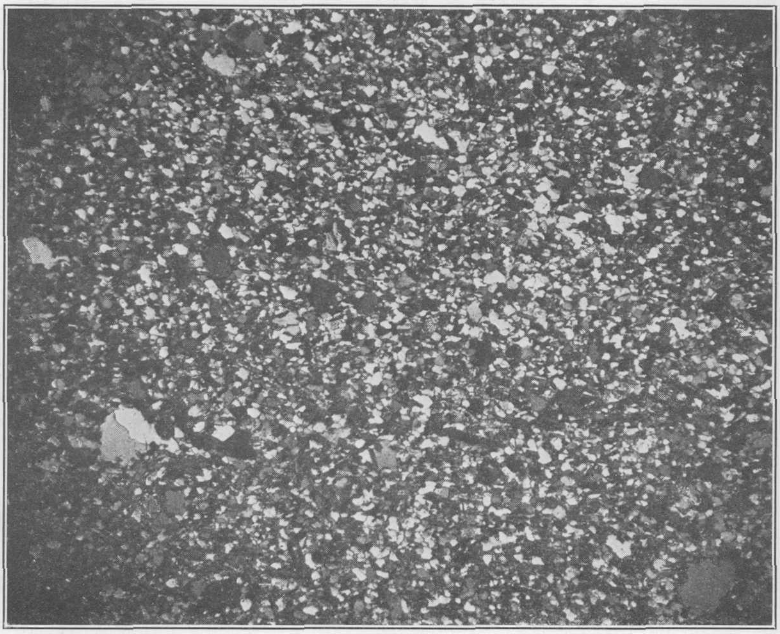


B. PHOTOMICROGRAPH OF AMPHIBOLE SCHIST

Hbl, Hornblende; *Ep*, epidote; *F*, Feldspar. Enlarged 26 diameters



A. RIVER PORTAL MICA SCHIST FROM VERNAL MESA



B. PHOTOMICROGRAPH OF MICA SCHIST

parallel arrangement. (See Pl. VI, *B*.) Most of the rocks have a granoblastic structure,[13] (Pl. V, *B*) the crystals averaging between 0.5 and 1 millimeter in diameter, with many individuals above and below those limits.

In most of the specimens studied quartz and feldspar are present in nearly equal amounts and with biotite are the principal mineral constituents. Quartz invariably occurs in the biotite schists, and in many of them it is the most abundant mineral, in an even greater number it exceeds or equals in amount the predominating variety of feldspar, and in a relatively few varieties it is subordinate to the feldspar and even to the biotite. It is usually clear and pellucid but may contain microscopic inclusions not easily determinable and in some grains shows undulatory extinction. This evidence of straining is, as a rule, more marked in the quartz of injected material than in that of the schists themselves. Many of the quartz crystals are larger than their companion grains of the other minerals.

Of the feldspars microcline and soda plagioclase are invariably present and in many specimens occur in nearly equal amounts, although either may predominate. Orthoclase is almost always to be found but is surprisingly subordinate. The feldspars occur in anhedra and range in composition from albite to oligoclase, rarely to andesine. The microcline in many specimens is intergrown with plagioclase as microperthite or with quartz as micropegmatite. Where weathering has occurred microcline is commonly the least affected of the feldspars.

Biotite occurs characteristically as thin lamellae, averaging from 0.05 to 0.15 millimeters in thickness and from 0.5 to 1 millimeter in length, arranged in parallel planes, which, in sections oblique to the schistosity, show an alternation with bands of quartz and feldspar. (See Pl. VI, *B*.) Most of the biotite is brown to black, and some is green. It shows irregular arrangement and absence of crystal outline, being as a rule ragged and frayed.

Muscovite is present in smaller quantities in about half the section of biotite schists examined. Hornblende is rather rare and is very subordinate where present. The muscovite and hornblende, like the biotite, occur in lamellae parallel to the schistosity.

Magnetite is perhaps the commonest accessory mineral, although apatite, titanite, and garnet are usually found. Zircon is present in places, and calcite was seen in several slides, but may be of secondary origin. Sericite, epidote, and zoisite occur in decreasing amounts in the order named.

Classification and origin.—In the classification of Grubenmann the biotite schists of this type belong to the kata-biotite-orthoclase gneiss[14]

[13] Grubenmann, U., Die kristallinen Schiefer, 2d ed., p. 97, 1910.

[14] Op. cit., p. 146.

in the group of the alkali feldspar gneiss of the deepest zone (Kata-Gesteine). This zone in general corresponds to the zone of flowage or anamorphism of Van Hise.

The schists and gneisses of the type here discussed are characterized by their abundance of alkali feldspar, particularly the potash varieties, expressed as microcline and orthoclase. This fact with the amount of biotite present indicates that the original rock was relatively rich in potash with an uncertain content of soda. In the field the rocks give evidence of a profound metamorphism such as might well obliterate slight differences in original character from place to place. However, from a study of their mineral composition and texture it seems probable that they were derived from rocks having the composition of a granite or a quartz monzonite.

QUARTZ-MUSCOVITE SCHISTS

General features.—The quartz-muscovite schists occur as a narrow border to the biotite schists in the Cebolla Creek basin and seem to grade into them. In outcrop these schists are of lighter color than the biotite schists and on fresh surfaces range from light gray with a satiny luster to dark gray. On surfaces parallel to the schistosity the fine muscovite flakes give them a characteristic silvery sheen, whereas surfaces at angles to the schistosity may show delicate alternate bands of dark gray and white or pink. The schists are typically fine grained and very fissile, and a few of them have almost a slaty cleavage. The individual minerals are so fine as to be difficultly distinguishable to the unaided eye, although with the aid of a strong lens quartz, muscovite, feldspar, and more rarely biotite and chlorite can be seen on favorable surfaces. The schists of this type in general resemble the large body of River Portal mica schists described on pages 22–28. These quartz-muscovite schists form a zone about half a mile wide, which extends along the border of the Archean schists and gneisses, in contact with the Dubois greenstone, for about 5 miles from the west side of Cebolla Creek eastward to Spencer on Wildcat Gulch. Along the zone westward from Cebolla Creek the schists become more and more like the typical biotite schist, although of a finer-grained phase, and where its extension reaches the Lake Fork canyon biotite schists of the normal canyon type are found. The zone has been traced eastward only as far as the Iola road, 1 mile east of Spencer, although rock suggesting it was observed several miles east of Vulcan in South Beaver Creek. The structure of this zone of schist conforms in every way with that of the adjacent biotite schists, which are also fine-grained. Indeed, it was thought that in Wildcat Gulch here was a gradation from the quartz-muscovite schist to the typical biotite schist. Hence it was not practicable to draw a definite line of contact between the two types of schist, although dotted lines indicate the approximate width of the quartz-muscovite schist zone from Cebolla Creek eastward to the Iola road.

There are several small isolated bodies of this schist within the Dubois greenstone, not far from the northern boundary of that complex. The wedge-shaped area mapped as chlorite schist half a mile southwest of Spencer contains zones of this schist.

Associated with this type of quartz-muscovite schist are several smaller zones of chlorite schist. These rocks are diverse in texture and composition and form a rather incomplete gradation in their content of chlorite toward the more chloritic phases of the quartz-muscovite schist. They are found in zones, as a rule not more than a few hundred feet wide across the strike and differing in persistency along it. The only zone observed outside the Dubois greenstone area was a very small one in the quartz-mica schist on the west side of Cebolla Creek below the mouth of Goose Creek. The larger and more persistent zones occur in the greenstone on the borders of the isolated areas of muscovite schist and are described in connection with that body (pp. 34–35).

Petrography.—Under the microscope the quartz-muscovite schists are marked by their fineness of grain, the individual minerals ranging from almost submicroscopic size to 0.5 millimeter in diameter. They are holocrystalline, allotriomorphic, and well banded, showing alternations of mica, chiefly muscovite, with quartz and feldspathic minerals. In sections cut parallel to the schistosity these rocks show an equigranular to seriate fabric, although the individual crystals may be slightly elongated in the plane of foliation.

Owing to the fineness of grain the various constituent minerals can not be easily studied. However, quartz, feldspar, muscovite, and to a less degree biotite are the chief minerals. Quartz is by far the most abundant, occurring as fine, irregular-shaped grains, which are clear save for a few inclusions and are characterized by sharp extinctions. Owing to the presence of untwinned soda plagioclase in these rocks the quantity of quartz is likely to be overestimated. However, in some sections it appears to constitute considerably more than 5 per cent.

In many rocks the next constituent in order of abundance is muscovite, occurring in thin lamellae parallel to the schistosity, whereas in other rocks, particularly those richer in biotite, feldspar is prominent and may surpass the muscovite. The muscovite usually occurs in very fine grains without any trace of crystal outline, and in many of the schists it occurs as fine interstitial material between the larger crystals of quartz and mica. So far as could be determined the feldspar consists of soda plagioclase and microcline with little orthoclase. For the same reason that the amount of quartz may be overestimated the amount of plagioclase may be underestimated, and doubtless a chemical analysis of the rock would show the presence of considerably more of this mineral than the microscope. Indeed, in one slide little if any feldspar could be distinguished.

Biotite, occurring in similar manner to the muscovite, is common, particularly in the portions of the mass poor in feldspar. Chlorite is present in greater or less amount in nearly all the rocks of the group but is most abundant in the small masses within the areas of the Dubois greenstone already mentioned. From its relations and occurrence the chlorite appears to be for the most part the product of the same deep-seated metamorphism that has affected the schistosity of the rock, although here and there it may have been produced by processes of weathering. It is typically colorless to very pale green, much of it is slightly pleochroic, and it shows the characteristic low birefringence with anomalous blue color and in one section spherulitic extinction. Magnetite, apatite, zircon, and in one slide a small amount of tourmaline were observed as accessory minerals. Sericite, epidote, and calcite occur in places as secondary minerals.

Origin and relations.—Notwithstanding the fact that these rocks now show similarity to the larger mass of biotite schists, their texture, composition, and occurrence indicate that they have been derived from rocks of a different kind. The highly quartzose composition of some of them raised the question whether they had come from sedimentary or igneous rocks. No significant variation from place to place in the mass such as might be characteristic of a sedimentary series could be established, although sections along and across the strike of the schistosity were carefully studied. These sections were alike in showing intense metamorphic changes, but they exhibited differences from place to place in the apparent content of feldspar and dark mica, the rocks with more muscovite carrying more feldspar and those with abundant biotite being as a rule more quartzose. Although there is no good evidence as to the original character of the quartz-muscovite schists of this belt near Spencer, yet owing to their similarity and proximity to the River Portal schists it seems probable that they were formed from similar rocks, which in turn were substantially different from those from which the great mass of biotite schists were derived. Furthermore, their resemblance to some phases of the granite porphyry described on pages 41–44, together with their mineralogic character, suggests that they may have been derived in part from rocks such as are found in that mass.

GRANITE GNEISS

General features.—Differing in greater or less degree from the types above described are the granite gneisses of the region. These rocks are light gray with pinkish tones, have a granitoid texture, in places almost entirely changed to gneissic, and as the name implies are believed to be metamorphosed granite. They are of rather fine, uniform grain and show various degrees of lamellation. Quartz and feldspar, particularly the pink varieties, are more prominent and mica far less so than in the schists. It is difficult to distinguish without very careful examination between some rocks of this type and the banded injection gneisses of the canyons.

A considerable body of this rock is exposed in a zone that crosses the ridge at the northwest end of Vernal Mesa adjacent to the Vernal Mesa granite mass. It is about half a mile in width along this ridge; its other limits, which seem to be vague and gradational, have not been determined, the canyon in this vicinity being inaccessible for study. At places throughout the area similar rocks may be observed as narrow zones of little persistency—for example, along Gunnison River near Hierro and in Willow Creek.

Petrography.—The microscope shows that the granite gneisses are holocrystalline and possess a granoblastic structure in which the grains are of nearly equal size, averaging between 0.5 and 1 millimeter in diameter, and are almost entirely without crystal boundaries. The rocks show considerable granulation, although less than those of the first type, to which they are similar in composition. They consist chiefly of quartz and feldspar in approximately equal amounts, with subordinate biotite. The quartz contains many microscopic inclusions and commonly shows undulatory extinction, and the feldspar consists of microcline, sodic plagioclase (albite-oligoclase), and orthoclase decreasing in abundance in the order named. Much of the biotite is ragged in outline, and some is in poikilitic intergrowth with quartz. Muscovite is seen in most slides as very small grains and is, in part at least, of katamorphic origin. Garnets in small round grains are numerous, and magnetite, zircon, and apatite were observed in very subordinate amounts. Sericite and epidote are present as alteration products after feldspar and biotite respectively.

Origin.—The granite gneisses can usually be readily distinguished in the field by their granitic character, although gradations toward the mica schists and injection gneisses preclude a sharp line of separation in some places. It is believed that most of these rocks resulted from the metamorphism of very ancient granitic bodies which did not differ greatly in composition from those later intruded into the metamorphic complex.

AMPHIBOLE SCHIST

General features.—Petrographically the complex of schists and gneisses is separable into two major classes, one containing the mica-rich rocks already discussed and the other the hornblende-rich metamorphic rocks. The rocks of this second class are of even more diverse character than those of the first, ranging from little changed metadiorites to amphibolites made up almost entirely of hornblende and from rocks of highly schistose texture to those showing scant evidence of dynamic metamorphism. For convenience of description they may, with the exception of a few ultrabasic rocks, to be described elsewhere (p. 20), be classed as amphibole schists. They range in color from very dark gray through rather dark green to black, and weathering may introduce browns and reds. There are all gradations of texture from fine to moderately coarse grained and from well foliated to granular rocks. (See Pls. VII, *A*, and VIII, *A*.) Such gradations have been observed within a single body. However, most of the masses appear to have suffered some dynamic metamorphism, which has rendered them more or less schistose. The very hornblendic varieties are, as a rule, the most schistose, whereas the more feldspathic types grade from a banded to a pseudodioritic texture. Megascopically hornblende is invariably the most conspicuous mineral, although feldspar and less commonly quartz and biotite can be distinguished.

Although the total area of outcrop of these rocks is small, the number of occurrences is large. Indeed, rocks of this general character are scattered throughout the area of schists. The bodies in which they occur, with few exceptions, conform to the schistosity and have been to a greater or less extent affected by the metamorphic forces that have acted upon the entire region. They are characteristically vague in outline, some of them grading imperceptibly into the surrounding schists and gneisses.

These rocks are believed to represent, in many places at least, ancient intrusions of basic rock in the original or partly metamorphosed mass from which the present highly foliated rocks were derived. They occur in zones ranging from a few feet in width up to considerable size, the Dubois greenstone belt being an unusually large and complex area of rocks of this class. Some of these zones are very short; others can be traced for many miles along the schistosity.

A characteristic zone, outlined on the map, crosses Cebolla Creek at the narrow gorge nine-tenths of a mile north of the mouth of Wolf Creek and extends from the volcanic rocks of Sapinero Mesa 4 miles east to those of the ridge east of Wildcat Gulch. It ranges in width from 150 yards to more than a quarter of a mile, and its schistosity conforms in the main with the general structure of the vicinity, which strikes north of west and is nearly vertical. A similar area three-tenths of a mile wide stretches from Gunnison River northwestward across Steuben Creek and then goes under the later rocks, and in East Red Canyon 1 mile from its mouth the mica schists are banded with bodies of amphibole schists as much as several hundred yards wide. The rocks of all these areas conform with the structure of the metamorphic rocks of the vicinity.

Petrography.—In thin section these schists, or most of them, are found to have a granoblastic structure and to be holocrystalline and allotriomorphic with a seriate fabric. The photomicrographs shown in Plates VII, *B*, and VIII, *B*, illustrate the structure in sections cut respectively oblique and perpendicular to the schistosity. The constituent grains range from a small fraction of a millimeter to several millimeters in length, the average falling between 0.5 and 1 millimeter. The hornblende grains as a rule are the largest. The most abundant constituents are hornblende and feldspar, although here and there quartz may become of equal or even slightly greater abundance. In the more mafic rocks the hornblende is in excess of the feldspar and may constitute as much as 90 per cent of the rock, though there are all gradations from this composition to that in which the feldspar exceeds the hornblende. The hornblendes, which even in the minimum development make up at least 25 per cent of the schist, are of irregular outline, with ragged or frayed borders, and invariably show poikilitic inclusions of apatite and magnetite and in places of quartz and feldspar.

The feldspar is chiefly plagioclase and has a composition approximating that of andesine—some of it that of oligoclase. Small quantities of orthoclase, micropegmatite, microperthite, and microcline are to be observed. Quartz occurs in various proportions and rarely approaches the feldspar in abundance, as in the band of amphibole schist that crosses Cebolla Creek north of Wolf Creek.

Biotite in subordinate quantity is present in about half of the rocks studied and occurs characteristically in very small flakes. Augite was noted in one or two slides in very meager amount and was apparently in process ot change to amphibole. Chlorite, sericite, epidote, calcite, and the iron ores are present as secondary minerals after hornblende and feldspar. Apatite, epidote, muscovite, magnetite, titanite, rutile, and zircon are to be found here and there as accessory constituents.

Origin.—The rocks classed as amphibole schists are not only diverse in character but, it is believed, were derived from material of equally varied character and age. Their smaller abundance and their relations to the ancient schists, as well as the less highly metamorphosed character of some of them, show that they were metamorphosed from material in the main younger than that of the biotite schists. They are cut by stringers and dikelets of granite and are certainly older than the igneous intrusions described on pages 36–38 The largest proportion of the amphibole schists are believed to belong to relatively the same larger time unit as the other schists. However, as little or no schistosity is developed in some of these rocks, it seems quite possible that there were basic intrusions during the last stage of the deformative movements. Evidence supporting this inference is afforded by an occurrence of amphibole schists on the east slope of the Lake Fork canyon east of the abandoned railroad station of Twin Buttes, from which specimens were collected, showing a complete gradation from a metadiorite only slightly metamorphosed to a typical lamellated amphibole schist. This body, which is vague in outline, can not be more than a few yards wide and conforms with the schistosity of the biotite schists in which it occurs, having been traced for several hundred feet in a N. 50° W. direction.

These facts, together with the mineral composition of the amphibole schists, seem to indicate that they were derived in large part from rocks closely akin to a diorite.

The rocks of this group fall for the most part into the family of the kata-hornblende-plagioclase gneiss of the soda-calcic feldspar gneiss group of the Grubenmann classification[15] but are gradational toward the amphibolate group.

ULTRABASIC ROCKS

General features.—In addition to amphibole schist small and poorly defined exposures of a much coarser, extremely hornblendic type of rock were observed at several localities along the Black Canyon and in Cebolla Creek. The ultrabasic rocks differ most noticeably from the amphibole schists in their almost complete lack of schistosity. They are granular and in hand specimens look like hornblendites; they are black with local greenish or yellowish tones due to weathering;. they range from fine to medium grain; and, save in the rare specimens in which feldspar is seen, hornblende is the only mineral in them visible to the unaided eye. The best examples are to be found at the west line of the Uncompahgre quadrangle, on the north slope of Stumpy Creek and on the point of the ridge south of Crystal Creek. The small metamorphism of the rocks of this type indicates that they are younger than any others of the group.

Petrography.—When studied in thin section these ultrabasic rocks are found to be granular, of seriate fabric, and to be made up of allotriomorphic crystals ranging in size from 0.5 to 2.5 millimeters

[15] Die kristallinen Schiefer, p. 180.

with hardly a suggestion of schistose structure or of the kind of metamorphic change characteristic of the amphibole schists. Green hornblende is by far the most abundant constituent and occurs commonly as allotriomorphic or hypidiomorphic crystals, the color of which is not uniformly distributed but makes irregularly shaped patches of varied tones. This variation, together with the fine, almost fibrous cleavage and many inclusions of magnetite, epidote, apatite, or biotite, sometimes gives the hornblende the appearance of uralite. However, in two slides the hornblende looked quite fresh and was in hypidiomorphic grains. Subordinate quantities of other minerals may be present. Epidote occurs in equal if not greater abundance than any other mineral save hornblende and is in irregular grains and much of it in large crystals. Zoisite is less abundant, being found usually as small, vaguely outlined crystals. Feldspar and quartz are commonly but not invariably present and occur in fine interstitial grains. The feldspar is hardly determinable but is apparently all plagioclase of intermediate composition. Biotite and muscovite were observed in about half of the rocks examined, and the biotite is in part secondary after hornblende. Apatite, titanite, magnetite, and rutile were observed as accessory minerals in various rocks.

Origin.—The rocks of this type have apparently suffered little metamorphism of the dynamic or pressure type, although changes due to thermal and strictly chemical action have manifestly been effected, possibly at considerably less depth than that at which the other metamorphic rocks here described were acted upon. In this feature they resemble very strongly the meta.gabbro body of Cebolla Creek, described below. In thin section they resemble some of the greenstones and particularly a hornblendite from Middle Island, Lake Superior, near Marquette, described by G. H. Williams.[16] It seems evident that some of these rocks have been changed more than others and that the fresher of them, particularly the small band on the west line of the Uncompahgre quadrangle 2 miles north of Stumpy Creek, have suffered very little metamorphic alteration. They were undoubtedly derived from mafic igneous rocks and in largest part from rocks that would fall within the gabbro family and the pyroxenite group of Rosenbusch.[17]

The ultrabasic rocks here described correspond most closely to the zoisite amphibolite classified by Grubenmann[18] as of the eclogite and amphibolite groups.

[16] Williams, G. H., The greenstone schist areas of the Menominee and Marquette regions of Michigan: U. S. Geol. Survey Bull. 62, p. 146, 1890.

[17] Rosenbusch, H., Mikroskopische Physiographie der Mineralien und Gesteine, 4th ed., Band 2, pt. 1, pp. 310 et seq., 479 et seq.

[18] Op. cit., p. 204.

RIVER PORTAL MICA SCHIST

OCCURRENCE

Distinct from most of the schists and gneisses already described, though resembling somewhat the quartz-muscovite schist near Spencer, are the quartz-mica schists found on Vernal Mesa and along the adjacent portion of the Black Canyon from a point a little more than 1 mile east of the mouth of Cimarron Creek to the beginning of the Vernal Mesa granite mass, in the vicinity of Big Draw and Grizzle Gulch. These schists are exposed in a strip running in a northwesterly direction for some 13 miles and ranging in width from little more than 1 mile at its narrowest part, northeast of Signal Hill, to 4 miles just east of Pool Gulch. The portion of the Black Canyon walled by these rocks is one of the wildest and most picturesque along the Gunnison, being in few places less than 1,000 feet in depth. Owing to their excellent exposures in the vicinity of the river portal of the Gunnison tunnel, which is 4½ miles from the northwest end of the strip, the schists of this area are here named the River Portal mica schist.

On the northeast side the overlying formations come practically to the canyon rim; on the southwest side, except in a few outliers and near Signal Hill, they are a mile or more back from the river, the sediments being in fault contact with the pre-Cambrian as far west as the River Portal road. On the east the River Portal schists abut against biotite schist highly injected with granitic material (see Pl. II, *B*) and are believed to be separated from it by a fault running nearly north; on the west they are in contact with the Vernal Mesa granite mass or with biotite schists. The latter boundary is rather vague and with the scanty amount of time available could be drawn only in a generalized way.

The full extent of the River Portal schist under the later formations of course can not be surmised, though it is safe to say that the rocks are very extensively developed and represent a zone at least 10 miles wide across the strike of their schistosity in the much more extensive basement of the Archean schists and gneisses described above. At several places on the southwest side of the Black Canyon below Vernal Mesa specimens were collected which in petrographic features resemble very closely the River Portal type of mica schists. Most of the bodies from which these specimens were taken are vague or inaccessible, and none have been well studied as to their extent or relations. Two examples of these occurrences will suffice for description, although many others doubtless exist. One is on the ridge north of the lower end of Bostwick Park half a mile west of the Vernal Mesa granite body, and the second is on the west rim of West

Red Canyon. At the latter locality the same type of rock continues for some distance along the canyon and may form a body of considerable size, but time was not available to make the necessary exploration to determine its extent. The schists here strike N. 10° E. and were followed for nearly 1 mile along the strike.

GENERAL CHARACTER AND RELATIONS

In outcrop and from a little distance the River Portal mica schists can not be distinguished from the biotite schists, although owing to their highly developed structural planes and the close spacing of joints distinctive physiographic forms have been developed at several places. This development is notable in the Black Canyon from a point above Long Gulch to a point below River Portal, where the river cuts the northeast schistosity and the prominent jointings obliquely, producing picturesque spirelike forms on the steep canyon slopes. (See Pl. IV, *A*.) The exposures of these schists are of a somber gray to drab color, weathering to various shades of brown; in many places they exhibit a trelliswork of lighter granitic veinings as is well shown in the canyon walls below River Portal.

