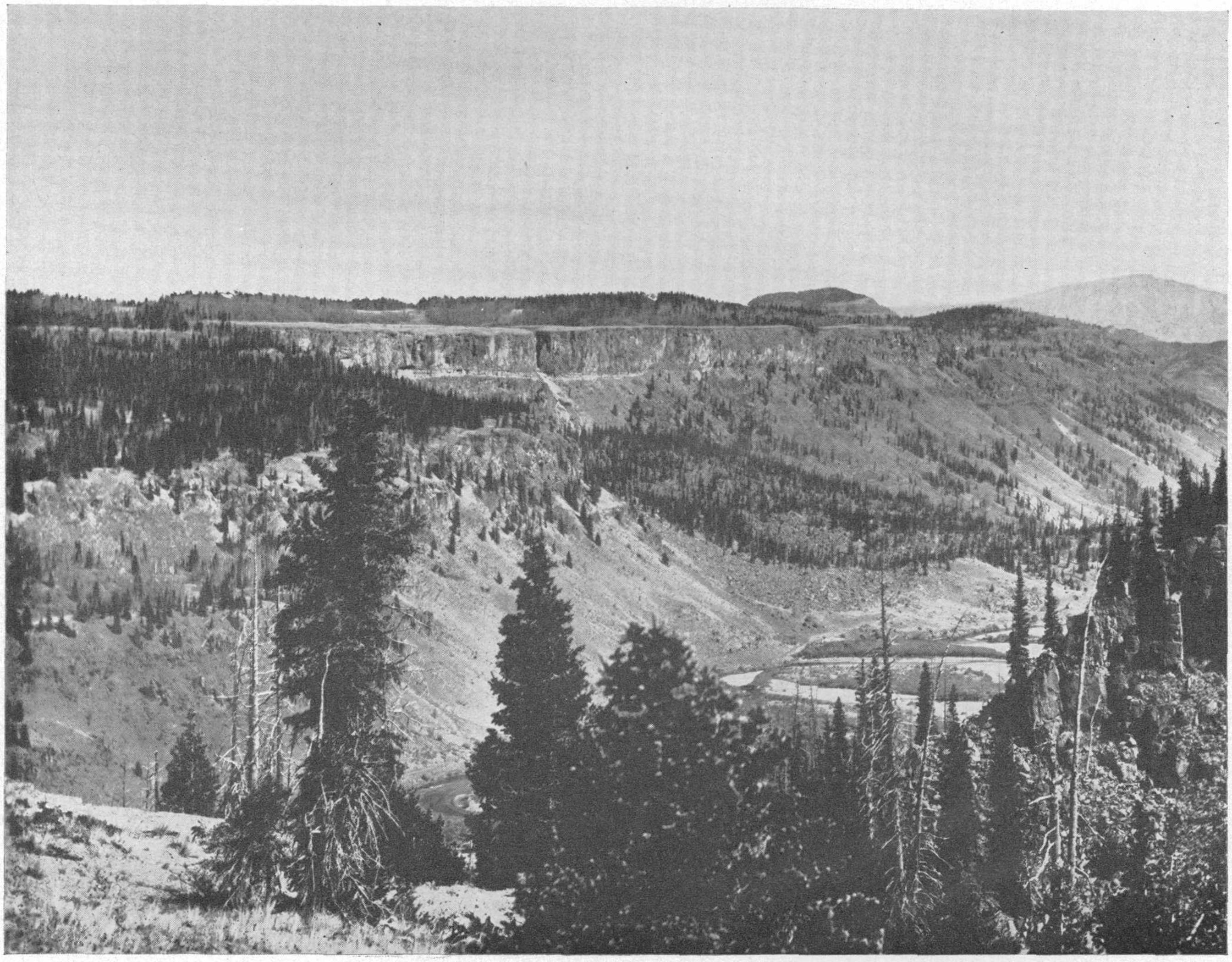

Well-layered lavas of the Potosi volcanic series as seen down the valley of the Rio Grande from north of Weminuche meadows, San Cristobal quadrangle. The upper cliff-forming flow is Piedra rhyolite; the lower talus-covered slopes are underlain by Huerto quartz latite and Alboroto rhyolite.

Geology and Petrology of the San Juan Region Southwestern Colorado

By ESPER S. LARSEN, JR., *and* WHITMAN CROSS

GEOLOGICAL SURVEY PROFESSIONAL PAPER 258

A comprehensive geologic and petrologic study of the occurrence and origin of the rocks in an area of 12