On closer examination of fresh surfaces most of the River Portal schists are found to be distinct from those of the schist and gneiss group already described in that they have a much finer texture and as a rule are less compact and fissile, breaking with irregular surfaces. Exceptions to this character are not infrequent, for good cleavage is developed in places, and rarely the rock has the fissility of slate. Nevertheless the finer grain and relative obscurity of the mica, which commonly occurs as very fine pepperlike grains sprinkling the mass, will serve to distinguish most of the River Portal rocks from the biotite schists.

However, on the east end of the mass, crossing the Black Canyon and Mesa Creek, there is a zone nearly 1½ miles wide of a coarser type of well-laminated mica schist very similar in texture to the biotite schists, although differing somewhat in composition. These quartz-mica schists of Mesa Creek are hardly more than a border phase of the much more extensive fine-grained mica schist that forms the bulk of the River Portal mass, but they are of peculiar interest owing to their possible derivation, at least in part, from sedimentary material. Further attention is given to this subject in the section describing the results of a microscopic study of these schists (pp. 24–26).

The River Portal schists show structure resembling and conformable with that of the neighboring metamorphic rocks. Although these schists are, as a rule, less laminated and fissile, owing doubtless to the fineness of the micas, there are certain strongly marked bands and cleavage lines, emphasized in many places by joints, which represent the structural elements developed by the metamorphic forces. This structure is usually very steep and strikes north from the mouth of Cimarron Creek to Crystal Creek and then swings more to the east, becoming northeast near the western limit of the mass.

The absence from the River Portal schist of biotite schist of the type common to the Black Canyon schist, together with the presence of small bodies of rock similar to the River Portal schist in the biotite schist at several localities lower down the canyon vaguely suggests that the River Portal schists are younger than the biotite schists, although further evidence to this effect is lacking. These rocks contain all the varied kinds of intrusions and inclusions that are found in the metamorphic rocks of the region, including granite, pegmatite, dioritic rocks, and hornblende schists. Indeed, by every indication they seem to belong to the same general time era as the schists and gneisses already discussed, and, furthermore, they are unlike any younger rocks known in the Rocky Mountains. Hence there seems to be no ground whatever for regarding them as belonging to other than the Archean complex.

The rocks of the River Portal mica schists may for convenience of description be divided into two types—the mica schists proper with local quartzose phases and the quartz-mica schists of the Mesa Creek zone.

MICA SCHIST

General character.—Throughout the area of River Portal mica schists occur rocks of the feldspathic type, whose resemblance to the quartz-muscovite schists near Spencer has been mentioned. In hand specimens the schists of this type suggest graywackes (see Pl. IX, *A*), are bluish gray to very dark gray, though many specimens show pink, brown, or yellow shades, and are commonly of very fine, almost sugary texture, approaching that of an indurated argillaceous sandstone. Micas, as a rule are relatively inconspicuous, so that the rocks lack the fissility and sheen of the schists near Spencer, are usually of lower specific gravity, and break with less regular surfaces. With the aid of a strong lens minute grains of quartz and feldspar can be made out, although it is not always possible to distinguish between them. Minute particles of biotite or muscovite or both, resembling a sprinkling of pepper, are characteristic of most of these schists. An interesting feature seen in some is a very delicate banding at an angle to the cleavage.

Petrography.—A microscopic study of this type of schists shows them to be holocrystalline, allotriomorphic, very fine grained—the individual crystals ranging from 0.05 to 0.5 millimeter in diameter—of seriate to slightly porphyritic fabric, and of schistose structure, which, owing to the fineness of the micas, is not conspicuous megascopically. The porphyritic tendency of some of the specimens studied suggests their possible origin from rocks of an effusive nature. (See Pl. IX, *B*.) Quartz is usually the most abundant mineral constituent, although the total feldspar may equal or even exceed it in some specimens. It occurs as fine, irregularly shaped grains and as larger individuals resembling phenocrysts and is usually characterized by minute inclusions and undulatory extinction. Many of the feldspars are so fine as to be hardly determinable, and microcline, which, because of its grating structure and low index, can be most easily distinguished, is most conspicuous, although the chemical analysis given below indicates the greater abundance of soda plagioclase. Much but not all of the plagioclase shows imperfect albite twinning, and it is likely to be underestimated in section. A study of the chemical analysis of a typical mica schist shows that the plagioclase has the composition of albite, a portion of the lime having gone into garnet and epidote, and that it makes approximately 35 per cent of the rocks, whereas the potash feldspar makes less than 15 per cent.

Biotite is always present and in nearly all the rocks is the dominant mica. Muscovite usually occurs in greater or less amount and in several slides was more abundant than the biotite. Chlorite is present here and there and may have resulted from surface weathering, whereas hornblende was observed in only one slide and in small quantity. In this rock, as in other schists, the micas occur as irregular-shaped leaves arranged in parallel planes of foliation. In several specimens crystals of muscovite a millimeter or more in diameter were found poikilitically intergrown with quartz and feldspar.

Garnet, apatite, titanite, epidote, zircon, and magnetite are the commonest accessory minerals. Many of the garnets occur as phenocrysts, one seen being 0.3 millimeter in diameter. Zoisite, sericite. calcite, and chlorite were observed as secondary minerals, and tourmaline was found in one section.

QUARTZOSE PHASE OF MICA SCHIST

Here and there throughout the River Portal mass are scattered small vaguely outlined patches of rocks that resemble in appearance the mica schists just described, although containing considerably more quartz and proportionally less feldspar. These schists, which are of peculiar interest, owing to their possible origin from sedimentary rocks, show all gradations toward the rocks just described and may be called the quartzose phase of the mica schists. In hand specimens they do not differ from the other schists, except in showing a lighter-gray shade, but under the microscope the greater abundance of quartz, which forms from 60 to 80 per cent of the rock, becomes apparent.

The quartz occurs in extremely irregular-shaped crystals, many of them interlocking, which exhibit undulatory extinction. It is at least twice as abundant as the feldspar and in some rocks is many times as abundant. Subordinate quantities of feldspar, chiefly microcline, are invariably present. Biotite also is always present and is as a rule slightly in excess of the muscovite. Chlorite occurs in some places, and the same accessory minerals are to be found as in the other schists.

QUARTZ-MICA SCHIST OF MESA CREEK

General character.—Along the border of the River Portal schists so far described and grading into them is a zone of quartz-biotite schists which runs nearly north and is about 1½ miles wide. In appearance and composition these rocks are intermediate between the biotite schists of the canyon and the quartzose phase of the River Portal mica schists. Typical specimens are gray to pink with streaks of yellow or brown, and the abundant mica may give them glistening cleavage surfaces. The texture is in general fine grained, with only a moderate amount of lamellation, although a rather fine banding is common. Unusual textures locally developed have produced coarsely micaceous and schistose varieties.

Petrography.—Under the microscope these schists are found to be holocrystalline, allotriomorphic, and of fine to medium grain, the individual crystals ranging from 0.5 to 3 millimeters in diameter, with 1 millimeter as an approximate average. They are of equigranular to seriate fabric and of decidedly gneissic structure. Quartz is invariably the most abundant mineral, making up from 50 to 75 per cent of the more typical rocks. Muscovite is as a rule in slightly greater abundance than biotite; feldspar, consisting chiefly of soda plagioclase and microcline, is very subordinate. The usual accessory minerals, apatite, magnetite, and garnets are present. However, the schists of this zone are rather varied, so that specimens collected from different places in it may show considerably more feldspar, more biotite, or less muscovite. East of the mouth of Cimarron Creek and on the slope north of Mesa Creek are bands of very quartzose mica schist containing large flakes of fibrolite of silverlike appearance. Microscopically the fibrolite appears in characteristic sheaf-like arrangement of fibers with myriads of fine needles protruding out into and through the quartz.

DERIVATION

By reason of the texture, structural lines, and character of the River Portal mica schists they were at first thought to be of sedimentary origin. Further study and a chemical analysis have pointed to an opposite conclusion. Indeed, the amount of aluminous minerals—

feldspars and micas—seems to preclude their being derived from any sediment save a very arkosic sandstone. A specimen of compact gray quartz-mica schist (G. C. 58, see Pl. IX), taken from Vernal Mesa three-quarters of a mile south of Nyswonger Spring, which on microscopic examination was thought to be intermediate in content of feldspar and to represent the predominating type of this group of rocks, was analyzed by George Steiger, of the United States Geological Survey. The result of this analysis is shown in column 1 of the table below, which includes analyses of other rocks for comparison.

Analyses of River Portal mica schist and similar rocks

	1	2	3	4
SiO_2	71.06	70.09	73.18	72.59
Al_2O_3	13.23	15.13	13.66	13.47
Fe_2O_3	1.17	1.72	.21	1.58
FeO	3.57	1.13	2.24	1.32
MgO	.95	1.22	.93	1.05
CaO	1.48	2.61	2.10	2.12
Na_2O	3.98	3.61	3.70	4.63
K_2O	2.74	2.75	2.72	2.52
H_2O-	.32	----------	.10	----------
H_2O+	1.16	.78	.57	.18
CO_2	----------	Trace.	.17	----------
TiO_2	.60	.67	.25	.52
ZrO_2	.02	Trace.	----------	----------
P_2O_5	.16	.11	.09	----------
Cl	----------	.02	----------	----------
S	.02	----------	----------	----------
FeS_2	----------	.02	----------	.26
MnO	.13	.08	.07	None.
BaO	None.	None.	.10	----------
SrO	None	----------	Trace.	----------
Li_2O	None.	----------	Trace.	----------
Cu	----------	.04	----------	----------
	100.59	99.98	100.09	100.24

1. River Portal mica schist (G. C. 58) (lassenose), three-quarters of a mile south of Nyswonger Spring Vernal Mesa, Montrose County, Colo. Analyst, George Steiger.
2. Granitite gneiss (lassenose), Mazaruni district, British Guiana. Analyst, J. B. Harrison.
3. Soda granite (lassenose), Agua Fria Creek, Mariposa County, Calif. Analyst, W. F. Hillebrand. Described by H. W. Turner, U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, p. 721, 1896.
4. Obsidian (lassenose), east of Willow Park, Yellowstone National Park. Analyst, J. E. Whitfield. Described by J. P. Iddings, U. S. Geol. Survey Mon. 32, p 426, 1899.

The norm and systematic position of the mica schist in the quantitative classification is as follows:

Q	31.30
or	16.12
ab	33.54
an	6.67
C	1.22
hy	7.02
mt	1.86
il	1.22
ap	.34

Class: $\frac{Sal}{Fem}=\frac{87.63}{11.66}=7.5+=I$, persalane.

Order: $\frac{Q}{F}=\frac{31.30}{56.33}=0.56=(3)4$, (quarfelic) quardofelic.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{93}{24}=3.9=2$, domalkalic.

Subrang: $\frac{K_2O}{Na_2O}=\frac{29}{64}=0.45=4$, dosodic.

Symbol: I.(3)4.2.4, (alsbachose) lassenose.

A comparison of the analysis of the mica schist with the other analyses given and consideration of the position of the rock in the quantitative classification brings out its resemblance to various granites, granite gneisses, and rhyolites and clearly point to an igneous rather than a sedimentary origin. Although the rock shows a moderately high percentage of quartz in the norm (31.30 per cent) and a very slight excess of alumina over that necessary to satisfy the 1:1 ratio for the feldspars, this evidence hardly suggests a sedimentary origin, especially as the amount of corundum in the norm is only 1.22 per cent. On the other hand, the important criterion of the double relationship $K_2O > Na_2O$ and $MgO > CaO$ shown by Bastin[19] to be most significant in identifying metasedimentary rocks fails entirely, for the Na_2O exceeds the K_2O by more than 1 per cent and the CaO exceeds the MgO by 0.53 per cent. From this circumstance and from the absence of decisive field evidence to the contrary it seems fair to conclude that these schists are more probably of igneous than of sedimentary origin.

The unique texture, structure, and composition of this metamorphic unit and the fact that it has suffered metamorphism of the same kind and degree as the other schists of the region show decisively that they were derived from a mass of rock differing in character from the source of the other metamorphic rocks. They appear to have been entirely recrystallized, so that all evidence as to their original texture has been obliterated. However, by reason of their exceptional fineness of grain, their composition, and local suggestions of a porphyritic texture, it does not seem improbable that they were derived from a series of fine-grained effusive or hypabyssal rocks of the general composition of a rhyolite or rhyolitic tuff. The patches of the highly quartzose phase of the mica schists in the more typical series and the band of quartz-mica schists crossing Mesa Creek are likewise of uncertain origin, although the paucity of feldspar and the predominance of quartz, together with their somewhat arenaceous texture, render it at least possible that they were derived from sedimentary material of the character of arkosic sandstone.

DUBOIS GREENSTONE

OCCURRENCE

The Dubois greenstone consists of a series of metamorphosed basic rocks of the class called metabasites by Hackman,[20] comprising hornblende gneisses, amphibole schists, chlorite schists, and basic associates that extend in a zone of varying width and persistency from Lake Fork of Gunnison River on the west to a point beyond South Beaver Creek on the east, a distance of approximately 18 miles. This zone ranges in width from 4 miles to less than 1 mile. Although the mass

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[19] Bastin, E. S., Chemical composition as a criterion in identifying metamorphosed sediments: Jour. Geology, vol. 17, pp. 445–472, 1909; vol. 21, pp. 193–201, 1913.

[20] Hackman, G. V., as recorded by Sederholm, J. J., Comm. Geol. Finlande Bull. 23, p. 92, 1907.

is continuous throughout its length, it contains many large and small bodies of granite, granite porphyry, and mica schist, so that the space it occupies is represented on the map by a long irregular strip, much dissected by narrow parallel bands. In the Cebolla Creek valley the irregularities in the shape of the body are associated with the intrusion of huge masses of granite and granite porphyry of the Powderhorn granite group. The mass owes its name to the old mining camp of Dubois, on Goose Creek, where the greenstones or metabasites are well exposed. It lies at the foot of the steep slopes that come down from the high volcanic mountains on the south and marks the beginning of the broad mesas that slope northward to Gunnison River. On the north these rocks are in contact with mica schists and granitic bodies, although on some of the divides the contact is overlain by Tertiary volcanic rocks; on the south they extend under later formations save in the Cebolla and Willow Creek valleys, where erosion has exposed pre-Cambrian granites and granite porphyry adjacent to them; on both the east and west they run under later formations, so that their further extension is of course, conjectural. However, to judge from the exposed contacts in Cebolla and Willow creeks, they probably do not extend much farther south than the present exposures indicate. No idea whatever of their extension westward can be had; and the projection of the belt eastward to the pre-Cambrian exposures in Cochetopa Creek finds gneissoid granite, so that this particular mass is not believed to extend far east of South Beaver Creek.

GENERAL CHARACTER

The Dubois greenstone, unlike many of the canyon-forming rocks, occurs most characteristically in small irregular cliffs, bluffs, and jagged outcrops dotting the rolling upland country or the somewhat steeper slopes of the larger streams. Only in Lake Fork and Cebolla Creek do the valleys approach the character of canyons. The rocks are commonly dark, many showing a decided greenish tone on close inspection, particularly where they are weathered. They range in petrographic character from hornblende gneiss and metadiorite to chlorite schist, amphibole schist, and amphibolite and in texture from coarse to very fine fibrous.

A division of the Dubois greenstone area into two parts on the basis of petrography would correspond very closely to a division on the basis of structure. West of the lava-capped ridge between Goose Creek and Lake Fork the rocks are in general homogeneous, being fine, green, and commonly fibrous amphibole schists or amphibolites. These are notably well exposed on the east slope of the Lake Fork canyon from Madeira siding to the beginning of the granite mass 1¼ miles farther south. From the Goose Creek basin eastward the greenstones are much more heterogeneous, comprising a complex of hornblendic rocks that show diversity in both composition and texture. Everywhere in this complex, however, schist and amphibolite such as occur in the Lake Fork appear to be the fundamental rocks, in which the other types occur locally. For this reason the greenstones will be classified and discussed on the basis of their petrographic character rather than by areal divisions.

Over most of the area the greenstone exhibits a marked schistosity and locally many joint planes. The structure of the mass is chiefly of two types, the schistosity in the portion west of Goose Creek striking N. 45°–60° E. with a steep southeasterly dip and that in the portion from Cebolla Creek east to South Beaver Creek striking N. 70°–90° W. and either vertical or dipping very steeply to the south. There are many local variations some of which are adjacent to igneous intrusions, but on the whole the structure is uniform within each of the two areas mentioned. The difference between the two divisions may well be the result of forces attendant upon the intrusion of the granite masses along Cebolla Creek and on Lake Fork north of Madeira siding.

In many places the greenstone has been intruded by more siliceous rocks, as on Cebolla Creek 1 mile south of the mouth of Goose Creek, where the steep eastern slopes are literally ribbed with narrow dikes and dikelets of granite porphyry, most of them parallel to the direction of the schistosity of the greenstone. In Goose Creek also there are many intrusions of granite porphyry and granite and in one place of syenite. Aside from these intrusions there are within the greenstone mass several areas of quartz-muscovite schist of lenslike appearance in plan. (See p. 15.) They appear to have undergone practically the same amount of metamorphism as the greenstone, but whether they are earlier or later is not definitely determinable.

Quartz veins are more numerous in the Dubois greenstone than in any other group of the complex. Most of them run parallel to the schistosity but do not persist for very long distances. They have been extensively prospected and in a number of places are known to carry gold. The prospects and mines at Dubois, Spencer, Midway, Vulcan, and Midland are within the area of the greenstone. The most notable mines are the Vulcan, Mammoth Chimney, and Good Hope, near Vulcan.

RELATIONS

The rocks of this group are very similar to the amphibole schist that occurs in narrow bands throughout the fundamental complex of schist and gneiss. Indeed, they may constitute one of these bands of unusual size. The relative age of the greenstones and the quartz-mica schists adjoining them could not be definitely determined, for small bodies of mica schist in the greenstone in one place resemble ancient metamorphosed intrusive rocks, whereas in other places they resemble large inclusions. Furthermore, within the mica schist area there are many narrow zones of amphibole schist, and west of the mouth of Goose Creek there is an irregular mass which suggests an early intrusion of basic material in the mica schists. These occurrences, together with the numerous analogous dikelike zones of amphibolite schist in the biotite schist and the absence of similar zones of typical biotite schist in the Dubois greenstone area, support the belief that the greenstone is younger than most of the schist and gneiss complex, particularly the biotite schists. Although most of these rocks are believed to belong to the same general period as the Archean schists and gneisses, it is not impossible that certain little metamorphosed basic intrusives within them had their origin during the later stages of metamorphism or even subsequent thereto. Certain of these less schistose basic rocks resemble types found in the Irving greenstone mass of the Needle Mountains [21] although the major portion of the Dubois mass has been rendered far more schistose than the Irving rocks and has different structural relations.

Although the Dubois greenstones are of somewhat diverse types, it is not practicable nor desirable to separate them into cartographic units corresponding to their petrographic character. Some of the dikes of granite porphyry and granite, as well as the bodies of mica schist, have been outlined, however, and a typical zone of chlorite schist has been shown extending from a place south of Spencer west-northwestward to Cebolla Creek. South of this zone is a narrow strip of peculiar hornblende gneiss which has also been mapped. For convenience of description the Dubois greenstone may be divided into four types—hornblende gneiss, amphibole schist or amphibolite, chlorite schist, and ultrabasic rocks.

HORNBLENDE GNEISS

General character.—The hornblende gneisses, which appear to be largely metadiorite or meta quartz diorite, are light to dark gray rocks with locally a greenish tinge, and most of them possess a gneissic structure and show feldspar, quartz, and hornblende. By increases in the proportion of the hornblende and in the schistosity all gradations to amphibole schist are developed. Although rocks of similar character are found at various places within the metabasite area, the only sizable body observed was a wedge-shaped area along Cebolla Creek. This area is slightly less than 2 miles long and 0.2 mile across at its widest point. Beginning at the round knob

[21] Cross, Whitman, and others, U. S. Geol. Survey Geol. Atlas, Needle Mountains folio (No. 131), p. 2, 1905. Howe, Ernest, An occurrence of greenstone schists in the San Juan Mountains, Colo.: Jour. Geology, vol. 12, pp. 501-509, 1904.

8,400 feet high immediately south of the mouth of Goose Creek, it crosses Cebolla Creek and continues up its east bank in a south of east direction, pinching out at a point 1½ miles south of west of Spencer.

Petrography.—Under the microscope these rocks show a diversity of character but in general are allotriomorphic in texture and of fine grain, the individual crystals nowhere averaging more than 0.5 millimeter in diameter and usually being much smaller. The fabric ranges from seriate to porphyritic. Quartz and feldspar, chiefly plagioclase, make up the bulk of the rock, although in some specimens hornblende becomes one of the chief constituents. Biotite is present in more than half of the rocks but with few exceptions is subordinate to the hornblende. In the rocks that have a porphyritic or pseudomorphic fabric most of the phenocrysts are quartz and feldspar, but a few are hornblende. Much of the quartz occurs as lens-like aggregates, which appear to be granulated phenocrysts. The feldspar is chiefly plagioclase and where it is not too badly decomposed shows for the most part an index of refraction about that of andesine, although a little albite has been found in many specimens. The hornblende and biotite have been developed chiefly along shearing planes. In one specimen the amphibole is actinolite and shows strong dispersion. Epidote, zoisite, and sericite are common secondary minerals; apatite and magnetite are the commonest accessory constituents.

Origin.—From their mineral composition and texture the rocks of this class were apparently derived from quartz diorite or quartz diorite porphyry.

AMPHIBOLE SCHIST AND AMPHIBOLITE

General character.—By far the most prevalent type of rocks of the Dubois area are the amphibole schists and amphibolites. These rocks resemble the amphibole schists that form part of the schist and gneiss complex, although most of them have a finer and more homogeneous texture. They are invariably schistose, a few showing almost fibrous texture, and are dark green or black, becoming brown or yellow on weathering. They range from schist containing small quantities of salic minerals to amphibolite made up almost entirely of fine amphibole. On fresh surfaces amphibole is usually the only mineral visible, although occasionally mica or a little feldspar can be distinguished. Rocks of this character occur throughout the metabasite area and are believed to represent the host into which were intruded the rocks from which the hornblende gneiss and ultrabasic rocks have been derived.

Petrography.—Under the microscope these schists are found to be uniformly of fine grain, the individual crystals averaging 0.1 to 0.2

millimeter in length, although a few individuals as long as 1 millimeter have been seen. They are holocrystalline, allotriomorphic, and, with the exception of a few that show a slight porphyritic tendency, even textured. Sections transverse to the cleavage usually show the hornblendes arranged with their longest dimensions parallel, producing the schistose structure. Sections parallel to the cleavage give little indication of schistosity, the hornblendes being in short irregular-shaped laths that form meshwork. Hornblende, which is by far the most abundant mineral and makes up almost the entire content of a few of the schists, shows characteristic pleochroism in yellows, greens, and blues. The individuals are usually elongate to acicular and have vague or ragged outlines. Many crystals slightly larger than the average and much frayed are seen and may be remnants of phenocrysts. Many of these individuals show undulatory or irregular extinction, and a very few show what appears to be polysynthetic twinning.

The felsic minerals amount to as much as one-half in a very few of the rocks and grade down to less than 10 per cent in the others. Feldspar is probably more abundant than quartz, but this is difficult to determine, owing to the fineness of the grains which fill the spaces between the hornblendes. A few large crystals of plagioclase of rather sodic character, commonly showing poikilitic inclusions of amphibole, can be observed. The feldspar seems to be almost all plagioclase and to range from oligoclase to andesine. Although the quartz of these rocks is usually in fine grains between the hornblende crystals, it occurs also in very small veinlets, lenses, or aggregates, and in these forms, at least, is secondary.

A little biotite is present in some of the more felsic rocks, and a few of the slides show chlorite. Magnetite and ilmenite occur as fine opaque grains throughout the rocks and with titanite and apatite are the most important accessory minerals. Epidote and zoisite are very common constituents and in part have been derived from feldspars.

Origin.—In the classification of Grubenmann the amphibole schists and amphibolites here described fall into the family of hornblende schists[22] of the magnesium silicate group, but are gradational toward the plagioclase amphibolites of the amphibolite group and are regarded as of the middle zone (Meso-Gesteine).

The rocks of this type have been so intensely metamorphosed that all traces of their original character are obliterated. Although it is possible that some of the amphibolites were derived from a lime-rich sedimentary series, no great amount of calcite was discovered save in one specimen from a place near Spencer. Indeed, the studies in

[22] Grubenmann, U., Die kristallinen Schiefer, 2d ed., p. 217, 1910.

the field afford no evidence of sedimentary origin. On the contrary, the texture, composition, and field relations of the rocks suggest that they may have been derived from basic igneous rocks of the composition of diorites, diabases, gabbros, or even pyroxenites.

Recently Adams and Barlow[23] have shown that certain amphibolites of the Grenville series, in appearance not unlike those of this area, have been metamorphosed from limestone.

CHLORITE SCHIST

General character.—The chlorite schists are easily distinguished from all others by the predominance of the pale-green chloritic mineral on fresh fracture surfaces. They are almost invariably well foliated and schistose, and many show only smooth cleavage surfaces of chlorite with a satinlike luster on planes parallel to the foliation. On fracture surfaces transverse to the schistosity quartz, feldspar, biotite, amphibole, and garnets can frequently be observed between the flakes of chlorite. These rocks range in color from green-gray to green and weather to yellow or brownish tones. Most of them are moderately fine grained, although some contain clusters of coarse amphibole, mica, and garnet. They show also considerable diversity in composition and texture, forming incomplete gradations in their content of chlorite toward the more chloritic phases of the quartz-muscovite schists and in their content of amphibole toward the amphibole schists. They are found in narrow zones parallel to the strike of the local schistosity, ranging from a few hundred feet to half a mile in width and of varying persistency along the strike.

The best-known occurrence is the lenticular strip, extending from a place near the south end of Spencer west-northwestward for nearly 3 miles to Cebolla Creek. This strip contains much amphibole schist but is made up chiefly of chloritic material. Associated with this strip are the quartz-muscovite schists mapped, together with many similar but smaller zones whose outlines are less clear, dikes of granite porphyry, and zones of hornblende gneiss.

A second large area of chlorite schists occurs northeast of Vulcan on and east of the Gunnison-Saguache County line. This area has not been followed eastward nor studied in detail, but it is known to contain an abundance of schists resembling those of the quartz-muscovite type, which are all more or less chloritic. It is interesting to note that several of the better-known ore bodies, including those of the Good Hope, Headlight, and Florence mines, are in these chloritic schists. Small bodies of these schists occur throughout the metabasite area

[23] Adams, F. D., and Barlow, A. E., Geology of the Haliburton and Bancroft areas: Canada Geol. Survey Mem. 6, p. 104, 1910.

but have not been separated on the map. The intense metamorphism that produced these schists has also obliterated all evidence as to their former relations to the surrounding rocks.

Petrography.—A microscopic study of these rocks reveals few additional features. They range from even-textured schistose varieties in which all the grains are less than a millimeter in length to a slightly coarser, more porphyritic variety in which there are phenocrysts of quartz several millimeters across. The individual crystals are allotriomorphic, having usually an irregular or even ragged outline. Chlorite is less conspicuous in slides than in hand specimens, although at its maximum abundance it predominates over other minerals. In most of the rocks examined it is less common than the salic minerals, and in some it makes up as little as 10 per cent of the rock. It usually shows little pleochroism, low birefringence with occasional anomalous blue colors, and irregular extinction. Pale-green amphibole, in large part hornblende, is common as slender blades embedded in aggregates of chlorite and other minerals.

Quartz is found in all the chlorite schists, at its maximum proportion making up nearly half the rock. Feldspar, which seems to be chiefly soda plagioclase, is sparingly present, and small quantities of biotite in irregular-shaped leaves were seen in most of the specimens examined. In addition garnet, muscovite, epidote, magnetite, apatite, and titanite occur here and there in the rocks of this type.

Origin.—The uncertainty as to the relations of the chlorite schists to the quartz-muscovite schists and to the amphibole schists has been set forth. The microscopic study of sections of these rocks adds no decisive evidence on these relations, nor does it give any clue as to the derivation of the rocks. However, the variety of phases of the chlorite schists seems to indicate a considerable range in the character of the original rocks from which they have been metamorphosed. One specimen from the area northeast of Vulcan is made up almost entirely of quartz and chlorite and suggests a sedimentary rather than an igneous origin, whereas certain specimens from the area on the east slope of Cebolla Creek show a porphyritic tendency with abundant feldspar and appear to be more closely related to igneous rocks.

BASIC ASSOCIATES

General features.—The rocks of the fourth type included in the Dubois greenstone are certain basic associates that, as a rule, show less dynamic metamorphism than the rocks already described. Most of them resemble the ultrabasic rocks that occur in the schist and gneiss complex, but some specimens suggest affinities with the metagabbro rocks of Cebolla Creek. They differ from the amphibole schists in being slightly coarser grained and more granular, although in color they are very similar, being dark green to black. Hornblende and here and there a little feldspar are the only minerals discernible to the naked eye. The rocks of this type have been observed at only a few localities and in bodies whose relations are indeterminable.

Petrography.—When studied under the microscope these rocks are found to be of diverse character, grading from those made up almost entirely of hornblende to those containing considerable quantities of plagioclase and approaching metadiorite in composition. The most common phase, however, is a hornblende rock of seriate to seriate-porphyritic fabric, the constituent crystals of which are with few exceptions less than a millimeter in diameter and of allotriomorphic outline. Hornblende is invariably the most abundant mineral and is characterized by uneven extinction, many inclusions of fine magnetite or ilmenite, and ragged borders. It is usually pleochroic in greens or yellows, although in some sections it is a very pale green with large extinction and may have been derived from augite by a process of uralitization. Epidote and zoisite are common constituents of all these rocks and may have resulted from the metamorphism of plagioclase, which occurs only sparingly. Quartz, calcite, biotite, apatite, and magnetite are found in greater or less quantity.

Origin.—The basic rocks of this group are not only of varied character but were doubtless derived from ver different materials. They include a series of left-over rocks, not belonging to the other types of the Dubois greenstone, which have in common a rather basic character and show little evidence of dynamic metamorphism. Many of them, however, manifest metamorphic changes that probably resulted from thermal action, such as the alteration of pyroxene to amphibole and of plagioclase to epidote. It seems fairly clear that these rocks were derived from basic igneous rocks whose composition ranged from that of a gabbro to that of a pyroxenite. Their character and occurrence seem to indicate that they are relics of dikes or small intrusive bodies of basic rocks probably contemporaneous with or in a few places younger than the last stages of defo mation.

IGNEOUS INTRUSIONS

GENERAL FEATURES

The bodies of igneous material that have been intruded into the complex discussed in the foregoing pages show the greatest diversity in size, form, and character, ranging from stocks several miles across to dikes but a few feet in width and from granite to pyroxenite. Granite is by far the most abundant igneous rock in the area, and some masses are large enough to warrant separate mapping and description. Innumerable smaller bodies, representing several distinct types, are scattered throughout the area.

Part of a stock of somewhat metamorphosed gabbroic and dioritic rock is exposed at the southernmost part of the area in Cebolla and Beaver creeks, and small bodies of quartz diorite, diorite, gabbro, diabase, and lamprophyric rocks occur throughout the area but chiefly in the northeast quarter of the Uncompahgre quadrangle. Several small intrusions of augite syenite and many domes of soda syenite occur in the eastern part of that quadrangle. Near Iron Hill, 3 miles southeast of Powderhorn, there is a noteworthy series of highly sodic rocks comprising pyroxenite, ijolite, nepheline gabbro, soda cancrinite, and nepheline syenite, together with a peculiar melilite rock called uncompahgrite, perofskite, analcite, and apatite rocks. Pegmatite and aplite occur abundantly throughout the area and appear to be in many places genetically related to intrusive masses near by.

The age of these intrusive rocks is not determinable in the Gunnison River area alone, for neither Paleozoic nor any recognized Algonkian rocks are present here. In the Pikes Peak and Needle Mountains quadrangles granite masses intrude the Algonkian quartzites. In neither district do such masses penetrate the Paleozoic sediments, the lowest representative of which in the Needle Mountains area is the Ignacio quartzite, believed to be of Upper Cambrian (Saratogan) age. The igneous rocks here described not only intrude the Archean schists at all angles to their schistosity, but show no evidence of having been subjected to the profound metamorphism to which the present character of the schists is due. Further, with the possible exception of parts of the granite porphyry mass, none of these rocks show a metamorphism comparable to that of the Uncompahgre formation (Algonkian) of the Animas River and Uncompahgre River valleys, which they must have endured had they existed when it took place. For these reasons the igneous rocks are believed to be of the same age as similar rocks elsewhere in the San Juan Mountains—that is, late Algonkian or early Paleozoic.

The data for determining the relative age of the several intrusive masses are not as a rule decisive. The sequence of intrusion of the granite bodies is for the most part problematic, the only clue available being the rather untrustworthy indication afforded by the degree of metamorphism. In general it may be stated that the syenites and more basic rocks, together with the rocks of the Iron Hill area, are later than the major granite masses, but the position in the sequence of the large gabbro and diorite mass in the Cebolla Valley is uncertain.

GRANITES OF THE AREA

The Archean metamorphic complex of the Gunnison area, like those of the other large areas of the Rocky Mountains, is everywhere intruded by bodies of granitic material. These intrusions range from small veinlets and dikes to irregular masses and stocks covering many square miles.

These numerous bodies of granite show a greater diversity of texture than of mineral composition. They range from a very fine grained granite porphyry through medium-grained varieties of fairly uniform texture to coarse, almost pegmatitic rocks. In composition the granites are similar, differing chiefly in the relative amounts of potash and soda feldspar, biotite, and muscovite. They are characterized by a relatively high content of soda, expressed as oligoclase or albite, which as a rule approaches or equals in abundance microcline, the dominant feldspar.

Three granite intrusions are worthy of separate consideration because of their extent and distinctive character. These are the Powderhorn group of granites, comprising a number of types of rock, exposed chiefly in the valleys of Cebolla Creek and adjacent streams; the Vernal Mesa granite body, in the Black Canyon below the mouth of Grizzle Gulch and on Vernal Mesa; and the Curecanti granite, in the Black Canyon near Curecanti Creek. Small bodies of other types of granite occur in the northeast corner of the Uncompahgre quadrangle, in Pole Creek, on the east border of the quadrangle, and in other places throughout the region. Many of them are probably genetically related to the larger masses.

The relative age of the several granite bodies is largely a matter of conjecture. The granites of the Powderhorn group manifest a greater degree of metamorphism than most of the others and are believed to be among the oldest of the region. Associated in this mass are a number of types representing distinct eruptions, a partial sequence of which has been established.

POWDERHORN GRANITE GROUP

OCCURRENCE

The Powderhorn group of granites is exposed on Cebolla and Willow creeks and in the Lake Fork canyon, and constitutes the largest continuous body of granite in the region. It extends with interruptions for 11 miles along Cebolla Creek and in places is more than 6 miles wide.

The northern boundary of the granite runs north of west from a point 1 mile south of Midway, in a sharp, straight contact with the Dubois greenstone as far as Cebolla Creek. West of this stream a salient of granite projects northwestward and includes the hill southeast of Dubois. North of Powderhorn most of the divide between Cebolla and Goose creeks consists of these granites, but it includes a long, eastward-narrowing reentrant of metamorphic rocks that crosses the Cebolla Valley between Tolvar Peak and Carpenter Hill. South of Powderhorn the exposures of this group of rocks make only a narrow band running parallel to and in few places more than 1½ miles west of Cebolla Creek.

In addition to this main body there are a number of smaller, isolated masses. The most notable of them is the one that crosses the Lake Fork 1½ miles north of Madeira siding, which is 1 mile wide and 2 miles long and is probably connected under the volcanic flows with the small area of granite on Sapinero Mesa, 2½ miles south of Tenmile Spring. A second outlier is the strip of granite 2½ miles wide that crosses Willow Creek half a mile south of Midway.

The Powderhorn granites are in contact with metagabbro on the south and with Dubois greenstone on the north and northwest. The exposures are limited by overlying Tertiary volcanic rocks on the west and by overlying sediments on the east, so that the extent of the mass in these directions is unknown. The information available seems to indicate that the intrusion is a great stock of varying width whose longer direction runs approximately east. The body on the Lake Fork was injected along the contact of the biotite schist and the Dubois greenstone on the north. The adjacent biotite schist has been so much intruded by granite of the type of the larger mass that it is extremely difficult to draw an accurate line of separation.

The Powderhorn granites, save for a gap of less than 2 miles south of Powderhorn, completely surround the complexly intruded Iron Hill area of limestone. Indeed, these granites form a great bowl in which is contained this interesting series of rocks. Here the granite is variously in contact with younger intrusions of uncompahgrite, pyroxenite, soda syenite, and cancrinite syenite.

GENERAL CHARACTER

The Powderhorn group comprises a large number of genetically related and locally metamorphosed intrusive masses, forming an intricate complex of granite types, whose composition is believed to be nearly uniform but whose texture is strikingly diversified.

The rocks of this group range from granite porphyry (near a rhyolite porphyry) to coarsely porphyritic granite. Furthermore, they exhibit various degrees of metamorphism, ranging from massive granular types to highly gneissoid and banded types. Over most of the area they are porphyritic and invariably consist of quartz, microcline, and biotite with greater or less amounts of soda plagioclase and orthoclase. With rare exceptions they correspond in composition to a sodic biotite granite. A prevalent feature is the occurrence of peculiar cloudy quartz as phenocrysts in the granite porphyry and as similarly conspicuous individuals in the coarser rocks. The habitual and puzzling mixture of the coarser varieties with the finer, more aplitic granite is an indication of the close genetic relations of the rocks of this group. Foremost in the evidence of such a kinship is the vague and gradational character of many boundaries between the granites of the several types and the invariable mutual inclusion of adjacent types.

Three types, distinguished by their more conspicuous textural features, have been indicated on the map. These are granite porphyry, porphyritic biotite granite, and gray biotite granite. It has not been possible to study all the exposures with an equal thoroughness, and a portion of the granite area has been designated undifferentiated Powderhorn granite. With this division have been mapped certain highly metamorphosed granites whose affinities are not definite. They are found on the slopes immediately north of Powderhorn up to an altitude of about 8,600 feet, where the exposures are very poor but indicate a fine-grained gneissoid rock differing in texture from other Powderhorn granites but similar to them in composition. The long, narrow strip of granite crossing Willow Creek half a mile above Midway is sheared and gneissoid but of similar composition to the Powderhorn types.

RELATIONS

The area of the Powderhorn granite is characterized by high hills and rugged canyons. (See Pl. XV, *A*.) These rocks make many of the higher summits north of Powderhorn and form a wild and picturesque portion of the Lake Fork canyon. They have in no small degree produced the scenic features of Cebolla Creek and make the beginning of the upper Cebolla Canyon. In places, as east of Dry Powderhorn Creek, the granite is much altered and disintegrated, giving a marked reddish color to the slopes covered with soil and talus.

The outlines of certain bodies of the Powderhorn granites north of Powderhorn bear interesting relations to the structure of the adjacent schists. The area on the Lake Fork and the areas east of Cebolla Creek have their long dimensions parallel to the schistosity of the adjacent rocks, but in the area east of Goose Creek and west of Cebolla Creek the granite bodies cut the schistosity at all angles. In the last-named area a transition takes place from a northeast strike of the schistosity on the west to a north-northwest strike on the east. In a few places the granite includes small bodies of schist—for example, along the west periphery of the granite mass southeast of Dubois, where the schistosity of the metabasite is cut at nearly right angles. Here there is a zone averaging 100 feet in width in which the granite and metabasite are intimately mixed in approximately equal proportions. The granite is of a somewhat finer and more even texture than the bulk of the mass. Where the granite has been intruded parallel to the schistosity of the metabasite inclusions are much less abundant.

The granites of the Powderhorn group everywhere cut and are younger than the Dubois greenstone. The relation of this granite to the gabbro and diorite mass on the south is not so clear. The contact between these bodies is vague and in places appears to be almost gradational, as if the intruding rock had fused and assimilated material from the invaded rock. Although the gabbro has suffered considerable thermal metamorphism, it shows less evidence of shearing or dynamic change of a regional nature than the granite. On the east slope of Beaver Creek just south of the granite and gabbro contact and on the east slope of Cebolla Creek west of Miller Hill are small bodies of granite, in areas of poorly exposed quartz diorite, which form a peripheral zone of the gabbro mass. These bodies may be dikes, but appearances suggest that they are inclusions. On the east slope of Beaver Creek, north of the same contact, and along the Cebolla road a quarter of a mile north of bench mark 8346 there are dikelike bodies of basic rock bearing a close petrographic resemblance to rocks of the gabbro mass. On these somewhat uncertain evidences the Powderhorn granites are believed to be for the most part older than the gabbro and diorite mass to be described.

This granite is cut by and is older than the pyroxenite, syenite, and other rocks of the Iron Hill area. Its relation to the Iron Hill body of limestone has not been ascertained. Besides the intrusions already described small dikes of red soda syenite, aplite, and aplite porphyry, together with small areas of limestone possibly of vein origin, have been noted here and there throughout the mass.

GRANITE PORPHYRY

Distribution and character.—The principal area mapped as granite porphyry lies in the Cebolla Valley immediately north of Powderhorn and is 4 miles long from east to west by 3 miles wide. Save for a circular patch of overlying volcanic rocks in the center of the area, the granite porphyry occupies almost the entire basin of Milkranch Gulch and makes the ridge between that gulch and Cebolla Creek. West of the creek it occurs in a narrow triangular strip along the lower slopes of the granite hills. The granite porphyry is surrounded by granite except where it is overlain by the La Plata sandstone of Huntsman Mesa or bordered by pyroxenite of the series of rocks of Iron Hill. The largest of many smaller areas is an irregular-shaped body 1 mile across, which lies on Cebolla Creek north of Carpenter Ridge and sends out a long, narrow tongue to the east. The contact of this body with the greenstone on the north is indefinite because of the extensive mingling of the two rocks. A strip of granite porphyry more than half a mile wide is exposed east of Willow Creek and is without doubt an extension of the principal mass. Another body of this rock is mapped within the younger granite on the west side of Cebolla Creek a little more than a mile south of Cebolla Hot Springs. Many dikes of granite porphyry rib the steep walls of Cebolla Canyon east of Dubois and cut the metabasites parallel to their schistosity. Similar and hardly less numerous dikes occur on upper Goose Creek.

The rocks included in the granite porphyry division show considerable differences in petrographic character. Although they are all of granitic composition, they range in texture from a rhyolite porphyry to a granite porphyry and from a slightly metamorphosed rock to a well-banded gneiss, and more rarely to a schist. However, these rocks can as a rule be distinguished from others of the region by their fine-grained to aphanitic groundmass and porphyritic fabric, with phenocrysts of feldspar and quartz. Where a schistose structure is developed, as at and near the Lot mine, it trends northeast.

Everywhere in the granite porphyry body are small bodies of basic rock. These rocks are invariably hornblendic but differ considerably in the amount of metamorphism they have suffered. Most of them are similar in character to the amphibole schists of the Dubois greenstone and are clearly inclusions caught up by the later granitic magma. A small proportion of them show little metamorphism and appear to be diorite or quartz diorite dikes. The porphyry is cut on the south fork of Milkranch Gulch by a large body of quartz diorite and in several other places by both augite and soda syenite.

The granite porphyry intrudes the Dubois greenstone in very many places. The relations of the other granites of the group are by no means clear. Most of the contacts with these bodies are vague and gradational and could be drawn only approximately. On Goose Creek a dike of fine-grained granite of the type associated with the porphyritic biotite granite includes granite porphyry. In the gully due east of Powderhorn a small mass of granite porphyry was found included in what is believed to be a border phase of the biotite granite. On this rather meager evidence is based the assumption that the granite porphyry is earlier than other granite types.

The granite porphyry includes bodies of fine, even-textured, somewhat aplitic granite, some of which appear to grade into it and others to intrude it. The best example of the intrusive variety is on the 9,000-foot knoll east of Cebolla Creek, 1¾ miles east of the mouth of Milkranch Gulch. The rocks of such bodies are intermediate in texture between the porphyritic biotite granite and the granite porphyry.

Petrography.—The granite porphyry shows a great diversity of character from place to place throughout the mass. In color it ranges from light gray to dark bluish gray, some of it displays pinkish shades, and freaks of weathering make it in places rusty yellow or brown. In the freshest and least altered specimens it is a dense bluish rock resembling rhyolite porphyry. (See Pl. X, *A*.) The rocks of this type are for the most part characterized by an aphanitic or a fine-grained porphyritic texture and by containing phenocrysts of quartz, many of which have a cloudy appearance, and glassy, well-formed feldspars. The largest of these phenocrysts are 10 millimeters in diameter. Locally they are very numerous and have the appearance in hand specimens of quartz pebbles in a metamorphosed conglomerate. They are most conspicuous in slightly weathered material. In some parts of the mass the phenocrysts are much less noticeable and consist largely of crystals of feldspars. The coarser phases, such as are found on the high ridge between Cebolla Creek and Milkranch Gulch, approach in character certain types of the granite of Tolvar Peak. Many of these rocks show a moderate degree of banding, and rarely imperfect lamellation is developed.

The microscope shows these rocks to be holocrystalline and to be made up very largely of a very fine, allotriomorphic mixture of quartz, feldspar, biotite, and chlorite. (See Pl. X, *B*.) In texture they range from a highly porphyritic and perpatic phase, in which the individuals of the groundmass can be distinguished only by a high-power lens, to a seriate porphyritic and dopatic phase, in which the groundmass is made up of crystals averaging as much as 0.3 millimeter in diameter. Quartz, plagioclase of the composition of albite or oligoclase, and less commonly orthoclase occur as phenocrysts, which, if not mashed or metamorphosed, are hypidiomorphic or idiomorphic. These larger crystals exhibit all stages of straining, crushing, and granulation. Some of the quartz crystals are bipyramidal in section and well formed, although most of them show undulatory extinction and various degrees of granulation. A few are surrounded by vague rims of fine crystals with parallel orientation and slightly finer granularity than the rest of the groundmass. The feldspar and particularly the orthoclase phenocrysts are usually altered to a fine sericitic mixture. Albite and less commonly Carlsbad twinning can still be distinguished as a ghostlike structure.

The groundmass is a fine-grained mixture of quartz, feldspar, biotite, muscovite, and chlorite, decreasing in abundance in the order named. The quartz is characteristically clear and fresh, but much of it shows evidence of straining. The feldspar is as a rule much altered but appears to be largely orthoclase and microcline with a small proportion of plagioclase. The biotite occurs in fine leaves which approximate parallel orientation. In some of the more crushed specimens this parallel arrangement is well developed, giving the rock a gneissic banding. In other specimens the biotite is present in clusters and aggregates, their arrangement being probably due to local shearing within the mass. Muscovite is invariably present and is in the main a sericitic alteration after feldspar. Chlorite showing good pleochroism in bluish-green, greens, and yellows was seen in about half of the thin sections studied and appears to have been derived from the alteration of biotite or of a combination of biotite and feldspar. Micropegmatitic intergrowths of quartz and feldspar are not uncommon, and most of them if not all are secondary. Small quantities of epidote, calcite, tourmaline, and amphibole occur locally in the granite porphyry, and it is believed that they were added after it crystallized. Apatite, magnetite, and iron ores are the commonest accessory minerals.

The texture of the granite porphyry suggests a hypabyssal and in places even an extrusive rock. However, the structure and associations of the mass do not bear out the latter possibility, and it seems more probable that the part of the mass now exposed was intruded at relatively shallow depth.

PORPHYRITIC BIOTITE GRANITE

Distribution and character.—The porphyritic biotite granite is found throughout the area of the Powderhorn granites save in the areas occupied by the gray granite, described below (p. 46), and the granite porphyry. The best exposures are in the Lake Fork canyon, in the hill southeast of Dubois, on Carpenter Ridge, on Tolvar Peak, along the western slopes of Huntsman Mesa, in Rudolph Hill and the adjacent portion of Cebolla Canyon, and on the slopes south of North Beaver Creek.

The rock of the several bodies classed as porphyritic biotite granite is not of uniform character. In nearly all masses two or more types are present, which may differ widely in appearance and may represent separate intrusions. The prevalent type in each mass may be described as a medium to coarse grained granite having more or less porphyritic tendencies. It is usually pink with black splotches of biotite, which, if sufficiently numerous, give the rock a gray shade. A finer and more even textured aplitic type of somber gray to pinkish color is found in most of the bodies intruding the more abundant coarser phase, in many places in a very intricate manner, as on the west wall of the Lake Fork canyon. The mass here exposed has resulted from a series of intrusions from a granitic magma, and it has not been found practicable to delimit them or to determine which was the earlier. Patches of the coarser material occur within or blend into areas of the finer and appear to be inclusions in it.

These inclusions show a tendency to orient themselves with their longest dimension trending northeast, parallel to the longest dimension of the mass and to the strike of the schistosity of the adjacent schists. Moreover, the outcrops and ridges in this locality also have a prevailing northeast trend. These facts suggest that the coarser variety of porphyritic biotite granite was early intruded into the metamorphic complex and the granite porphyry. The magma from which the finer and more aplitic variety crystallized found its way later into the coarser mass through fissures and cracks, many of which owed their direction to forces acting transverse to the schistosity of the neighboring schists. The blending of these two varieties makes it seem probable that the earlier magma was intruded by the later one before it had entirely cooled.

Furthermore, portions of each magma may have differed slightly from other portions, and these differences would be accentuated by crystallization. After these granites were crystallized they were subjected to regional compression, which found certain parts of the masses less resistant than others, with the result that a further heterogeneity was developed.

Petrography.—The normal porphyritic biotite granite is pink or pinkish gray with dark spots and streaks due to the presence of leaves or clusters of biotite. Feldspar (usually microcline) is the most conspicuous mineral, and the particles are of various sizes, the largest being 25 millimeters in length. Crystals of quartz, many of them milky or bluish gray, are everywhere present. Except where weathered, the rocks of this type are very compact and are hard to split. Locally metamorphism has developed in them a fair degree of foliation, as on the east side of Beaver Creek north of the gabbro contact, on the same creek south of the contact with the intrusive rocks of the Iron Hill area, and on the west side of Cebolla Creek opposite the mouth of Huntsman Gulch.

Save for a subordinate number of well-formed phenocrysts the individual crystals are allotriomorphic and in the groundmass range from slightly less than 1 millimeter to 5 millimeters or more in diameter. In fabric the granites range from seriate porphyritic to distinctly porphyritic with a very pronounced groundmass. Feldspar is the most abundant constituent and consists of microcline, orthoclase, and soda plagioclase, usually albite but never more calcic than oligoclase-albite. Microcline predominates over orthoclase and like it is nearly everywhere perthitic. The potash feldspars make up approximately one-third of the rock, and quartz is but slightly less abundant. Plagioclase is usually subordinate but in a very few places equals or slightly exceeds the potash feldspars, notably in the foliated granites. It may be more or less abundant than the biotite, which makes up at most approximately 15 per cent of the rock. The biotite commonly occurs as a fine equigranular aggregate and rarely as large individuals.

In one slide there is a crystal of allanite 7 millimeters long surrounded by a rim of minute epidote crystals. Other accessory minerals observed are apatite, magnetite, zircon, and rarely titanite.

Sericitic muscovite and epidote and in less quantity chlorite, calcite, and iron oxides have been developed through alteration. Perthitic intergrowths of orthoclase and microcline with albite are characteristic, and micropegmatite is usually present in small amounts.

Locally, particularly near the periphery of the bodies, the rocks have been subjected to incipient metamorphism, as shown by the quartz, which exhibits undulatory extinction or is crushed and even granulated. The feldspars less commonly show similar phenomena. Near the granite and metagabbro contact the granites are finer grained and are more altered than usual, with extensive development of epidote and highly pleochroic chlorite, derived chiefly from biotite.

The granites of Willow Creek mapped as undifferentiated Powderhorn granite differ in character from place to place and can not all be definitely correlated with the types here distinguished. On the east side of the creek near the contact with the granite porphyry the rock is a moderately coarse porphyritic biotite granite, resembling the typical porphyritic biotite granite, although just across the valley there is a body of fine-grained, even-textured granite in which biotite is relatively inconspicuous. Farther up the creek the slopes show scattered exposures of granite somewhat similar to the type here described. Locally the granite of this valley is much sheared and banded.

GRAY BIOTITE GRANITE

The gray biotite granite, so called, occurs in a rudely semicircular area at the beginning of the granite canyon of Cebolla Creek. It walls the west side of that creek opposite Beaver Creek and makes the shoulder rising to Rudolph Hill, 1 mile southeast from Cebolla Creek. In all it is exposed over an area of about 1 square mile. This granite represents a distinct and probably later intrusion than that of the porphyritic biotite granite.

The rock of this body is much more homogeneous than that of the one just discussed. It is characteristically of a pepper-and-salt gray on fresh fracture and of moderately fine-grained and fairly uniform texture, although there are a few crystals of quartz as much as 5 millimeters or more across. In places the granite displays a vague gneissic structure.

Thin sections of the rocks show them to be of seriate porphyroid fabric, in which the crystals are of allotriomorphic to hypidiomorphic outline and of various sizes, the largest being 1.5 millimeters in diameter. Feldspar is slightly more abundant than quartz and consists of sodic plagioclase, which ranges in composition from albite to oligoclase, orthoclase, and microcline, decreasing in quantity in the order named. The orthoclase almost invariably shows microperthitic intergrowths.

The plagioclase crystals are generally idiomorphic and appear to have crystallized before the other feldspars or the quartz. Biotite is next to quartz in order of abundance and occurs in ragged, allotriomorphic leaves, some 1 millimeter across, or in fine aggregates. Allanite in a well-formed crystal 0.5 millimeter long was found in one section along the contact of feldspar and quartz crystals and is undoubtedly an original mineral. Apatite, zircon, garnet, and magnetite occur as accessory minerals. Sericitic muscovite, epidote, and chlorite are commonly present, having resulted from the alteration of the other constituents.

The rocks of this type are somewhat more sodic than the other Powderhorn granites and approach in character the soda granites of the northeast corner of the Uncompahgre quadrangle described below. In neither of these rocks is the plagioclase calcic enough to make the rock a quartz monzonite.

VERNAL MESA GRANITE

OCCURRENCE

Near the northwest end of Vernal Mesa and walling the adjacent portion of the Black Canyon is another body of coarse porphyritic granite suggesting in some respects the coarsest phase of the Powderhorn granite. This mass, which is here named the Vernal Mesa granite, is from 1 mile to 1½ miles wide and is 2½ miles long in a north-northeast direction across the canyon and Vernal Mesa. Its eastern boundary crosses the canyon immediately above the mouth of Grizzle Gulch, on the south line of sec. 19, T. 50 N., R. 7 W., and extends across and up the west side of Big Draw. The body is bordered on the east by the River Portal schists and an area of granite gneiss and mica schist highly injected with granitic material; on the west it is in contact with granite gneiss, and on the north and south it plunges under Mesozoic sediments. Indeed, there is a small capping of sandstone, probably La Plata, on the ridge northeast of the head of Dawson's Gulch. The granite appears to have been intruded for the most part parallel to the structure of the adjacent schists, so that it probably extends for greater distances to the northeast and southwest under the later formations. The mass, particularly on its west side, is vaguely outlined, and it is in many places intricately injected with smaller bodies of granite. In this locality the Black Canyon is inaccessible, so that the contacts here had to be sketched in large part from the rims of the canyon and are therefore generalized.

Two miles west of the main mass of porphyritic granite is a smaller one, more than half a mile wide by a mile long, exposed on the ridge west of Red Rock Canyon. Small exposures of similar granite have been observed along the River Portal road 1 mile southwest of Nyswonger Spring. In driving the Gunnison tunnel a granite body almost identical in mineral composition and texture with the Vernal Mesa granite was encountered at 2⅓ miles from River Portal and persisted for a little more than a quarter of a mile.

GENERAL CHARACTER

The Vernal Mesa granite makes sheer walls more than 1,000 feet high along the Black Canyon below the mouth of Grizzle Gulch and with the adjacent River Portal schist produces the wildest and most picturesque scenery in the region. Near the western border of the granite mass the abrupt cliffs of the canyon give way to precipitous slopes with bold rounded forms. The large flat area of granite on Vernal Mesa west of Big Draw represents the peneplaned surface at the top of the pre-Cambrian rocks from which later sediments have been eroded.

Like the coarser phase of the Powderhorn granite the Vernal Mesa mass is not very homogeneous, and especially near its borders contains numerous inclusions of biotite schist and gneiss. It is also cut by many dikes of aplite and pegmatite, some of which are shown in the small body at the head of Red Rock Canyon. Finer granite occurs in small irregular patches throughout the mass and may represent segregations within the intruding magma. In typical exposure the granite of this body is dark and is streaked with yellow and brown iron stains. Its surface is rough and pitted, owing to its coarse, uneven texture.

PETROGRAPHY

The Vernal Mesa mass is made up chiefly of a biotite granite whose distinguishing characteristic is its porphyritic texture. The rock appears megascopically as a mixture of quartz, feldspar, and biotite, studded with phenocrysts of pink or flesh-colored feldspar, the largest 3 centimeters across, many of which show Carlsbad twinning. In section the minerals making up the rock are seen to be for the most part allotriomorphic and of all gradations in size, although those from 1 to 2 millimeters in diameter are the most numerous. So far as could be judged from the study of a few thin sections plagioclase, usually of the composition of oligoclase, appears to be slightly more abundant than any of the other minerals. With microcline it forms nearly all the phenocrysts.

Quartz equals or exceeds in amount the microcline and is commonly filled with fine inclusions, some of which resemble needles of rutile. Orthoclase is present in small amounts and like the microcline is usually perthitically intergrown with plagioclase. Biotite is very abundant and in some rock makes as much as 10 per cent. Apatite, titanite, zircon, epidote, and magnetite are accessories. Alteration has produced sericite, epidote, iron ores, and a little zoisite.

The rock of the Vernal Mesa mass is a soda granite and conforms with the granite of the eastern part of the Uncompahgre quadrangle in mineral composition and resembles the coarser phases in texture. Like them it approaches the composition of a quartz monzonite or granodiorite.

CURECANTI GRANITE

OCCURRENCE

The Curecanti granite, one of the most interesting granite masses of the region, is exposed for 3½ miles along the Black Canyon, from a point 1½ miles east of Curecanti Creek to Nelson Gulch. It extends only a short distance up Curecanti Creek but walls the lower canyon of Blue Creek for 1½ miles from its mouth. Although the granite as exposed covers little more than 2 square miles it is peculiarly well located for study, as the Gunnison has cut through it from east to west, and Curecanti and Blue creeks have crosscut it at right angles to the main gorge. These creeks, coming from opposite directions, empty into the Gunnison at practically the same point, at a famous scenic feature of the Black Canyon, the Curecanti Needle, a monolith of granite 790 feet high. (See Pl. II, *A*.)

The overlying sedimentary and volcanic rocks come down to the rims of the canyons, so that the limits of the intrusion are not visible. However, the many deeply cut canyons of the vicinity have served to block out the mass fairly well, and it is not believed to extend far under these rocks. The granite was intruded into Archean biotite schist and is bounded by this rock where erosion has exposed its edge. The western limit of the mass along the Black Canyon and the southern limit on Blue Creek are extremely indefinite and had to be somewhat arbitrarily drawn. Near the edge of the body on these sides the granite contains many inclusions of biotite schist, and the adjacent metamorphic rocks are much intruded by granite, largely of the Curecanti type, so that the change from granite with inclusions of schist to schist with many injections of granite is in many places imperceptible. Furthermore, the steepness of the canyon walls does not everywhere permit a close examination of the boundaries of the granite, and as weathering has made all the rocks equally dark it is difficult to distinguish them even from a short distance.

GENERAL CHARACTER

The most rugged and wonderful part of the Black Canyon traversed by the railroad owes its character to this hard and homogeneous mass of granite, which in places makes almost sheer walls more than a thousand feet high. (See Pl. XI.) On the south rim of the canyon, west of Blue Creek, the overlying beds have been removed from the granite for a short distance, exposing the old peneplain. Elsewhere the Curecanti granite is exposed only in the canyon walls. In the outcrops it is commonly a little lighter in color than the biotite schist, but the two are hardly distinguishable at a distance. The Curecanti mass is more homogeneous than the other granitic bodies of the region and is made up in the main of a pink to gray fine-grained even-textured granite in which either biotite or muscovite, or both, may be present. Small irregular patches of coarser, in places pegmatitic granite are scattered through the mass and with the many inclusions of biotite schist are the only foreign constituents observed.

RELATIONS

The Curecanti granite shows even less evidence of having been metamorphosed than the granite bodies of the Cebolla and adjacent valleys and doubtless was intruded after the great deformative movements which caused the schistosity of the Archean complex. The only rock known to cut it is diabase, which occurs in two well-defined dikes east of Nelson Gulch. Except where it is overlain by post-Cambrian formations it is in contact with biotite schist. On the north and east the limits of the mass are well defined, but on the south and west they are indefinite, as already stated. On the north wall of the Black Canyon east of Curecanti Creek the relation of the granite stock to the schists is strikingly shown. (See Pl. XI, *A*.) The contact between these rocks starts in the bottom of the canyon 1½ miles east of the mouth of Curecanti Creek and gradually rises on the wall until it reaches the rim 1 mile farther west, where the granite comes into contact with the sediments instead of with the biotite schist. For this distance the roof of the granite stock is thus exposed, but it is not accessible for close study save in the first gulch east of Curecanti Creek. The contact is remarkably straight and is sharp and "frozen," although the granite cuts the schistosity at nearly right angles. On the east wall of the Curecanti gorge the contact is equally sharp but is marked by a prominent jointing. On the other hand, the western limit of the granite in the Black Canyon and the southern limit on Blue Creek are marked by a maze of apophyses, dikes, and smaller extrusions from the main mass so intricate that there is no definite line of demarcation between the schist and the granite.

The different relations between the intruding and the intruded rocks on the two sides of the granite area are apparently accounted for by the structure of the schists in the adjacent area. Although the biotite schists that form a roof for the granite in the canyon wall show considerable lack of uniformity of structure, those east of the granite are remarkably persistent in strike and dip. From the easternmost point of the granite area eastward beyond the mouth of the Black Canyon and up the Lake Fork for many miles the metamorphic rocks, save for a few local variations, strike N. 60°–70° W. and dip north-northeastward at various angles from 55° to 80° or more. The rocks near the forks of Blue Creek have a similar structure. West of the granite body the structure changes to a dominant northward trend as the result of an ancient fault that crosses the canyon at Nelson Gulch. From these facts it appears that the intrusion has been much influenced by the structure of the invaded schists. It is conceived that the rising magma found its easiest advance along the planes of foliation of the schists and hence followed the rise of the structure, which was south-southwestward.

INCLUSIONS

The Curecanti granite mass almost everywhere contains inclusions of material similar to the invaded rock. The number of these bodies is only slightly greater near the edges than in the center of the exposed portion of the mass. Owing to the steepness of the walls containing them, together with the similarity in appearance of much of the darkly weathered granite and the gneiss from a short distance, it is not possible to study many of these bodies and their elations in detail. However, several have been sketched in a general way from the most available vantage points.

These inclusions range from very small bodies up to enormous masses extending ertically as much as 700 feet and exposed along the canyon for a quarter of a mile; one which is less than 700 feet thick is three-quarters of a mile long. Good examples of these bodies a e found just east of the mouth of Blue Creek in the bottom of the Black Canyon, and another is exposed on the north side of the canyon, extending westward from a point opposite Curecanti Needle. These inclusions are of irregular shape and many show much crumbli g and contortion of the lamellae. No relation could be observed between the metamorphic structure of the inclusions and the structure of the adjacent inclosing gneiss.

The contacts of the granite with the inclusions are almost invariably sharp, without any alteration or crushing, and with only a few apophyses of granite extending into the foreign material. The periphery of only one or two inclusions suggested that partial fusion and recrystallization had taken place. The jointing of many of the included bodies is the same as that of the inclosing granite.

JOINTING

The Curecanti mass has no very persistent system of joint planes. The most common are two that are nearly vertical, one running about N. 30° E. and the other about N. 60° W. These are found only east of Curecanti Needle. West of this point, in the deeper part of the canyon, a vertical jointing running about N. 80° E. and in places nearly parallel to the direction of the canyon is noteworthy. Vertical joint planes running in almost every direction may be observed from place to place. There is also a nearly horizontal jointing, which, however, is not persistent. The joints, where well developed, increase the picturesqueness of the canyon, and west of Curecanti Needle they give a peculiar steplike character to the south wall.

PETROGRAPHY

The Curecanti granite is very uniform in mineral composition and in texture. It is a sodic quartz-microcline granite of fine to medium grain and even texture. On fresh fracture it is usually pink but may be gray, pinkish gray, or red. In thin section the rock is seen to consist chiefly of an allotriomorphic mixture of quartz, microcline, and soda plagioclase in slightly varying proportions, together with smaller quantities of orthoclase, muscovite, and biotite. It is of seriate homeoid to seriate porphyroid fabric, in which the individual grains range from 0.5 to 3 millimeters in diameter. The average of measurements of the mineral content of several thin sections from three localities by the Rosiwal method resulted as follows:

Quartz	39. 5
Microcline	27. 8
Plagioclase	24. 4
Mica (muscovite and biotite)	5. 1
Orthoclase	3. 2
	100. 0

The quartz occurs in irregular grains of various sizes, is usually filled with minute inclusions and cavities, and is not infrequently found as poikilitic inclusions in microcline. The microcline is commonly streaked with microperthitic intergrowths of soda plagioclase. The plagioclase is largely albite, although some of it is as calcic as oligoclase ($Ab_{85}An_{15}$). It is usually better formed and probably crystallized, in part at least, earlier than the microcline, which is as a rule less altered than the other feldspars. Orthoclase is present in subordinate amounts and is characteristically altered to sericite.

White mica is slightly more abundant than the biotite. It occurs as irregular-shaped leaves and usually shows faint pleochroism $Z \gtrsim Y > X$. This is particularly noticeable along cracks or strong cleavage planes and around inclusions, some of which are thought to be zircon. Besides the original muscovite, sericite is abundant, having resulted from the alteration of the feldspars. Chlorite, epidote, and iron ore are the chief secondary minerals. Garnet is the most abundant accessory and is present in almost every section. Crystals of this mineral are generally less than 1 millimeter in diameter, but many are large enough to be distinguished megascopically, and the largest are several millimeters across. A few have borders of and cracks filled with a chloritic material, which appears to be an alteration product of the garnet. Apatite, zircon, and magnetite are present in very small quantities.

Scattered throughout the Curecanti body are irregular patches of coarse or even pegmatitic granite. The rock of this phase consists chiefly of microcline and quartz in large part intergrown and in crystals as much as 3 inches across. Muscovite commonly forms a large part of the coarse mixture, though biotite is locally present. This coarser phase of the granite mass resembles very closely many of the pegmatite bodies described beyond (pp. 77-79). From its occurrence in irregular areas in the walls of Curecanti granite this pegmatite phase is believed to have been formed at the same time as the rest of the granite mass and to represent a greater facility of crystallization, due possibly to the presence of water vapor or other agents that locally reduce the viscosity of the magma.

SMALLER GRANITE BODIES

OCCURRENCE

In addition to the large bodies of granite there are innumerable smaller ones scattered throughout the region, which range from mere threads up to masses comparable in size to the major stocks. They occur in an almost infinite variety of shapes—as lamellae injected between the planes of schistosity of the metamorphic rocks and as stringers, dikes, lenses, or irregular bodies of the most diverse character. Such bodies are most numerous near the large granitic stocks, with which they are no doubt connected. Thus in the Black Canyon for several miles west of the Curecanti granite mass the biotite schist is ribbed and veined by dikes and irregular intrusions of granitic rock. There are similar areas in the Lake Fork canyon adjacent to and north of the large body described as a part of the Powderhorn porphyritic granite and adjacent to the large granite mass on Vernal Mesa. Here and there are more isolated areas of extensive granite injection; as on Cebolla Creek below the mouth of Wildcat Gulch and on Lake Fork at the mouth of Little Willow Creek. In the northeast quarter of the Uncompahgre quadrangle there are similar areas in which so much granite has been injected into the schists that a delimitation of the rocks would be almost impossible. Such areas have been mapped along the Ninemile Hill road, on Willow and Sugar creeks, and in the extreme northeast corner of the quadrangle. On and east of the quadrangle line are several larger bodies of granite whose size and shape have not been determined.

No attempt was made to map the minor granite intrusions further than to show a few of the more typical ones.

AGE AND RELATIONS

That these bodies belong to more than one period of intrusion is very evident from the occurrence of many intersecting dikes and from the structural relations of the injected material to the deformation of the more ancient rocks. An example of this evidence is shown in Plate XII, *B*, which illustrates two injections of granite that occurred during widely separated periods. The first injection took place during or before the development of the schistosity and the folding of the invaded rocks, and the strong crosscutting bodies were manifestly injected much later. A less common structural evidence of two periods of intrusion is shown by Figure 2. The earlier intrusion developed a characteristic pinch and swell series of connected lenticles between the folia of the schist and the later body cut both the schist and the earlier granite in a sharply defined dike.

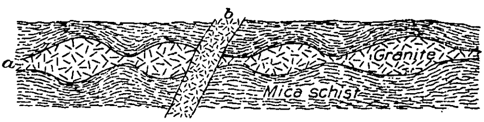


FIGURE 2.—Two injections of granite. *a*, Earlier injection with pinch and swell structure; *b*, later injection of a sharply defined dike

The evidence shows that the smaller granite bodies range in age from the time of the deformative movements that foliated the metamorphic rocks or earlier nearly to that of the last intrusions. From the abundance of small granite bodies in proximity to the larger ones and from their very close mineralogic and textural similarity to them—for example, in the area west of the Curecanti granite—there can be no doubt that a large proportion of the smaller granite bodies are genetically related to certain of the larger stocks described. Although these smaller granite bodies cut the schist at all angles, many of them conform more or less closely with the schistosity. In places, as on the north side of the Black Canyon between Nelson and Cabin gulches, these dikes together with pegmatitic dikes are so numerous as to give character to the topography. Here great dikes and high irregular-shaped walls of schist, intersected and buttressed by granite intrusions, rib the steep canyon slope and give rise to very rugged and striking effects. (See fig. 3.)

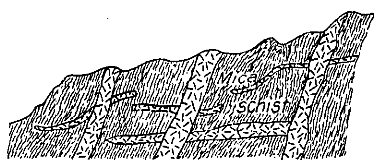


FIGURE 3.—Side view of a thin wall of schist intersected and buttressed by granite intrusions, on the north slope of Black Canyon east of Cabin Gulch

NORMAL MICROCLINE GRANITE

Except for a few types found east of the Cebolla basin, the granite of these smaller bodies is so similar in character to rocks already discussed that it needs little further description. It is generally pink or red, less commonly gray, and ranges from moderately fine to coarse grained and from a uniform to a slightly porphyritic texture. The most prevalent type in such bodies is a quartz-microcline-biotite granite in which soda plagioclase (albite to oligoclase) may be nearly as abundant as the microcline. Muscovite, orthoclase, microperthite, and the ordinary accessory minerals are commonly present. This type may be described as the normal microcline granite of the region.

SODA GRANITE

Occurrence.—At many places between Willow and Cochetopa creeks there are small irregular bodies of a gray soda-rich granite. Save in a few localities in the eastern part of the Uncompahgre quadrangle these bodies have not been critically studied. The best-known occurrences are in the band of granite that crosses Sugar Creek a mile north of Vulcan and in the series of roughly parallel bodies of granite running in a northwesterly direction across the northeast corner of the Uncompahgre quadrangle. These bodies are extremely numerous but are characteristically lacking in persistency and grade laterally as well as longitudinally from granite with many inclusions of schist to schist highly injected with granite. In the walls of the canyon of the Gunnison below Hierro switch there are splendid exposures of this granite which have been injected into the highly foliated schist along the planes of schistosity so as to form bodies of many shapes and sizes. The largest single mass observed was the one that crosses South Beaver Creek 4 miles from the point where that stream empties into Gunnison River, which exceeds a quarter of a mile in width and can be traced for more than 2 miles. The Aberdeen granite quarry is in this body. A considerable body of similar granite is exposed in Lick Creek near Chance but has not been studied.

Petrography.—Some of the soda granite approaches a quartz diorite in composition, but all gradations from this extreme to the normal microcline type can be found even in the same outcrop. The soda granite appears to have been intruded more recently than the normal microcline granite. Where typically developed the thick sprinkling of black biotite through the transparent quartz and white feldspar gives the rock its general gray appearance. The granite is of even texture and of medium grain, the individual crystals averaging from 2 to 3 millimeters in diameter and few being larger than 7 millimeters.

In thin section the rock appears to be allotriomorphic and of seriate intersertal fabric. The essential mineral constituents in descending order of abundance are plagioclase of the composition of oligoclase, quartz, biotite, and potash feldspar (microcline and orthoclase). In the typical soda granite the potash feldspar is subordinate, comprising as little as 5 per cent of the rock, although in the gradational phases microcline becomes more abundant and biotite is diminished—an interesting relation which suggests that the amounts of potash in the two types of rock may not differ much. There is a little hornblende in some of the more basic rocks. The accessory minerals are magnetite, apatite, zircon, epidote, calcite, and titanite.

An estimate of the mineral percentages of the granite from the Aberdeen granite quarry by the Rosiwal method gave the following results: Quartz, 36; feldspar, 51; biotite, 12; accessory minerals, 1.

FINE PORPHYRITIC GRANITE

Associated with and probably genetically related to the soda granite in several localities there is a fine-grained porphyritic phase. This rock is well exposed at several points on Sugar Creek at the Uncompahgre quadrangle line and appears to be older than the soda granite, which may be a differentiate from it. The largest body of this type of granite is on the north side of Pole Creek and extends southeastward for several miles from Big Mesa and in places is more than a mile wide. Although the rock varies locally in texture and contains many patches or segregations of coarser material, it is most commonly very fine grained, porphyritic, and perpatic, with phenocrysts of feldspar (chiefly oligoclase) and quartz, the largest 2.5 millimeters in diameter. In texture it suggests the granite porphyry of Cebolla Creek. The groundmass is composed essentially of quartz, microcline, soda plagioclase, biotite, muscovite, and a little orthoclase, in order of abundance as named. Magnetite, apatite, and zircon were observed as accessories. This type differs from the soda granite most markedly in texture, but it also contains a much larger percentage of potash feldspar.

METAGABBRO

OCCURRENCE

Unique among the rocks of the region both as to its composition and as to the character of the metamorphism which it has undergone is the body of metagabbro and quartz diorite in the Cebolla and Beaver Creek basins more than 6 miles south-southeast of Powderhorn, midway between North Beaver and Rock creeks. The mass is exposed in a roughly rectangular area 1½ miles in width and 3½ miles in length, with its longer direction running northeast. It extends from the west side of Cebolla Creek to the east side of Beaver Creek, making, with Miller Hill, the divide between those basins.

On the south the body is overlain by the lavas which apparently flowed over an irregular surface of it. The contact in this portion extends up Cebolla Creek and gains the top of the divide a quarter of a mile south of Miller Hill. It then swings northward, the only marked irregularity being the small peninsula-like area half a mile east of Cebolla Creek. On the east the mass is bounded and overlain by La Plata sandstone, lying upon a smooth surface that dips gently southward. On the north and west, except where overlain by small outliers of lava, the metagabbro is in contact with the Powderhorn granite mass. The contact is in general straight and runs southwestward across Beaver Creek to Cebolla Creek, but on crossing that creek it swings nearly due south and then runs up a deep gulch that empties into Cebolla Creek at an altitude of about 8,400 feet. The straight and sharp character of the contact suggests a fault, but local irregularities point rather to intrusive relations. The exposures are not decisive, although careful examination along the contact disclosed more evidence in favor of an intrusive relation than of a fault.

The further extension of the body under the later rocks can only be conjectured. However, the occurrence, at the southernmost part of the mass, in Cebolla Creek, of small amounts of granite and of a zone of diorite similar to that on the north border suggests that the edge of the mass on this side is not a great distance from the limit of the exposures.

GENERAL CHARACTER

Owing to its hardness the metagabbro has produced very rugged topography, particularly on Cebolla Creek, where it walls a narrow canyon 1½ miles long and 500 feet deep, which is one of the most picturesque features of that interesting creek. The metagabbro area on Beaver Creek is characterized by more gentle topography, more timber, and fewer good exposures than that on Cebolla Creek. The exposures of this rock are characteristically dark to black and show a variety of iron staining. The only suggestion of structure is a tendency to northeasterly ridges and quartz veins of similar trend on the east slope of Cebolla Creek. Even here no decided schistosity could be discerned. For this reason the mass is believed to have been intruded since the period of deformation that gave to the metamorphic complex its foliated character. Quartz veins and a few dikes of aplite constitute the only foreign material observed in it.

By reason of this scarcity of intersecting bodies as well as of the obscurity of the contact with the Powderhorn granite on the north, the relative age of this body of metagabbro and the other pre-Cambrian rocks is not definitely determinable. The metagabbro has suffered greater metamorphic change than the granite, although the metamorphism has been thermal and possibly local and is of no importance as a criterion of age. The detailed relations of the Powderhorn porphyritic biotite granite and the metagabbro are described on page 39. On the basis of the evidence available, it seems probable that the granite was intruded earlier than the metagabbro.

The rocks of this body vary from place to place both in petrographic detail and in degree of metamorphism. The major portion of the mass consists of metagabbro, but it is bordered by zones of little metamorphosed quartz diorite. Owing to the close association of these zones with the main part of the mass, their smaller size, and the difficulty of delimiting them the quartz diorite will be discussed as a phase of the metagabbro. These two more general types are believed to have been intruded separately and have been roughly distinguished on the map. The metagabbro is not only cut by the quartz diorite but is found included in it as well and is therefore believed to be older. This assumption is corroborated by the more metamorphosed character of the metagabbro. However, the two types appear to have close genetic relations, their contacts being vague and in places gradational, and it may be that the quartz diorite is merely a peripheral differentiate of the metagabbro mass, intruded before that mass had entirely cooled.

In addition to these two major types of rocks, several basic associates were observed from place to place. The most common of these is a dark, fine-grained, even-textured rock, which under the microscope suggests a metadiabase in structure and mineral content. Another specimen, which was badly altered, had the composition of a granodiorite. These rocks form small and vague bodies, some or all of which may be differentiates of the gabbro or quartz diorite. Intrusions of aplite and inclusions of biotite and chlorite schist were observed in the quartz diorite.

PETROGRAPHY

Metagabbro proper.—The most abundant type of rock in the mass under discussion is the metagabbro. It is characteristically dark green, of medium grain, of slightly porphyritic texture, and heavy. Hornblende in conspicuous platy crystals forms a meshwork in which fine light to greenish-tinged zoisite resembling feldspar can easily be discerned. The only other minerals visible to the unaided eye are small amounts of feldspar, hardly distinguishable without the microscope from zoisite, and a few fine grains of pyrite.

A microscopic study of the metagabbro discloses its highly altered and metamorphosed character, amphibole, zoisite, and epidote being the most abundant constituents. None of the sections studied showed even a semblance of schistosity. The minerals are allotriomorphic in outline, and few exceed 1½ millimeters in mean diameter, although amphibole crystals reach an extreme length of 10 millimeters. The rocks, which before alteration were probably of moderately even grain, now possess a pseudoporphyritic fabric, the amphibole occurring as larger individuals with aggregates of finer crystals of zoisite and epidote.

In most of the slides examined amphibole is the most abundant mineral. It is mainly hornblende, but much of it is actinolitic and it is commonly fibrous, of ragged outline, and full of inclusions of quartz, magnetite, and fine mineral grains whose nature could not be ascertained. It commonly exhibits but slight pleochroism, being nearly colorless to pale green, although the centers of a few crystals show deeper color with stronger pleochroism in bluish greens, greens, and yellows. The hornblendes show rather large extinctions (about 25° Z to crystallographic c), low indices of refraction ranging from 1.62 to 1.64, and frequent twinning. They are believed to have resulted, in part at least, from the metamorphism of pyroxene.

Next in abundance to the hornblende and in a few specimens of equal or greater importance are zoisite and epidote. These minerals are present in nearly all the metagabbro and are, at least in part, alteration products after plagioclase. A few zoisite crystals exhibit "ghosts" of the former albite twinning structure of the original plagioclase, but in the more feldspathic phase described below plagioclase crystals are dotted with fragments of zoisite and epidote, plainly alteration products of their hosts. The zoisite and epidote, which make at the utmost approximately 40 per cent of the rock, occur in irregular-shaped grains or aggregates, and save in a few specimens the zoisite predominates over the epidote. The zoisite resembles the epidote but is distinguished when viewed with crossed nicols by its beautiful blue color, resulting from its low birefringence and strong dispersion.

In a few sections traces of plagioclase are still recognizable. Magnetite is invariably present and may make up as much as 2 or 3 per cent of the mineral constituents of the rock; in a few specimens it shows pseudomorphic structure after amphibole. Pyrite, apatite, quartz, calcite, and chlorite occur in small quantities.

In the classification of Grubenmann the rocks of this type fall with the zoisite amphibolite of the middle zone.[24] They are believed to have acquired their metamorphism at much less depth than the schists already described. For this reason pressure has probably been far less effective in giving them their present character than

[24] Grubenmann, U., Die kristallinen Schiefer, 2d ed., p. 204, 1910.

temperature. It is believed that these rocks were originally crystallized from a magma of approximately the composition of gabbro, that the pyroxene minerals have been changed to amphibole through the familiar processes of amphibolization, and that the calcic plagioclase has been almost entirely transformed into zoisite and epidote by heat and the chemical action of deep-seated solutions or vapors.

Feldspathic phase of metagabbro.—In a small area on Beaver Creek a more feldspathic phase of the metagabbro occurs in a body of vague and indefinite outlines. Only a few specimens of this phase were collected, and no attempt was made to outline the body, which probably represents a differentiate of the gabbro magma less affected than usual by metamorphism. These rocks vary markedly in texture and to a less degree in composition, but they are alike in containing considerable amounts of unaltered plagioclase, which gives them a somewhat lighter color than the metagabbro proper. Save for one small exposure, which is of very coarse grain, these rocks are of moderately fine and uniform texture. At the sharp bend in Beaver Creek they have a somewhat gneissic structure. Microscopic examination showed them to be composed chiefly of plagioclase, ranging in composition from bytownite to anorthite, and of hornblende, zoisite, and epidote, named in order of decreasing abundance. The hornblende and zoisite have the same appearance as those of the metagabbros proper, and the rocks possess the same accessory minerals.

The rocks of this phase are gabbros that have undergone less alteration than those of the more prevalent type and therefore suggest the original character of the mass. The local coarser granularity indicates that the original mass was of variable texture and more or less differentiated. These differences may have been the source of differing resistance to the processes of metamorphism, or the areas of less alteration may have been more protected from the solutions and gases that affected the mass. In any case, the occurrence of these more feldspathic rocks affords further evidence that the rocks of this mass are derived from granular igneous rocks of the composition of gabbros.

Quartz diorite.—Associated with the metagabbro mass are two narrow marginal bands of quartz diorite. The rocks of this type are easily distinguished from the metagabbro by their coarser grain and spotted gray color. Their principal constituents are dull but light-colored feldspar, milky vitreous quartz, and dark-green hornblende, all of which can be recognized megascopically.

The two bands of quartz diorite have been roughly outlined on the map, bordering the north and south sides of the metagabbro mass. On the north side the band is about a quarter of a mile wide and extends from the east side of Beaver Creek westward to the east side of Cebolla Creek. On the south side the quartz diorite occurs in a band of somewhat greater width that crosses Cebolla Creek. The volcanic rocks come down over the pre-Cambrian rocks in this locality, so that the southward extent of the quartz diorite is not known, although the band must be more than half a mile wide. The quartz diorite is found in stringers cutting the metagabbro and appears to have been intruded later than that rock, probably along the margin of the mass. Even though the quartz diorite is found to be younger than the Powderhorn granite the relation between the age of that body and that of the metagabbro proper remains uncertain.

In thin section the quartz diorite invariably exhibits more or less weathering and is of a seriate porphyroid fabric in which the constituent minerals are allotriomorphic, the largest 5 millimeters in length, and averaging approximately 2 millimeters in diameter. Feldspar, quartz, and hornblende are the dominant minerals of the rock, although biotite, chlorite, and epidote are common. The feldspar, which is as a rule much altered, is the most abundant mineral and consists very largely of plagioclase with the composition of andesine, although in some places the alteration seems to have rendered it more sodic, so that oligoclase or even albite has resulted. Microcline was noted in small quantities in a few slides, but orthoclase, if ever present, is now entirely decomposed. Quartz, which, save for minute inclusions, is clear and fresh, is second in abundance to the plagioclase in most of the sections studied, although hornblende may equal or exceed it in others. The hornblende is characterized by irregular and ragged outlines and in places includes small fragments of quartz, magnetite, biotite, and other minerals. It exhibits the usual pleochroism in greens and yellows, and some of it shows strong dispersion of the bisectrices. The commonest accessory minerals are apatite, zircon, garnet, and the iron ores. In one place, on the west side of Cebolla Creek near the southern limit of the mass, a small quantity of graphite occurs with rock of this type. Biotite, chlorite, muscovite, epidote, zoisite, and calcite occur in subordinate amounts as alteration products after feldspar and hornblende. There is little evidence in these rocks of the extensive metamorphism suffered by the metagabbro mass.

QUARTZ DIORITE AND DIORITE

OCCURRENCE AND RELATIONS

In addition to the metabasites and the metagabbro with its diorite associates there are many small intrusions of a variety of unmetamorphosed mafic rocks, including quartz diorite, diorite, diabase, and gabbro. Of these the quartz diorite and diorite, which appear to be closely related, are the most abundant. They occur chiefly in the northeast quarter of the Uncompahgre quadrangle, in small bodies of irregular outline. Among the best-known occurrences are those on Willow Creek, between Sugar and Camp creeks, on the west slope of South Beaver Creek northeast of Big Mesa, along Gunnison River 1 mile east of Iola and a small mass on the north side of Gunnison River northwest of the mouth of North Beaver Creek.

These bodies range in size from small dikelets to masses 1 mile or more in length. They are characteristically of irregular outline and contain considerable quantities of granite and schist, the former intruded and the latter picked up as inclusions. The areas mapped as diorite along Willow Creek represent a series of irregular injections into the schist too close together and too numerous to be mapped separately.

These dioritic rocks are intruded into the biotite schist and in many places are associated with the soda granite. In the body northeast of Big Mesa there are intermediate phases between the soda granite and the quartz diorite, so that it seems not improbable that they are genetically related. In the exposure northwest of the mouth of North Beaver Creek the diorite is included in the soda granite and is therefore older. Very similar dioritic dikes were found cutting the Dubois greenstone near Dubois, the Powderhorn granite east to Powderhorn, and the granite porphyry in the southeast fork of Milkranch Gulch. The diorite is in many places cut by pegmatite and aplite and in the area west of Iola by quartz-microcline granite. It is not likely that all the diorite intrusions are of the same age. However, all are later than the deformative movements that gave the schists their present attitude, and some are without doubt later than the earlier granite intrusions.

PETROGRAPHY

The rocks of this group range in color from a pepper and salt gray to black, in granularity from fine to moderately coarse, and in composition from a quartz diorite near a soda granite to a diorite approaching a gabbro. On fresh surfaces feldspar and hornblende are the most conspicuous minerals, although quartz, biotite, and epidote are locally abundant. In thin section these rocks are allotriomorphic, locally hypidiomorphic, and of seriate or seriate intersertal fabric, in which the individual crystals are rarely less than 1 or more than 3 millimeters across. They are composed essentially of plagioclase, hornblende, quartz, and biotite, named in order of descending abundance. The plagioclase is chiefly andesine, but ranges in composition from calcic oligoclase in the quartz diorite associated with the soda granite to labradorite in some of the varieties near gabbro or near diabase. The plagioclase is commonly altered and in some places has been almost entirely changed to a confused mixture of sericite, epidote, and albite. In most of the sections examined the hornblende is of irregular outline, contains inclusions of magnetite, biotite, apatite, and feldspar, and is thought to be original. However, some grains show irregular and fibrous extinction with strong dispersion of the bisectrices, and these are probably secondary. In a few places the augite has borders of amphibole, as in the small body of quartz-biotite-hornblende rock near the mouth of Camp Creek. Quartz is present in most of the thin sections studied, exceeding the hornblende in a few, but is entirely absent in several of the more basic rocks. Biotite is even more variable in its occurrence than quartz, but in general is more abundant in the quartz-rich rocks and in a few places exceeds the hornblende. Sericite, epidote, chlorite, and the iron minerals are the chief products of the rather extensive alteration undergone by many of the rocks of this group. Apatite is the most abundant accessory mineral and is present in practically all the rocks examined, occurring in slender rods, many of which are more than a millimeter in length. Magnetite, zircon, titanite, and rutile were observed in meager quantities.

OLIVINE GABBRO

OCCURRENCE AND RELATIONS

On Willow Creek at the mouth of Sugar Creek there is exposed a small body of olivine gabbro which is distinct in character from any other rock of the region. It is not more than 200 feet across in its widest part and extends for about three-quarters of a mile north-northwestward along Willow Creek, although its exposure is interrupted for nearly a third of that distance by the alluvium of the creek. The larger exposure is on the east side of the creek and the smaller on the west side, opposite the mouth of Sugar Creek. The gabbro is bordered by diorite, into which it appears to have been intruded. Its outcrop is distinctive owing to its peculiar rounded form, its rusty-brown color, and its rough and pitted surface. Its exposure and megascopic appearance strikingly suggest the shonkinite body in Wildcat Gulch. (See p. 71.) The rock maintains its textural features throughout the mass and varies but slightly in mineral content from place to place.

PETROGRAP

On fresh surfaces the gabbro is a black medium-grained rock, in which lustrous flakes of biotite and plagioclase, poikilitically intergrown with other minerals, are conspicuous. It is exceedingly heavy and hard to break or trim. Close examination with a hand lens reveals the presence of olivine and augite in abundance. A microscopic study of several sections from this mass showed the order of abundance of the minerals to be approximately olivine$\gtrsim$augite$\gtrsim$ labradorite > biotite$\gtrsim$hypersthene > magnetite. The olivine and augite crystallized first and occur as idiomorphic crystals, some exceeding 2 millimeters in length. These are poikilitically included in large plagioclase crystals (Pl. XII, *A*) and less commonly in biotite. The plagioclase has the composition of labradorite (approximately Ab_{45} An_{55}) and appears to have been among the last minerals to crystallize, for it includes all other constituents of the rock. It is usually fresh but contains submicroscopic inclusions, which give it a dusty appearance and a slightly brownish tinge. The olivine is partly altered to magnetite and serpentine, and the serpentine forms a yellowish-green meshwork through it. The augite has a faint pleochroism and an extinction c : Z of about 45° and may be near diopside in composition. The biotite has a striking reddish-brown color but is less conspicuous under the microscope than in a hand specimen. Magnetite, serpentine, sericite, and a little chlorite have resulted from the alteration of the original minerals. The relative quantities of the several minerals of this rock vary somewhat from specimen to specimen. Olivine and augite together are invariably the most abundant minerals, although plagioclase may equal or even exceed either of them alone in quantity.

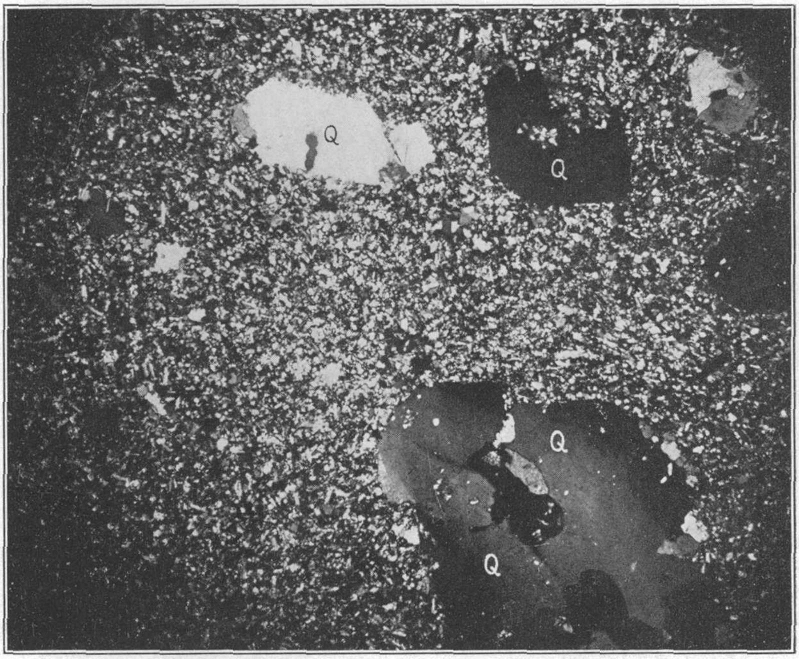
The olivine gabbro is noteworthy for several reasons. It is intermediate in composition between a gabbro and a peridotite and in its less feldspathic phases approaches the latter. Again, although poikilitic structure is common in rocks of this type, such structure involving the inclusions of olivine, augite, and hypersthene in labradorite is not common. Finally, the similarity in mineral facies and structure of this rock and the shonkinites associated with the augite syenites in Wildcat Gulch and on Goose Creek, many miles distant, is very striking. The only notable difference between these types is the presence of orthoclase and microcline in the shonkinites instead of plagioclase.

AUGITE SYENITE

OCCURRENCE AND RELATIONS

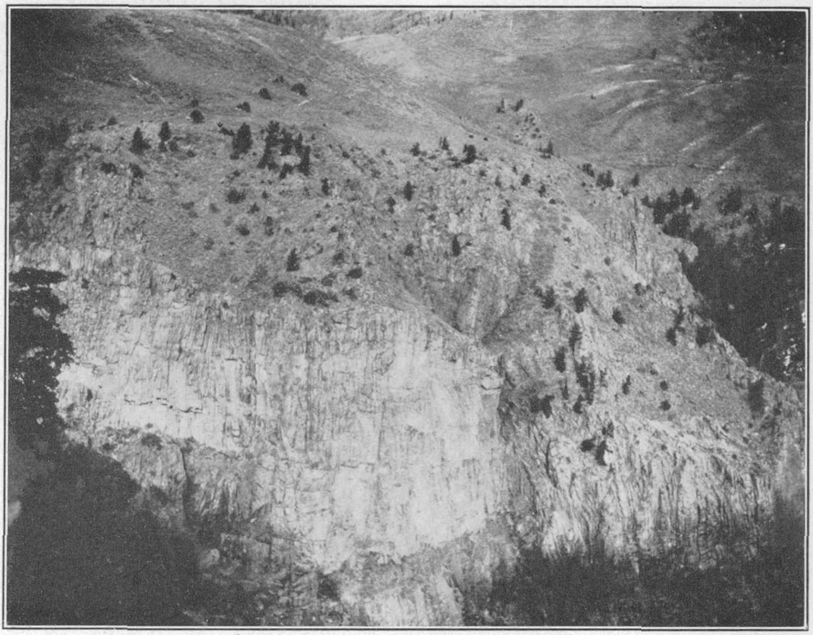
The augite syenites and their associates, which occur in small scattered areas in the Cebolla basin north of Powderhorn and on Willow Creek above Midway, are of extraordinary composition and of peculiar petrographic interest. The largest and one of the best known exposures crosses Wildcat Gulch 1½ miles above its mouth. This body is about 1 mile long from north to south and narrows northward to a point from a width of three-tenths of a mile in the gulch. Along its western side lies a small body of a peculiar olivine-rich rock representing a separate intrusion but probably genetically

A. GRANITE PORPHYRY OF POWDERHORN GRANITE GROUP

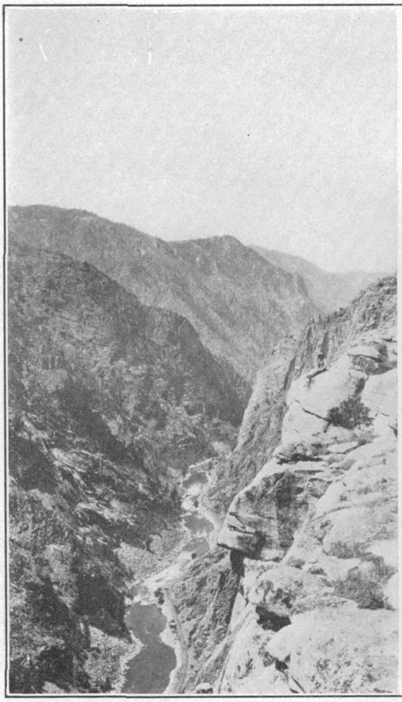


B. PHOTOMICROGRAPH OF GRANITE PORPHYRY

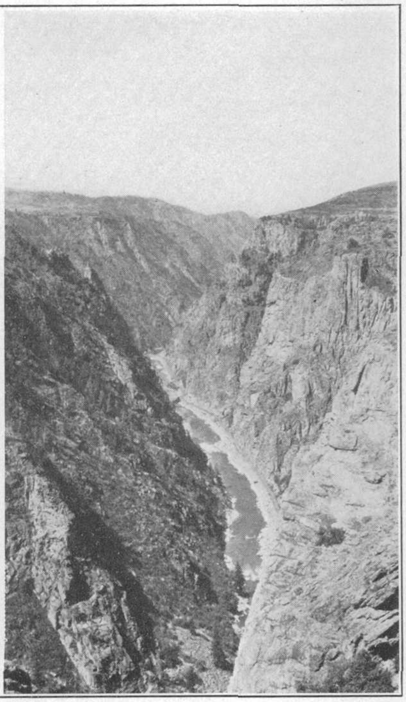
Q, Quartz. Enlarged 26 diameters



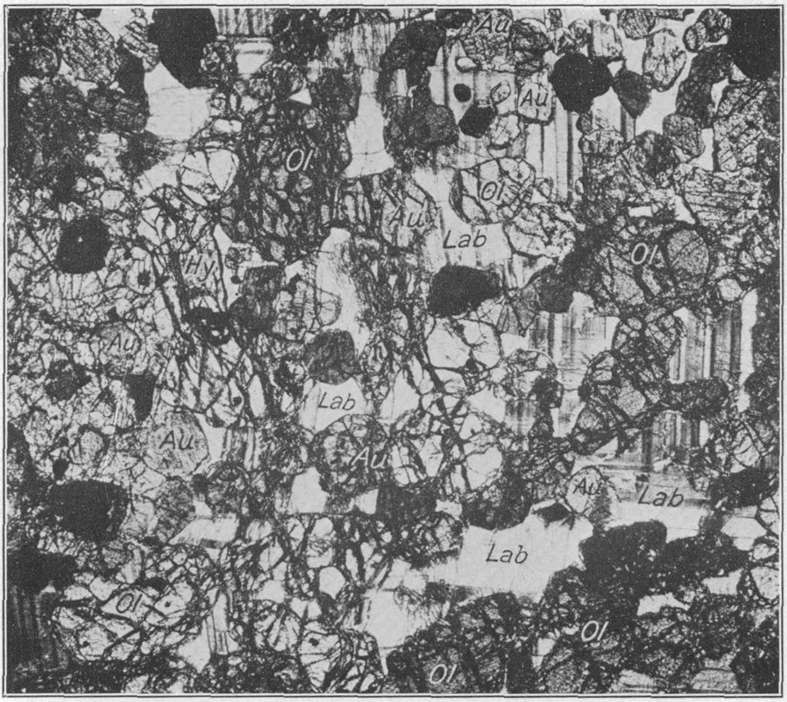
A. NORTH WALL OF BLACK CANYON 2 MILES EAST OF CURECANTI NEEDLE



B. BLACK CANYON FROM NORTH RIM HALF A MILE WEST OF CURECANTI NEEDLE

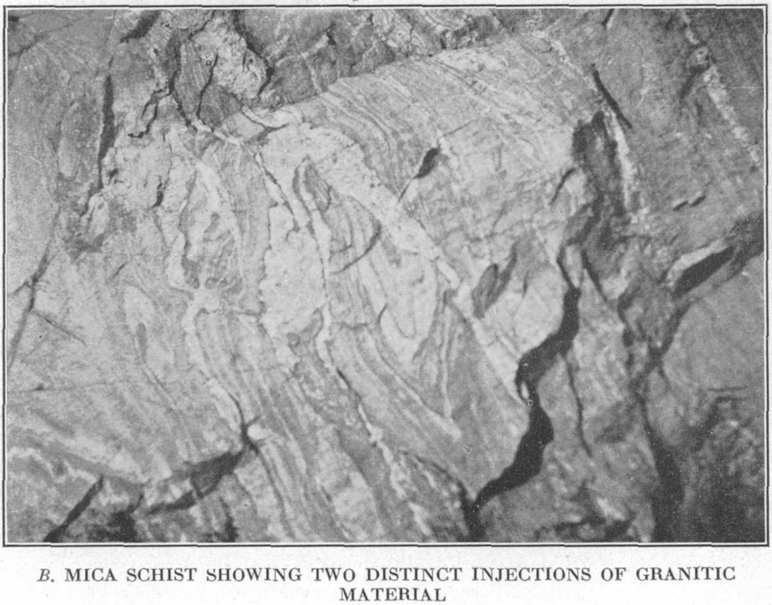


C. BLACK CANYON FROM POINT HALF A MILE WEST OF COTTONWOOD GULCH

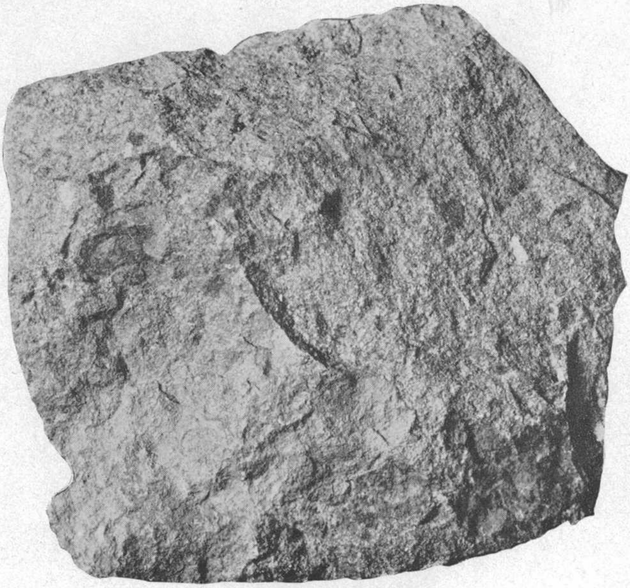


A. PHOTOMICROGRAPH OF OLIVINE GABBRO

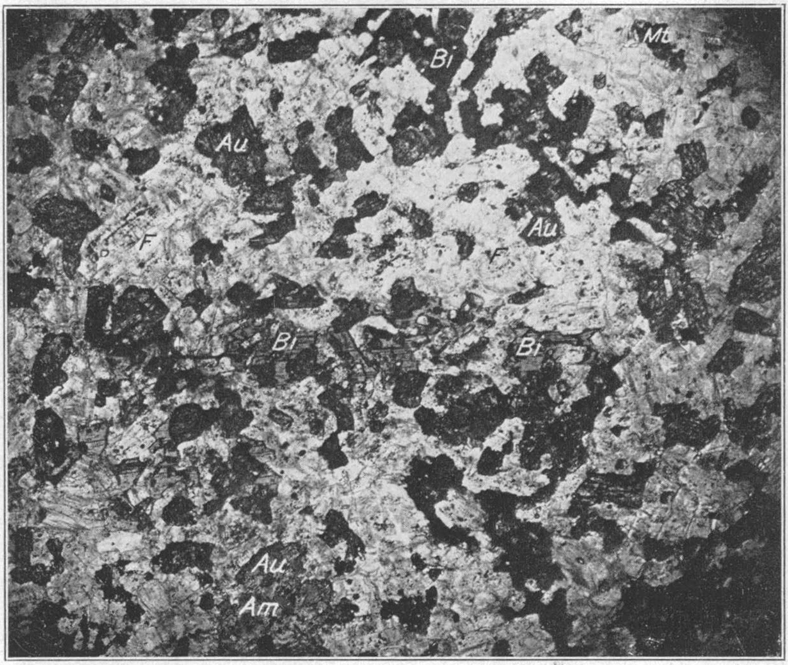
Ol, Olivine; *Au*, augite; *Lab*, labradorite; *Hy*, hypersthene. Enlarged 26 diameters



B. MICA SCHIST SHOWING TWO DISTINCT INJECTIONS OF GRANITIC MATERIAL

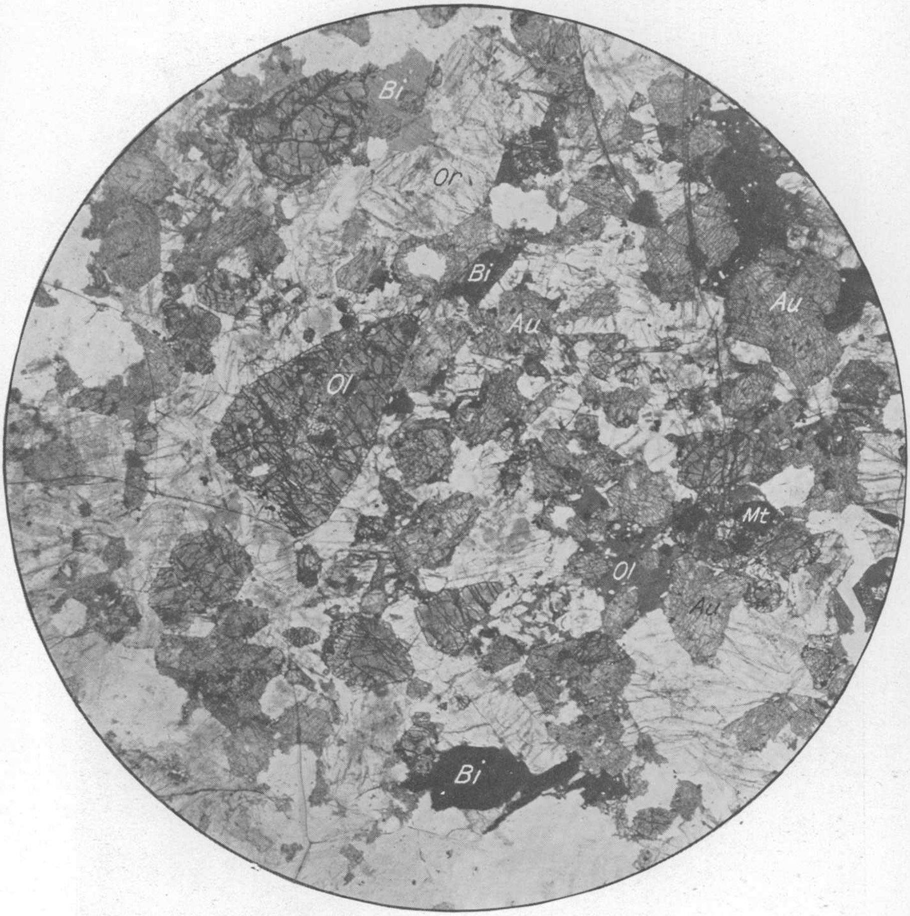


A. AUGITE SYENITE



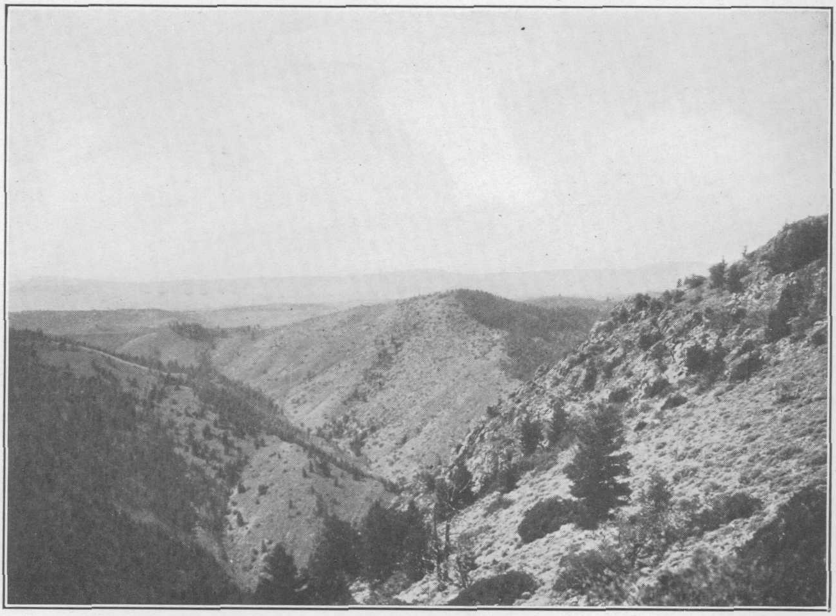
B. PHOTOMICROGRAPH OF AUGITE SYENITE

Bi, Biotite; *Mt,* magnetite; *Au,* augite; *Am,* amphibole. Enlarged 26 diameters

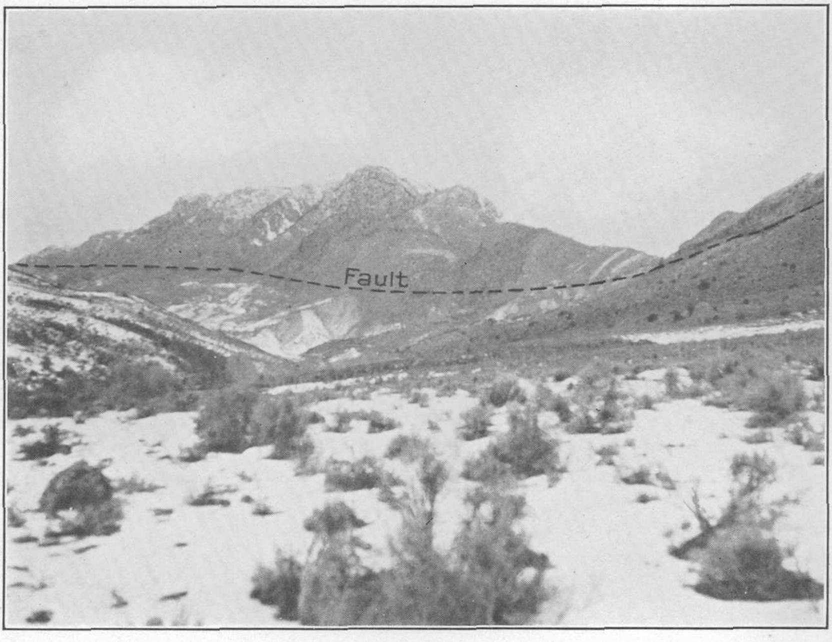


PHOTOMICROGRAPH OF SHONKINITE

Bi, Biotite; *Ol*, olivine; *Mt*, magnetite; *Au*, augite; *Or*, orthoclase. Enlarged 8 diameters



A. VIEW FROM EAST RIM OF CEBOLLA CANYON OPPOSITE TOLVAR PEAK



B. VIEW FROM CIMARRON CREEK ROAD SHOWING CIMARRON FAULT ESCARPMENT related to the larger mass. A second, somewhat smaller body of strikingly similar rock, with a similar olivine-rich associate along its border, lies on Goose Creek 1¼ miles west of Dubois. A third very interesting body crosses Wolf Creek six-tenths of a mile from its mouth. This mass is more differentiated than the others, and the rock is for the most part coarser grained. Smaller intrusions of this type have been mapped at Spencer, above the Lot mine in Milk-ranch Gulch, and on the west side of Willow Creek 2¼ miles south of Midway.

Except in the body near the mouth of Wolf Creek, which stands out in bold dikelike outcrops on either side of the creek, the syenites are no more resistant to erosion than the rocks adjacent to them and hence are inconspicuous. On Wildcat Gulch and Wolf Creek these rocks cut across the schistosity of the biotite schist, and on Goose Creek they bear the same relation to the Dubois greenstone. Elsewhere they intrude granite porphyry and granite of the Powderhorn group. Although they are younger than some of the granite intrusions they are cut by pegmatite and aplite dikes.

PETROGRAPHY

Augite syenite of Wildcat Gulch and Goose Creek.—The augite syenites vary but little more from mass to mass than they do within the individual bodies. The two largest masses, those on Wildcat Gulch and Goose Creek, not only show the strongest resemblance to each other but contain all the types of these odd rocks known throughout the several bodies. Although they differ considerably in texture and appearance these syenites with a few exceptions are of similar mineral composition. The most abundant type as well as the type common to all the occurrences is a dark-gray to black fine-grained rock, in which biotite stands out as large poikilitic phenocrysts with characteristic mottled, glistening surfaces, producing the effect sometimes called "luster mottling." (See Pl. XIII, *A*.) The abundance and size of these mica crystals give textural variety to the rocks. Thus in places where they are little developed the syenites are of fine, even grain and break easily with smooth surfaces. On the other hand, where they are numerous and large the rocks break with rough and angular fracture and appear at first glance to be coarse textured. In the average rock feldspar and augite can be distinguished in the groundmass only with difficulty, although in the coarser phases these minerals are distinct, the abundant microcline in many such rocks giving them a pinkish tinge. Locally the syenites in outcrop are characterized by pocked or pitted surfaces due to the weathering out of former phenocrysts of augite or amphibole.

The most typical phase of the augite syenites is seen in thin section to be hypidiomorphic and of seriate homeoid fabric in which the crystals average about 0.8 millimeter in diameter. From this there are all gradations to a porphyritic fabric in which phenocrysts of augite may be 1.5 or even 2 millimeters across and nearly equal in quantity to the groundmass. Poikilitic biotites are always present (see Pl. XIII, *A*) and are usually larger than other crystals, many being 6 to 8 millimeters across and a very few reaching 18 to 20 millimeters. The mineralogic character of the augite syenites can be represented approximately as follows: Feldspar > augite > biotite > amphibole $\gtrsim$ magnetite > apatite ± quartz, titanite, zircon, and rutile.

The greater part of the feldspar is microcline, although locally orthoclase is equally or more abundant. Both show microperthitic intergrowths and are characterized by a dusty brownish color due almost to submicroscopic inclusions. The microcline shows extremely minute microcline twinning and is in part soda microcline (anorthoclase). Carlsbad twinning is common. In addition individual crystals of soda plagioclase (probably albite) can be distinguished in most slides but in small amounts. Next in abundance to potash feldspar is augite, which makes up 20 to 25 per cent of the rock. It commonly occurs in idiomorphic crystals and is frequently observed in the process of alteration to amphibole, which is commonly fibrous and actinolitic. Scattered through the rocks are irregular patches and aggregates of a similar pale-blue amphibole with strong dispersion of the bisectrices, which resembles chlorite. This is for the most part, if not altogether, of secondary origin. Hypersthene is present in a few of the slides examined.

Biotite is less conspicuous in thin sections than in hand specimens, in which, owing to the tendency of the rock to break along its cleavage planes, the proportion of the biotite is likely to be overemphasized. It appears to have been among the latest minerals to crystallize and includes crystals of feldspar, augite, magnetite, and zircon. Magnetite and other iron minerals occurring as fine grains scattered throughout the rocks of this type are the most abundant of the accessory constituents. They are largely original, although some of them have been derived from the alteration of augite. Apatite in small grains and prisms is invariably present; titanite is most abundant in the quartzose peripheral phases. Zircon, rutile, and garnet are found here and there.

In the most typical phases quartz is rarely present, occurring as fine interstitial grains and in meager amounts, but in some of the border phases and particularly in the lower Wolf Creek body quartz is considerably more abundant and may equal or even exceed the hornblende, which in these rocks has entirely replaced the augite. In Wildcat Gulch there is such a rock, which might be described as a hornblende granite, along the west contact of the augite syenite. Although it may have been intruded after the syenite its mineralogic facies marks it as genetically related to the augite syenite.

A typical fine-grained, even-textured augite syenite (see Pl. XIII) from the middle of the Wildcat Gulch body, was analyzed by George Steiger in the laboratory of the Geological Survey. The result of this analysis is given in column 1 of the following table, in which are included analyses of several closely allied rocks for comparison.

Analyses of augite syenite and related rocks

	1	2	3	4
SiO_2	54.99	56.90	61.28	56.99
Al_2O_3	12.98	18.50	14.71	15.65
Fe_2O_3	3.13	.17	1.21	3.56
FeO	3.92	4.61	2.85	1.99
MgO	5.50	5.10	1.69	4.43
CaO	5.67	6.17	5.61	3.75
Na_2O	2.83	2.99	2.99	4.41
K_2O	7.08	4.14	7.70	6.50
H_2O-	.41	.51	.43	----------
H_2O+	.58	----------	.28	2.22
TiO_2	.99	.19	.41	.83
ZrO_2	.04	----------	----------	----------
CO_2	None.	----------	----------	----------
P_2O_5	1.00	.79	.16	.41
SO_3	----------	----------	.08	.10
Cl	----------	Trace.	----------	----------
S	.05	----------	----------	----------
Cr_2O_3	.01	----------	----------	----------
V_2O_3	None.	----------	----------	----------
NiO	.04	----------	----------	----------
MnO	.13	Trace.	Trace.	----------
BaO	.47	----------	.72	----------
SrO	.17	----------	.04	----------
	99.99	100.07	100.16	100.84
Specific gravity	22.833	2.857	----------	2.681

1. Augite syenite (ilmenose) (U 2266), south side of Wildcat Gulch, 1½ miles northeast of the mouth of Wolf Creek (altitude 8,300 feet), Uncompahgre quadrangle, Colo. George Steiger, analyst.
2. Augite-mica syenite (shoshonose), near Morrison, Jefferson County, Colo. L. G. Eakins, analyst. Described by Whitman Cross, U. S. Geol. Survey Mon. 27, pp. 296, 308-311, 1896.
3. Augite syenite (highwoodose), east side of Turnback Creek, about 1 mile north of Carter post office, Tuolumne County, Calif. H. N. Stokes, analyst. Described by H. W. Turner, U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, p. 663, 1896.
4. Porphyrite (ilmenose), Gotteskopf, Nord Ilmenau, Thuringia. Fischer, analyst. Described by H. Loretz, K. preuss. geol. Landesanstalt Jahrb., Band 13, p. 135, 1892.

The norms of the corresponding rocks are as follows:

Norms of augite syenite and related rocks

	1	2	3	4
Q	----------	1.3	3.4	----------
or	42.26	24.5	45.6	38.4
ab	20.96	25.2	25.2	32.5
an	1.39	24.7	3.9	3.6
ne	1.70	----------	----------	2.6
di	17.63	1.4	16.0	9.6
wo	----------	----------	1.9	----------
hy	----------	21.3	----------	----------
ol	5.98	----------	----------	4.7
mt	4.41	.4	1.6	4.2
il	1.98	----------	.8	1.5
hm	----------	----------	----------	.6
ap	2.17	----------	----------	1.0
pr	1.04	1.7	----------	----------

The position of the augite syenite in the quantitative system is indicated by these data:

Class: $\frac{\text{Sal}}{\text{Fem}}=\frac{66.31}{33.21}=1.99=\text{II}'$, dosalane.

Order: $\frac{\text{L}}{\text{F}}=\frac{1.70}{64.61}=0.026=5$, perfelic.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{122}{5}=24.4=1$, peralkalic.

Subrang: $\frac{K_2O}{Na_2O}=\frac{76}{46}=1.65=(2)3$, (dopotassic) sodipotassic.

Symbol: II′.5.1.(2)3, (highwoodose) ilmenose. (Subrangs corresponding to III.5.1.(2)3 are unnamed.)

The symbols of the related rocks whose norms are tabulated above are:

No. 2, II.5.3.3, shoshonose.
No. 3, II.5.1.2, highwoodose.
No. 4, II.5.1.3, ilmenose.

The augite syenite here described is conspicuous for its relatively low silica and alumina and its high potash content. The adjacent shonkinite (pp. 71–73) possesses a lower alkali content than its genetic relative, the augite syenite, and shows a higher ratio of potash to soda. This difference is the more interesting because the syenites and related rocks of the Iron Hill area are characteristically sodic.

The rock here described does not differ greatly in mineral composition from certain European minettes and augite syenites, and it resembles megascopically and microscopically an augite-mica syenite that occurs in small irregular masses in the Archean near Morrison, Jefferson County, Colo.[25] The latter rock (see analysis 2 in the table), however, contains orthoclase as the dominant feldspar instead of microcline, some plagioclase, and considerable rhombic pyroxene, in addition to augite that is presumably rich in alumina. The two rocks differ distinctly in chemical composition, the Jefferson County rock being higher in silica and alumina and lower in potash. These differences are even more striking in the norm, where the greater supply of silica develops normative quartz instead of nepheline, the abundance of alumina renders it necessary to calculate more anorthite, and the lower potash decreases the amount of orthoclase. This is an interesting example of similarity in texture, mineral content, and geologic occurrence obscuring the chemical differences in rocks.

Column 3 shows the analysis of a rock determined in the qualitative mineralogic classification to be an augite syenite. Mineralogically and texturally it is very distinct from the Wildcat Gulch rock, but curiously enough it resembles that rock in chemical composition save for its higher silica content. In the norm the minerals have

[25] Cross, Whitman, Geology of the Denver Basin: U. S. Geol. Survey Mon. 27, pp. 296, 308–311, 1896.

approximately equivalent values, except that quartz has developed instead of nepheline, owing to the excess of silica, and olivine is absent. In the quantitative classification these two apparently dissimilar rocks fall very close together, whereas the two apparently similar syenites of analyses 1 and 2 fall into different parts of the system.

A comparison of the analysis and norm of column 1 with analyses given in Washington's tables[26] fails to show any very closely similar rock. Perhaps the nearest to it is a rock from Thuringia described as early as 1892 by H. Loretz as a porphyrite, with the analysis given in column 4 of the above table. Owing to its higher soda content the norm of this rock contains more albite than the augite syenite, whereas the lower lime content and the larger supply of alumina require the calculation of considerably less diopside and of slightly more anorthite. Owing to the abundance of microperthite and augite and the occurrence of biotite and amphibole it is hardly possible to calculate the mineral composition or mode of this augite syenite from the analysis. Although nepheline is calculated in the norm, no evidence of it was observed in the rock. The 17.63 per cent of normative diopside corresponds to the augite of the mode, and the 5.98 per cent normative olivine may be represented in the mode by augite, biotite, and amphibole. Finally, all the lime of normative anorthite, a considerable portion of the potash of the normative orthoclase, and perhaps some of the soda of the normative albite appear in the mode in these alferric minerals.

Augite syenite on Willow Creek.—The augite syenites in Willow Creek differ to some extent from the other rocks of this type. These rocks are dark pinkish and show considerable weathering and iron staining. Under the microscope they prove to be hypidiomorphic and of seriate porphyroid fabric, with grains averaging between 1 and 2 millimeters long. The feldspars are particularly interesting in that they show zonal structure combined with the characteristically fine microcline grating structure and the peculiar dirty color of the feldspars very common in this type of rocks. They are believed to be soda microcline in which there may be considerable lime, making them a lime-soda microcline or perhaps potash oligoclase. Both Carlsbad and albite twins are present and indicate a considerable amount of soda plagioclase whose index is much lower than that of Canada balsam. The augites and biotites are nearly all altered beyond recognition. However, the amphibolitic alteration product of the augite is interesting and significant in that it shows the violet, blue, and green pleochroism, strong dispersion, and low extinction of glaucophane.

[26] Washington, H. S., Chemical analyses of igneous rocks, 1884–1890: U. S. Geol. Survey Prof. Paper 14, pp. 250 et seq., 1903.

Apatite occurs in long, slender pinkish-brown rods and shows fain pleochroism. An analysis of these rocks would probably show them to be higher in soda than the augite syenite from Wildcat Gulch.

Syenite near the mouth of Wolf Creek.—The syenite body near the mouth of Wolf Creek is notable among the bodies of this type for its greater coarseness of grain, its quantity of hornblende, and the amount of differentiation that it exhibits. The central and major portion of this mass consists of a syenite in which large crystals of microcline, averaging 4 to 6 millimeters in diameter, include poikilitically albite, hornblende, biotite, quartz, and accessory minerals. The microcline is invariably perthitically intergrown with soda plagioclase and in much of the rock includes large patches of it. The hornblendes are of ragged outline and deep green color, having characteristic pleochroism in thin section, and are probably secondary. Quartz, where present, is subordinate in amount to all except the accessory minerals. This rock is unusually rich in titanite, crystals of which are as large as a millimeter in diameter. Magnetite and apatite are relatively abundant accessories.

The periphery of the mass differs considerably from the interior and consists of a fine-grained dark mafic rock in which hornblende, biotite, and augite equal or exceed the microcline. The microcline is perthitic and may be in part soda microcline and includes the other minerals, as in the coarser syenite. Hornblende is the most abundant mafic mineral and has probably in part been derived from augite. The two phases grade into each other, so that no separation is possible. The finer mafic phase is very similar to the most abundant phase of the Wildcat Gulch and Goose Creek areas, and the coarser phase resembles or is identical with the coarser and more quartzose phases found along the border of the Wildcat Gulch mass. The lower Wolf Creek body presents an excellent illustration of differentiation in place, in which the mass becomes coarser and more felsic toward the center. On the other hand, the Wildcat Gulch body presents coarser and more felsic phases, intruded after and along the border of the more abundant, fine-grained, more mafic phase, presumably as an outcome of deep-seated differentiation.

A very coarse hornblendic syenite with an unusual amount of apatite, exposed near the forks of the road in Spencer, is unique and worthy of mention.

Other varieties of augite syenite are exposed in Wolf Creek at Spencer, but they differ from the phases here described chiefly in their textural features and hardly warrant further discussion.

Mica syenite near Lot mine.—Very different in appearance from any so far described is a biotite-rich syenite of the body in Milkranch

Gulch immediately north of the Lot mine. Although some of the rock of this mass resembles the augite syenite typical of the other areas, the major portion is richer in biotite. It is of medium grain and of dark-green color and has a rough, uneven fracture surface glistening with flakes of biotite arranged in all possible positions. In section these rocks are not widely different from certain of the augite syenites, except in the abundance of biotite, which frequently exceeds the hornblende, and in the slightly coarser texture. Augite is rarely found in these rocks, having been almost entirely altered to hornblende. A small quantity of quartz is usually present. Poikilitic structure, with microcline including plagioclase, hornblende, biotite, and other minerals, is notably developed in most of the rocks of this type. Apatite, magnetite, titanite, calcite, garnets, and epidotes are present in subordinate quantities. A mica syenite of somewhat coarser texture but of the same general composition was found along the periphery of the augite syenite mass in Goose Creek.

SHONKINITE

OCCURRENCE

Associated with the augite syenite of Wildcat Gulch and Goose Creek are two small bodies of a very unusual olivine-augite-orthoclase rock, which may best be called a shonkinite. The body in Wildcat Gulch is intruded along the western contact between the augite syenite and the biotite schist and is 50 feet wide by about 200 feet long. It weathers in rounded forms, is characterized by a rough, uneven surface, and stands out distinctly from surrounding rocks in much the same manner as the olivine gabbro mass at the mouth of Sugar Creek. The body on Goose Creek is similar in every way to that in Wildcat Gulch, although it is not so large. Here again the shonkinite has been intruded along the periphery of the augite syenite and appears to be later than all the other rocks in the vicinity except possibly the aplite dikes.

PETROGRAPHY

The shonkinites are dark medium to coarse grained rocks, containing large glistening brown micas. They are heavy, break with uneven surfaces, and are exceedingly tough. Feldspar, augite, and olivine can be distinguished megascopically in addition to the biotite. Microscopically the rock is hypidiomorphic, granular, and of seriate porphyroid fabric, in which the crystals range from 0.5 to 5 millimeters across. The approximate mineral composition of the rock can be represented thus: Orthoclase$\gtrsim$augite$>$olivine$>$biotite$>$magnetite$>$apatite. Most of the feldspar if not all is orthoclase. This mineral is commonly fresh but shows very fine fiberlike structure, is characterized by a small optic angle, and commonly shows the minute inclusions producing dusty brown patches that are characteristic of the feldspars of the augite syenites and of the olivine gabbro. The augites are idiomorphic, are light green with faint pleochroism, and exhibit rather high extinction angles. The olivine has a peculiar gray shade and contains innumerable black specks of iron, probably magnetite, arranged parallel to the c axis. (See Pl. XIV.) It is negative in character and shows a relatively small optic angle ($2v = 60°-70°$). Because of these properties it was at first thought to be high in iron and to approach the composition of fayalite, but this suggestion is not borne out by the rock analysis, which shows but 5.21 per cent of FeO and 11.26 per cent of MgO. The olivine is altering to a yellow serpentinous substance and magnetite but on the whole is remarkably fresh. The biotite possesses a peculiar red tone and is marked by very strong absorption. Grains of magnetite and rods of apatite are abundant in the shonkinites. In order of crystallization the magnetite and apatite appear to have been first and were followed by olivine, augite, biotite, and feldspar, approximately in the order named, although the periods of crystallization of the several minerals were by no means mutually exclusive, as can be seen from the inclusions of olivine in augite and of augite in olivine.

In mineral composition the rock here described is not unlike the original shonkinite described by Weed and Pirsson[27] from the outer portion of a laccolith of sodalite syenite at Square Butte, Highwood Mountains, Mont. In appearance and in its association and to a slightly less degree in its mineral composition it also resembles a shonkinite described by the same authors[28] from a stock in the Little Belt Mountains of Montana. No nepheline has been observed in these rocks, but as Washington[29] has explained this mineral is not essential to the composition of a shonkinite.

CHEMICAL COMPOSITION

The shonkinite of the small dike adjacent to the augite syenite mass of Wildcat Gulch has the composition given in column 1 in the table below, according to an analysis by George Steiger. Analyses of other shonkinites and closely allied rocks are given for comparison.

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[27] Weed, W. H., and Pirsson, L. V., Geol. Soc. America Bull., vol. 6, pp. 407-417, 1895.
[28] Geology of the Little Belt Mountains, Mont.: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, 479, 1900.
[29] Washington, H. S., Jour. Geology, vol. 9, p. 614, 1901.

Analyses of shonkinite from Wildcat Gulch and related rocks

	1	2	3	4
SiO_2	50.86	46.73	48.98	50.41
Al_2O_3	11.14	10.05	12.29	12.30
Fe_2O_3	2.93	3.53	2.88	5.71
FeO	5.21	8.20	5.77	3.06
MgO	11.26	9.25	9.19	8.69
CaO	6.97	13.22	9.65	7.08
Na_2O	1.73	1.81	2.22	.97
K_2O	5.85	3.76	4.96	7.53
H_2O-	.64		.26	.46
H_2O+	.95	1.24	.56	1.80
TiO_2	.84	.78	1.44	1.47
ZrO_2	.02			None.
CO_2	None.			
P_2O_5	.79	1.51	.98	.46
SO_3				None.
Cl		.18		Trace.
F			.22	
S	.02			None.
Cr_2O_3	.11		Trace.	
V_2O_3	None.			
NiO	.04			.04
MnO	.13	.28	.08	.15
BaO	.31		.43	.23
SrO	.22		.08	.06
LiO_2			Trace.	
	100.02	100.54	99.99	100.42
Specific gravity	2.94			2.88

1. Shonkinite (prowersose) (V. 413; see Pl. XIV) from south side of Wildcat Gulch just above the trail crossing, Uncompahgre quadrangle, Colo., altitude 8,100 feet. Analyst, George Steiger.
2. Shonkinite (shonkinose) from Square Butte, Highwood Mountains, Mont. Analyst, L. V. Pirsson. Described by Weed, W. H., and Pirsson, L. V., in Geol. Soc. America Bull., vol. 6, p. 414, 1895.
3. Shonkinite (shonkinose) from Yogo Peak, Little Belt Mountains, Mont. Analyst, W. F. Hillebrand. Described by Weed, W. H., and Pirsson, L. V., in Geology of the Little Belt Mountains, Mont.: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 479, 1900.
4. Syenitic lamprophyre (prowersose) from Two Buttes, Prowers County, Colo. Analyst, W. F. Hillebrand. Described by Whitman Cross in U. S. Geol. Survey Bull. 148, p. 182, 1887.

The norms corresponding to the rocks of the above table are as follows:

Norms of shonkinite from Wildcat Gulch and related rocks

	1	2	3	4
or	35.03	22.2	29.5	44.5
ab	9.43		5.3	4.2
an	5.00	8.2	8.6	6.7
ne	2.84	8.5	6.8	2.3
di	20.29	40.1	26.5	20.4
ol	17.47	10.3	11.7	8.6
mt	4.41	5.1	4.2	5.8
il	1.52	1.5	2.6	2.8
hm				1.6
ap	1.86	3.2	2.2	1.0

The position of the shonkinite from Wildcat Gulch in the quantitative system is indicated by these data:

Class: $\frac{Sal}{Fem}=\frac{52.30}{45.55}=1.14=III$, salfemane.

Order: $\frac{L}{F}=\frac{2.84}{49.46}=0.058=5$, perfelic.

Rang: $\frac{K_2O+Na_2O}{CaO}=\frac{91}{18}=5.0=''2$, domalkalic.

Subrang: $\frac{K_2O}{Na_2O}=\frac{63}{28}=2.25=2$, dopotassic.

Symbol: III.5.''2.2, prowersose.

The symbols of the related rocks whose norms are tabulated above are as follows:

No. 2, III.6.2.3, shonkinose.
No. 3, III.6.2.3, shonkinose.
No. 4, III.5.2.2, prowersose.

The shonkinite from Wildcat Gulch is an unusual rock by reason of its relatively high magnesia and alkali contents, with its decided preponderance of potash over soda. Occurring as a dike that extends along the border of the augite syenite it shows unmistakable mineralogic and chemical resemblances to that rock, the chief difference being in the greater development of olivine in the shonkinite with corresponding increase in the amount of magnesia. The augite syenite is also richer in the alkalies soda and potash. It should also be pointed out that the augite syenite is intermediate between Classes II and III of the quantitative classification and is transitional toward the unnamed subrang 2 of rang 1 (orendase) in Class III, with which the shonkinite is intermediate as regards rang 2. In other words, these two rocks show further resemblance in that they are intermediate or transitional toward a common position in the system. The shonkinite might be called an olivine-augite syenite.

A comparison of the shonkinite from Wildcat Gulch (column 1) and the originally described shonkinite (column 2) from Square Butte, Mont., shows a mineralogic accordance but interesting chemical as well as textural differences. Thus the small supply of silica in the Montana shonkinite results in the disappearance of albite from its norm and a corresponding increase in the normative nepheline. The smaller percentage of potash and magnesia and the higher lime content, noticeable in the analyses, becomes even more conspicuous in the norm in the relative decrease of orthoclase and olivine and the increase of diopside, respectively.

Although the Wildcat Gulch rock departs considerably from the first-described shonkinite, it resembles in many ways a rock described under that name from Yogo Peak, Mont. (column 3). In texture and association the similarity is remarkable, but in mineral and chemical composition the accordance is somewhat less complete. However, a comparison of the analyses and norms of columns 1 and 3 fails to show any significant difference between them.

Of nearest chemical approach to this rock is a syenitic lamprophyre from Two Buttes, Colo. (column 4), which, it is interesting to note, resembles it least of the three related rocks in mineralogic and textural features. The only conspicuous chemical difference between these rocks is the greater potash content and lower magnesia of the lamprophyre. In spite of being more potassic (it is transitional toward the perpotassic subrang), it falls into the same subrang as the shonkinite from Wildcat Gulch. However, even here the accordance is but little greater than with the Yogo Peak rock, as inspection of the analyses and their corresponding norms will show. The norm shows more orthoclase, albite, and nepheline than occurs in the mode, some of the potash and soda being used in the mode to make biotite and augite. Anorthite is not present in the rock, its corresponding lime of the norm going into augite. The normative diopside is represented in the mode by augite and biotite, whereas olivine is found in both though probably in smaller percentage in the mode.

OTHER SYENITES

OCCURRENCE AND RELATIONS

In addition to the several bodies of quartz-poor rocks described there are in a number of places in the eastern part of the Uncompahgre quadrangle small and as a rule poorly exposed masses of syenite of differing character. These syenite intrusions are most numerous near the igneous complex of Iron Hill and so closely resemble certain types more extensively exposed in that area as to suggest a genetic relationship to them. These rocks will be only briefly discussed here, their fuller description being left for the treatment of the Iron Hill rocks. They are commonly of dikelike form, ranging from a foot to 50 feet across, and few of them can be traced for any considerable distance.

For convenience of description these rocks may be classed in two groups—reddish syenites, most of which are porphyritic, and gray syenites, which are characteristically high in soda-bearing minerals. The rocks of the first class are more abundant than those of the second. They have been found in the metagabbro area on the east slope of Beaver Creek, a mile northeast of Miller Hill; in the Powder horn granite south of summit 9640 of Huntsman Mesa, which is southwest of the mouth of Beaver Creek, on the east side of Willow Creek due east of summit 9950 of Huntsman Mesa, on the ridge opposite the mouth of Beaver Creek, and on the east rim of the Cebolla Canyon 1¼ miles northeast of Carpenter Ridge; and in the Dubois greenstone 1 mile west of north of Vulcan. The gray soda syenite bodies are best exposed on the west side of Cebolla Creek opposite the mouth of Milkranch Gulch and in the granite porphyry area on the ridge south of Milkranch Gulch. These syenites are apparently among the latest of the igneous intrusives of the region.

PETROGRAPHY

Syenite porphyry.—The most typical variety of the syenite porphyry is a red to pink fine-grained, almost aphanitic, more or less porphyritic rock, much of which has been rendered porous by processes of leaching. Phenocrysts of feldspars, some 7 millimeters in length, are abundant, and these with mica and iron-ore pseudomorphs constitute the only megascopic minerals. The microscope shows these syenites to be holocrystalline and of trachytic texture, with scattered phenocrysts of feldspars, many of them considerably altered. The groundmass consists chiefly of orthoclase, and sodic plagioclase, with subordinate amounts of muscovite, biotite, apatite, calcite, and magnetite and other iron minerals. The feldspars are commonly clouded with innumerable minute inclusions of what is believed to be limonite, which effectually obliterate their optical character. Aegirine and actinolitic amphibole were observed in several of the specimens examined, and quartz occurs in many of them but in very meager amount. Although cancrinite was not found in any of the syenites of this type, they suggest cancrinite-bearing syenites of the Iron Hill area.

Soda syenite.—The soda syenites of the area differ considerably in character from place to place but are nearly all gray and fine grained and are characterized by dark streaks resembling "schlieren." Indeed, in several places they display banding and even a fairly well-marked schistosity. Curiously, in most occurrences they are associated with limestone or calcite, probably of vein origin. In thin section the soda syenites are seen to be allotriomorphic and somewhat porphyritic, and many exhibit a gneissoid structure. They differ mineralogically but consist essentially of soda plagioclase, chiefly albite, aegirine, a pale-bluish hornblende with strong dispersion of the bisectrices, biotite, calcite, apatite, titanite, pyrite, and magnetite. Orthoclase and microperthite are present in a few of the slides examined, as are small amounts of microcline, quartz, and muscovite. The rocks of this type are very similar to the soda syenite that occurs in moderately large bodies in Deldorado and Beaver creeks, within the area of the igneous complex of that vicinity.

PEGMATITE BODIES

OCCURRENCE

Throughout the pre-Cambrian area of the Gunnison River region, particularly in association with the granite stocks, are many pegmatite and aplite bodies. The occurrences of such rocks are so numerous and so similar that it would be impracticable as well as needless to describe or map them all. The principal areas of pegmatite studied are along Lake Fork from a point just below Marion nearly to the mouth of Lake Gulch; along the same stream in the vicinity of Twin Buttes; a single large body crossing Willow Creek 1 mile up from its mouth; many large and small bodies along the north wall of the Black Canyon, particularly near the Curecanti body, in Nelson Gulch, and on the south side of Long Gulch; and two on the south side of the Black Canyon, one in the region of Cimarron Creek and the other, a large mass, in Pool Gulch on Vernal Mesa.

These bodies range in size from small stringers up to masses nearly half a mile across. Possibly the most common development is in bodies from 10 to 50 feet across. The pegmatite intrusions may occur in large irregular-shaped masses, as at Long Gulch or Pool Gulch, but they are more commonly found in a series of dikes and sill-like bodies ribbing or honeycombing the canyon walls, as on the Lake Fort at Twin Buttes or below Marion. These intrusions may take the form of straight dikes of uniform width or of lenticular, sill-like masses injected between the lamellae of the metamorphosed schists or they may be totally without regularity of form. Typical examples of pegmatite intrusions are shown in the accompanying sketch of the north wall of the Black Canyon about 2 miles east of Curecanti Creek (fig. 4).

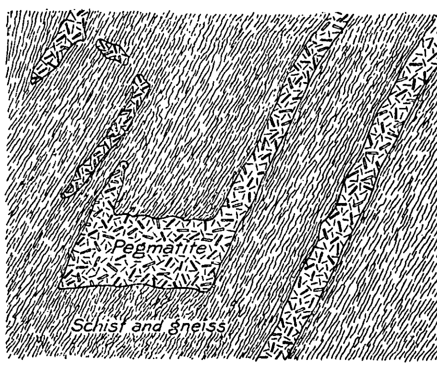

FIGURE 4.—Typica shapes of pegmatite bodies injected into the metamorphic rocks, north wall of Black Canyon, 2 miles east of Curecanti Creek

RELATIONS

Although a great many of the true pegmatite bodies are near to or associated with the granite masses and are probably to be considered as belonging to the same periods of intrusion, other large bodies are found at considerable distances from any known granite stock. The best examples of the latter class are the pegmatites of Pool Gulch and Twin Butte. However, it should be pointed out that probably some more or less extensive plutonic masses intruded into the pre-Cambrian are now covered by the mesa formations. The pegmatite bodies seem to have been little affected by regional metamorphism and may have been intruded after the more severe deformation had been accomplished. In general, they appear to have had their origin during the last stages of the several granitic intrusions and are consequently of various ages. Pegmatite dikes cut the quartz diorites and the augite syenite body of Wildcat Gulch. That some of them at least were earlier than the period of diabase intrusion is testified by the occurrence of a typical diabase dike cutting the pegmatite body in Long Gulch. The injection of the pegmatitic material has been guided largely by the schistosity and foliation of the metamorphic rocks, particularly where these features are markedly developed. Where foliation planes are less well developed apophyses or crosscuting bodies were injected. Where jointing or crushing has developed a zone of weakness in the schists adjacent dikes are either deflected or send off branches. This is well illustrated at Twin Buttes. In places the dikes may bifurcate and inclose bodies of country rock. The contacts between these inclusions and the containing pegmatites are devoid of any notable features save in a few places where the foreign body may be surrounded by fine-grained material showing a vague flow structure.

Like the minor granite bodies the pegmatite intrusives produce steep and rugged topography and in many places give rise to curious banding and ribbing of the canyon walls. This is well illustrated by the undulating sill-like body just above Twin Buttes, as well as by those in the wall of the Black Canyon below Big Draw. A radial or rudely spokelike development of pegmatite and granite dikes is a striking feature of the eastern wall of the Lake Fork opposite the mouth of Little Willow Creek.

As on most of the granite bodies the contacts with the country rock are characterized by their sharpness and by the absence of contact phenomena. They may be straight or irregular. The jointing in these intrusives is not characteristic, although a joint plane parallel to the walls of the body is common. Only in a few places did the jointing of the pegmatite appear to be the same as that of the invaded rock.

PETROGRAPHY

The pegmatites of the area range from rocks near the medium-grained granites already described to very coarse mixtures of quartz, feldspar, and mica having extremely irregular texture. The quartz ranges in manner of occurrence from that in fine intergrowths of micropegmatite or graphic granite up to stringers of nearly pure mineral several feet long. The feldspar is dominantly microcline and shows all gradations from fine individual crystals, as in granite, up to phenocrysts of pure mineral a foot or more in length. However, the microcline is most commonly intergrown with quartz. Muscovite is the mica most frequently found, although biotite is not rare. The micas show a tendency to cluster or segregate into irregular-shaped patches, and where the exposed surface of the pegmatite is at an angle to the cleavage surface of the mica the edges of the individuals may show a rudely radial pattern. Here and there, as in the Black Canyon east of Corral Gulch, biotites occur in plates elongated as much as a foot, and these long black blades in a vaguely lattice-like arrangement produce a striking appearance.

The microscope adds little to the better understanding of the pegmatites. It reveals the presence of orthoclase in greater or less amounts, along with the predominant microcline. Albite and oligoclase-albite are locally subordinate constituents. Microperthite is very common, especially in graphic granite. The crystal individuals except the quartz are hypidiomorphic to idiomorphic. Garnets and magnetite occur rather uncommonly as small individuals.

The pegmatites of this region are notably free from miarolitic cavities or from evidences of the action of mineralizing agents. However, a considerable quantity of black tourmaline was found in a pegmatite dike in a south side gulch of Crystal Creek. The tourmaline was found not only dotting the pegmatite but also impregnating the surrounding schist for as much as 2 feet from the dike. It was most abundant in the finer phase of the mass.

Unique among the pegmatite bodies of the region is that above the trail crossing in Wildcat Gulch, on the west border of the augite syenite mass. This dike is 2 feet wide and consists chiefly of quartz with patches of flesh-colored microcline and long slender crystals of green hornblende. Large brown sphene crystals as much as 1 inch in length were found in only one portion of the body. Specular hematite occurs in some abundance. Molybdenite is present in small quantity along little cracks or joints in the quartz and is also associated with the hornblende. The hornblende is deep green with characteristic pleochroism, has a rather high extinction angle, and has indices of refraction ranging from about 1.64 for α and β to 1.65+ for γ.

On Pine Creek half a mile below the Cimarron road crossing there is a pegmatite dike which contains large crystals of hematite in cubes as much as 1 inch across, believed to be pseudomorphs after pyrite.

APLITE

OCCURRENCE

The aplite is less common than the granite and pegmatite and is always associated with one of them. There are in the region all gradations from granite with aplitic tendencies to true aplite. The best example of extensive injection of true aplite is in the smaller body of Vernal Mesa granite near the head of Red Rock Canyon. Here innumerable clear-cut dikes and dikelets of aplite of uniform thickness and texture cut the coarse porphyritic granite. Similar dikes are associated with the numerous granite bodies in the canyon west of Hierro switch and with the Powderhorn and other granite bodies. The almost invariable association with pegmatite needs only to be mentioned. The aplites cut not only the granite bodies but also the metagabbro, the quartz diorites, the augite syenite, and even some of the pegmatites. Many of them are with little doubt genetically related to the adjacent granite masses and are as widely separated in age as those masses. However, from their occurrence in numerous other kinds of rocks the aplitic intrusion is believed to have persisted until the very last stages of pre-Cambrian igneous activity.

PETROGRAPHY

In composition the aplites differ from the granite dike material in their lack of dark constituents and their even texture. Under the microscope they are found to be allotriomorphic to hypidiomorphic, equigranular, with quartz subordinate to feldspar but about equal in amount to microcline. Orthoclase is abundant, and microperthite is commonly present in subordinate amount. Biotite, muscovite, apatite, magnetite, garnet, and zircon may be present in extremely small amounts. Fluorite was found in one locality but in hardly more than a trace.

DIABASE

OCCURRENCE

As in many other pre-Cambrian areas of the Rocky Mountains, the rocks of this complex are intruded here and there by diabase dikes. The two localities in the Gunnison region where such dikes are well developed are in the metabasite canyon of the Lake Fork, a little more than a mile north of Madeira siding, and in the Curecanti granite portion of the Black Canyon, a quarter of a mile east of Nelson Gulch. At the former place there is a diabase dike 150 feet wide cutting obliquely across the schistosity, and at the latter there are two, one 250 feet wide and the other only 7 feet wide. Neither of these extends for any great distance horizontally, hence neither could be found on the rims of the canyon in which it occurs. A further example is the well-defined dike about 100 feet wide northeast of the Lot mine in Milkranch Gulch, which is traceable in a nearly east-west direction for about a mile. Even larger dikes of very similar diabasic or gabbroic rocks have been mapped in the Deldorado Creek basin in the area of the igneous complex of Iron Hill. These rocks at places contain nepheline and are related petrographically to the highly sodic rocks of that area. These dikes have for the most part sharp and clean-cut boundaries and are of uniform width as far as they could be examined. At other places, as south of Long Gulch and on the ridge northeast of Bostwick Park, diabase outcrops are to be found, but the outlines of the bodies are very indefinite.

The diabase cuts not only the Dubois greenstone of the Lake Fork and the granite porphyry of Milkranch Gulch but also the Curecanti granite of the Black Canyon and a large pegmatite body south of Long Gulch. In the Deldorado Creek basin similar rocks intrude pyroxenite and syenite and appear to be among the latest of the complex series of rocks of that area. It thus appears that the diabase bodies belong to the latest stage of igneous injections of the region.

The larger of the two dikes east of Nelson Gulch in the Black Canyon is notable for its very extensive jointing, which has given the canyon wall picturesque meshlike markings and has produced a tremendous talus pile at its foot. The contacts of the diabase intrusions with the country rocks are, everywhere they were observed, sharp and without unusual phenomena.

PETROGRAPHY

These rocks are dark, are rather dense, and show characteristic diabase texture, well seen on weathered surfaces. They are of medium grain, the feldspar and augite individuals being easily distinguished macroscopically. When studied under the microscope the diabases are found to be hypidiomorphic granular with an intersertal texture in which augite makes up most of the interstices between laths of plagioclase that average 1 to 2 millimeters in diameter. The augite, in part at least, crystallized before the plagioclase but in places has formed a matrix in which are poikilitic inclusions of plagioclase, producing an ophitic texture. The feldspar, which seems to be almost entirely labradorite, is in excess of the augite and together with it constitutes most of the rock. The augites are brown, are subhedral in outline, and in many places show good twinning. Olivine was observed in only one specimen, whereas biotite is present in subordinate amounts in several. Micropegmatite is almost invariably present. Apatite and iron ores are the chief accessory minerals.

The rocks of this class show a moderate amount of alteration, the most conspicuous results coming from the breaking down of the plagioclase to a saussuritic mixture of sericite, epidote, and other feldspars. The augites are commonly altered to greenish-yellow chlorite or to yellowish-brown hornblende. The smaller diabase dike in the Black Canyon, east of Nelson Gulch but a short distance west of the larger one, is of very fine grain and porphyritic texture, the groundmass being aphanitic for a foot from the contact. This differentiation within the body is marked and persistent.

LAMPROPHYRE

In two localities lamprophyric bodies were observed. One, at the south end of the pre-Cambrian area, on the west slope of Cebolla Creek, is exposed only in a 3-foot ledge intruding a small outcrop of hornblende gneiss. The rock is dark and aphanitic, with phenocrysts of hornblende. Under the microscope it proved to be holocrystalline, hypidiomorphic, and porphyritic. Myriads of long acicular crystals of hornblende included in and somewhat obscuring the character of the feldspar are the most conspicuous feature of the rock. The feldspar, which is of low index and appears to be orthoclase and soda plagioclase, the hornblende, and a small quantity of augite altering to amphibole are the essential constituents. Apatite, biotite, garnets, and magnetite are accessory; chlorite and calcite are present as secondary minerals. The rock resembles most closely a vogesite.

The other lamprophyric body observed crosses the Black Canyon 1 mile southwest of the mouth of Lake Fork and is only a foot wide. The rock of this body is dark gray, aphanitic, porphyritic, and dopatic. It is very much altered and consists chiefly of secondary calcite and chlorite, together with biotite and a smaller proportion of feldspar. Owing to the extensive alteration which the rock has undergone its original character can not be determined.

The age relations of these lamprophyric bodies are not determinable, although their lack of metamorphism of the deeper-seated kind, together with their character, suggests that they were among the latest of the igneous intrusions.

STRUCTURE

The structural elements of the pre-Cambrian rocks are expressed in two ways, by the schistosity of the rocks and by faulting. In considering the schistosity it should be constantly borne in mind that the basis of discussion is the foliation produced through processes of metamorphism under great compression. By far the larger portion of these metamorphic rocks are believed to have been produced from igneous rocks. In localities where they may have been derived from sediments the original bedding seems either to have been entirely obliterated or to be indistinguishable from the present schistosity.

Although the chief structural features of the present rocks can be somewhat readily described, it would be an impossible task to set forth all the details of the minor crushing, folding, and subsidiary structure. Likewise the exact nature and directions of the forces which, acting through the long time since the Archean period, have produced present conditions are in large measure indeterminable. It will suffice to say that it seems highly probable that a considerable portion if not all of the lamellation of the metamorphic rocks was originally developed along horizontal or nearly horizontal planes, so that the present steep and distorted structural features are indicative of the amount of tangential shrinkage of this portion of the earth's crust since Archean time.

In addition to the development and folding of the schistosity the pre-Cambrian rocks of the region have been faulted both in pre-Cambrian and subsequent time. How extensive or intensive the earlier faulting was can not be fully determined, owing to the high degree of metamorphism that the rocks have since undergone. However, in several places certain discordances of structure are believed to be best explained by faults, and the evidence favoring such interpretations will be presented. Certain faults of later age, affecting the overlying formations, will also be described inasmuch as they have in considerable measure effected the exposure of the pre-Cambrian in the localities in which they occur.

SCHISTOSITY

GENERAL FEATURES

Although the metamorphic complex is not exposed over extensive areas in the Gunnison River region, the great canyons cutting across the strike of the schistosity at various angles afford opportunities for the study of the structure of these ancient terranes over great distances. Much of the local structure has been described in connection with the discussion of the several mapped units, so that it will be necessary here only to point out some general structural tendencies and the most striking variations therefrom. As a rule, where there are no large intrusive bodies the direction of the strike as well as the degree of dip of the schist remains fairly constant. This is best exemplified along Gunnison River east of the Curecanti granite mass, where for more than 20 miles the schist strikes N. 60°–70° W. and dips 60°–70° NE. with few local variations. On the other hand, in the vicinity of large intrusions, as might be expected, the structure of the invaded rock is in many places much disturbed and irregular. This is well shown in the vicinity of the Tolvar Peak mass of Powderhorn granite. However, many of the smaller intrusive bodies have been intruded parallel to the schistosity and are accompanied by no great discordance in the structure. This applies to most of the granite bodies in the canyon west of Hierro switch.

The dip of the schistosity varies more than the strike. In general, however, it is steep, rarely being less than 45° and in many places changing within short distances to verticality or even swinging over to the opposite direction. The steep dips are best seen in the area of the River Portal schist along the southeast slope of Crystal Creek and along the canyon wall below the portal of the tunnel. It is not possible to trace out any connected plan of the folding that would explain the dips, owing both to the complexity of the struc ure and to the fact that the large areas between the canyons are covered with later formations.

Viewed in a broad way, the structure conforms with rather marked persistence to two main types, resulting in two distinct districts—an eastern district, in which the dominant strike of the schistosity is west-northwest, and a western district, in which the trend is for the most part north. These two districts are separated by a zone of intense faulting. Within these areas there are numerous local structural features, many of them associated with the larger igneous intrusions, which depart rather markedly from the conditions described. Thus the greenstones in the vicinity of the Tolvar Peak masses of Powderhorn granite show discordant structure on a large scale as well as locally, the part west of Goose Creek striking N. 45°–60° E. and that east of it conforming to the west-northwest structure of the eastern district.

Another notable abnormality is that of the large block of River Portal schists along the Black Canyon northwest of River Portal, extending as far as Red Rock Canyon, in which the strike is northeast to east-northeast and the dip northwest. This area is almost in the middle of the western structural district and contains the large Vernal Mesa granite body. The occurrence of variant structure in association with the major intrusive bodies suggests some connection between them. Whether the intrusion of the igneous masses produced the variant structure, or whether the relief of certain stresses and strains has distorted the structure, at the same time inducing the injection of igneous material, is a problem in the mechanics of intrusion not determined by the present study.

There are other areas of discordance in both the eastern and western districts that are far removed from any large igneous body now exposed. The best examples of these areas are in the zone of quartz-mica schists of Mesa Creek, where a north-south fault is believed to have caused a sharp change of structure from a north-south to a nearly east-west direction; and again in the lowest 5 miles of Cebolla Creek the strike varies from east to N. 65° E., although the exposures farther up the creek and on the adjacent portion of Gunnison River exhibit the typical west-northwest strike of the eastern district.

An examination of the structure symbols of the map will disclose not only a remarkable variation between the types of structure of the two districts named but also the absence of any persistent agreement between the structure of these ancient rocks and the general trend of the Rocky Mountains. Although the north-south strike of the schistosity of the western district conforms to this trend, the west-northwest strike of the eastern district is oblique to it at an angle of approximately 45°. Indeed, the strike f the schistosity over most of the area is at a greater or less angle to the north-northwest trend of this great mountain system, and in a few places, as in the River Portal schists of Vernal Mesa, northwest of River Portal, and the Dubois greenstone west of Goose Creek, it is normal to that trend.

LOCAL DETAILS

In numberless places throughout the canyons local structural features have been developed, and crumpling, folding, contorting, and slipping of all kinds can be observed. These features are incidental to the major trends already outlined and can not be discussed in detail. However, one such minor structural feature may warrant a brief description, owing to its location along the railroad and its exposure by the canyon of Cimarron Creek. On approaching this canyon from upstream, the structure of the schistosity is strikingly brought out by large pegmatite and granite intrusions parallel to it. These intrusions plunge away from the line of the canyon somewhat symmetrically, as if the creek had cut its way down along the axis of a great anticline. Upon going down into the canyon, however, it is found that the structure is that of a plunging anticline whose axis, running approximately N. 15° W. and plunging to a greater or less degree southeastward, crosses the creek 150 yards above the railroad bridge and about one-eighth of a mile above its mouth. How far this structure extends to the north-northwest is not known, but it is almost exactly in line with the axis of the seeming sharp fold that crosses the ridge south of Crystal Creek. A sketch of the structure as seen along the railroad is shown in Figure 5. A second subsidiary fold on the eastern limb of the main one is clearly exposed on the northwest wall of the canyon just below the railroad bridge.

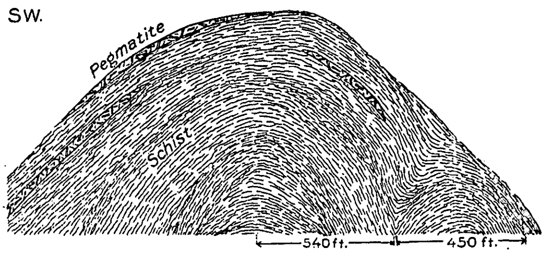

FIGURE 5.—Diagrammatic representation of structure of schist injected with pegmatite at railroad bridge near mouth of Cimarron Creek

The structure east of this fold, in the zone of the quartz-mica schist of Mesa Creek, veers from a south of east direction on the ridge east of Cimarron to northeast along the structural ridge south of Mesa Creek and to a nearly north direction north of that creek, the dip in all these places being to the south and southeast. The relation of this changing structure to the fold described is not clear, although it seems manifest that there is a fault and probably an overthrust immediately east of the crest of the fold.

This local structure typifies innumerable others of a similar character and suggests the extreme complexity of the structural history of these ancient terranes.

FAULTING

AGE

In addition to having suffered the varied processes of metamorphism the pre-Cambrian rocks of this region have been subjected to extensive faulting. Most of the faults observed throw the Mesozoic sediments but not the volcanic rocks and hence are of late Cretaceous or early Tertiary age. Other faults affect only the pre-Cambrian rocks, and in the absence of overlying sediments it is not possible to determine their exact age. That there are many pre-Cambrian faults within the metamorphic rocks there is little doubt, although owing to the obliterating effect of the metamorphism there are few evidences of their occurrence.

NELSON GULCH FAULT

The most notable of the older faults is that which crosses the Black Canyon at the west end of the Curecanti granite body. It has been pointed out that this body in a general way marks the division between the eastern type of structure, trending in general west-northwest, and the western type, trending to a large extent north. On examining more closely this line of separation between these two provinces it is found that the eastern type of structure prevails up to the Curecanti mass without any apparent possibility of extensive faulting. However, at the west end of the precipitous gorge cut in that granite the more open canyon at Nelson Gulch, with its steep, partly grassed and timbered slopes, presents a striking contrast. These slopes, particularly on the north, are characterized by innumerable irregular, jagged outcrops, chiefly of granite dikes, the intervening invaded schist being largely disintegrated. It is here that a zone of faulting is believed to cross the canyon in a west of north direction. The most convincing evidence supporting this belief, aside from the abrupt change in structure east and west of it, is the scarplike irregularity in the otherwise regular contact between pre-Cambrian and sedimentary rocks, particularly on the south rim of the canyon.

Moreover, the La Plata formation, although present in Cabin Gulch farther west and east of the fault line in Nelson Gulch, is absent on the shoulder west of the fault line and indeed appears to abut against pre-Cambrian rocks. For these reasons it is probable that the fault was reopened before the overlying volcanic rocks were erupted, and the east side was dropped 100 feet or more with respect to the west side. However, it is also possible that there was an old fault scarp here facing eastward, against which the Jurassic sediments were deposited.

Further evidence of an ancient fault zone is afforded by the crumpled and shattered condition of the rock, which consists of highly injected biotite schist. The unusual development of granitic and pegmatitic intrusives itself indicates a zone of weakness, such as a fault zone. Finally, the rocks in this zone show shattering, not only on a large scale but under the microscope as well. Many of the micas are bent or broken, and the quartz and feldspar exhibit an unusual amount of strain, the albite twinning lamellae being markedly curved.

The facts here set forth constitute the basis for the view that the area including Nelson Gulch and the slopes opposite on the south side of the river is a zone of intense faulting which has caused the difference in structure of the eastern and western districts. The details of the fault are of course not known, although the irregularity of the contact at the top of the pre-Cambrian and the presence of the La Plata sandstone on the east side of the fault line indicate that at least the most recent movements were of such a nature as to make the downthrow on the east side. Whether the earlier movement was of a similar nature or whether it was a thrust or normal fault can not be ascertained.

MESA CREEK FAULT

On Mesa Creek three-tenths of a mile below the forks there is a sharp change from a strike of N. 10°–15° E. with a steep northwest dip to a strike of N. 65° E. with a dip of 50° SE. The line of this change can be followed southeastward across Mesa Creek. There is also a slight difference in lithologic character between the rocks on the two sides of the line, those on the west being more quartzose than the biotite schist on the east side. A similar though less marked difference in structure may be observed at the end of the long ridge on the south side of the Black Canyon, nearly 2 miles east of Cimarron. For these reasons a fault has been mapped crossing Mesa Creek and the Black Canyon in a general north-south direction but with a notable convexity toward the east. The course of this fault is marked topographically by strong gullies and saddles, and there is reason to believe that the movement has been distributed over a zone instead of following a single line. Neither the nature nor the extent of the throw is determinable, and the age is not known further than that it is prevolcanic, as the volcanic rocks that overlie the fault line are unaffected.

CIMARRON FAULT

The faults so far discussed have affected chiefly the pre-Cambrian rocks and are poorly understood. The one now to be described is by far the most extensive fault in the region and indeed ranks as one of the major dislocations in this part of the Rocky Mountains. The name Cimarron is proposed for this fault because of its fine exposure just below the town of that name, where the railroad comes out of the canyon of Cimarron Creek. (See Pl. XV, *B*.) A. C. Peale as early as 1876 called attention to the high hills of the Archean complex rising 1,500 feet or more out of the shale. Other geologists in traveling through the canyon have frequently noted the strikingly clear fault relations, although, so far as known, no one has described this structural feature.

The fault forms the southwestern boundary of the pre-Cambrian area for 14 miles, from the head of Stumpy Creek, in the western part of the Uncompahgre quadrangle, to a point on the River Portal road 2½ miles northeast of Cedar Creek. Running in a general N. 60°–70° W. direction, which is suggestively parallel to the general trend of the schistosity of the eastern district, the fault can be traced, with some interruptions, for more than 50 miles, from Powderhorn on the east through the Uncompahgre and Montrose quadrangles, along the flanks of Vernal Mesa, northeast of Bostwick Park, past the head of Red Rock Canyon, and far down the eastern edge of the great Uncompahgre Valley.

On the southeast the fault is first observed at Powderhorn, where the La Plata sandstone crops out half a mile southwest of the post office, along the valley floor, at an altitude of 8,100 feet, whereas the pre-Cambrian rocks on the north side of the valley rise to 9,100 feet within less than a mile. The fault contact is covered by alluvium, but its location may well be indicated by the carbonate and hot springs that occur along the road on the east side of the Cebolla meadows. The continuation of the fault to the southeast is not understood, although it is probably lost in the Powderhorn granite mass.

Northwest of Powderhorn the fault is covered by the later volcanic rocks as far as the deep valley of the Lake Fork, where the Mancos shale is found in two small exposures, one on he east side of the river 0.8 mile south of Madeira siding and the other along the Cimarron road on the west side of the valley at an altitude of 8,000 feet, where it is in fault contact with the pre-Cambrian. Continuing northwestward the volcanic rocks again hide the fault as far as

Little Blue and Blue creeks, where the Mancos shale abuts against the pre-Cambrian. In a saddle at an altitude of about 8,900 feet between Little Blue Creek and East Fork there is evidence in the volcanic rocks that the fault has been locally reopened but that the movement has been in the opposite direction from that of the original dislocation.

From the head of Stumpy Creek northwestward the fault is very evident, even from a distance, the high, sharp ridge of crystalline rocks north of the fault line rising as much as 2,000 feet above the shale valley on the south side. Running in a N. 70° W. direction it continues along the southwestern slopes of this high ridge, crossing Cimarron Creek about 160 yards below the town of Cimarron. It bows in toward the northeast in this locality but maintains its general direction of N. 60°–70° W. Following the foot of the steep slope of Vernal Mesa, which represents the old fault escarpment (Pl. XV, *B*), it continues in the same general direction to a point near the Portal road 2½ miles N. 65° E. from Cedar Creek, where the throw is taken up by a cross fault running in a south of west direction, which drops the Mancos shale against the red shale of the McElmo formation, of Cretaceous (?) age.

From this point the Cimarron fault is lost in a greater complexity of structure of the overlying sedimentary beds and seems to split into a series of parallel faults, the details of which have not been studied. These faults run in a general N. 40° W. direction between Vernal Mesa and Bostwick Park, emerging as one fault at the north end of that park, where the road crosses the little saddle at the head of Red Rock Canyon. Here the Mancos shale is in contact with the Vernal Mesa granite for a quarter of a mile, beyond which the shale is faulted against the Triassic "Red Beds." The fault, which continues on a course approximately N. 65° W., was not followed farther in this direction, but it is known to extend for many miles along the eastern border of the Uncompahgre Valley.

The Cimarron fault is of the normal type, and the south side slipped downward over the north side. The fault plane appears to be uneven and of variable hade. The contact is almost everywhere covered by talus and slide, which preclude a careful study. In Lake Fork the dip of the fault is relatively small, although from Stumpy Creek to the Portal road, where the crystalline rocks are in contact with the Mancos shale, the fault plane seems to be nearly vertical. At a point 1½ miles due north of the forks of Cimarron Creek the shale, carrying a small ledge of calcareous sandstone, is turned up against the schist at an angle of 45°. The schist is somewhat crushed and crumpled and shows considerable disintegration. At several places irregular exposures of a sandstone resembling the Dakota sandstone and of red shale resembling that of the McElmo formation can be observed in contact with the schist, and these masses are believed to have been detached from their respective beds and dragged upward along the plane of movement. The best example of the effects of this action is seen in the deep gully leading to the saddle east of the Mesa Creek fault. Here rocks thought to be McElmo shale and Dakota sandstone rest against the pre-Cambrian in a way that suggests a depression in the fault plane, with possibly slight cross faulting.

Owing to the absence of good horizon markers, the throw of the Cimarron fault can not be accurately determined. It is known to vary considerably; thus at Powderhorn, if the supposition that the fault goes up the Cebolla Valley is correct, the throw as calculated from the relative positions of the La Plata sandstone on the two sides of the valley is more than 1,500 feet. In the vicinity of Cimarron the throw is even greater, affecting all formations up to at least the Mancos, of late Cretaceous age. A small exposure of what is thought to be La Plata sandstone was discovered on the east end of Vernal Mesa at an altitude of 9,350 feet, 1,500 feet above the Mancos shale at the fault line. The thickness of the sediments from the surface of the Mancos to the base of the La Plata is probably at least 1,000 feet and may be as much as 2,000 feet. From these data, if the supposition is correct that the outcrop of sandstone on Vernal Mesa is La Plata, the throw of the fault here must be at least 2,500 feet and may be as much as 3,500 feet.

Farther northwest the throw becomes less, and just east of the Portal road there is a tongue of pre-Cambrian rocks extending across the line of the fault as an inlier in the sediments, so that for a distance of a quarter of a mile the pre-Cambrian is faulted against pre-Cambrian, the only evidence of the structure being a prominent escarpment.

East of this point and 1½ miles northeast of the reservoir at Cerro Summit, there begins a series of saddles which form a line running toward the head of Pool Gulch in such a peculiar manner as to suggest that the main fault forks at this point, as indicated on the map. This supposition helps to explain the decrease of throw toward the west. The cross fault near the Portal road appears to take up most of the remainder of the throw, and beyond that point the La Plata sandstone rests in depositional contact on the crystalline rocks, although the tectonic effect of the major fault is expressed in a broad fold over Vernal Mesa, the southwestern limb of which dips rather steeply.

The complex faulting from the Portal road to the head of Red Rock Canyon affects the sediments at the surface rather than the pre-Cambrian and for this reason has not been taken up in this study. However, it may be pointed out that the limit of the pre-Cambrian rocks in the Gunnison tunnel is more than 16,700 feet, or 3.2 miles, from the river portal. This probably represents the crossing of the main fault at the depth of the tunnel. The throw of the fault in this locality and beyond Bostwick Park, where it is more simple, has not been worked out.

The age of the Cimarron fault seems fairly clear, for it everywhere affects the sedimentary rocks and nowhere affects the volcanic rocks. It is pre-volcanic and post-Mancos and is therefore of late Cretaceous or early Tertiary age.

RED CANYON FAULT

Another large fault, which affects the sediments as well as the pre-Cambrian rocks, was discovered where it crosses Gunnison River, about one-eighth of a mile south of the mouth of Red Canyon. Owing to its practical inaccessibility it was not followed; it was examined only in West Red Canyon and with the aid of glasses from favorable points on the east side of the river. The contrast in color between the dark pre-Cambrian rocks and the varicolored "Red Beds" renders the interpretation of this structure possible, even at a considerable distance.

The Red Canyon fault extends in a north-northeasterly direction down the north side of West Red Canyon and crosses the Gunnison a third of a mile below the mouth of the canyon. There it continues northward for about 3½ miles, recrosses the river at a point one-eighth of a mile above the mouth of East Red Canyon, continues in a northerly direction on the west side of the Gunnison, and finally enters the sediments three-quarters of a mile below the mouth of East Red Canyon. It is unexplored farther north.

The fault is of the normal type, with the downthrow on the east side. The throw is approximately 600 feet, and the fault plane appears to be nearly vertical. Where last examined, on the west side of the river below the mouth of East Red Canyon, the fault causes a very striking duplication of the strata of the "Red Beds" in the canyon walls.

The relation of this fault to the Cimarron fault is not known, nor is its age determined further than that it is later than the "Red Beds."

OTHER FAULTS

Several smaller faults that affect the pre-Cambrian rocks have been mapped, including those at Elkhorn, near the mouth of West Elk Creek, and south of Vulcan, but it will not be necessary to describe them. However, it should be pointed out that the faults of the area show a tendency to parallel the local schistosity of the crystalline rocks.

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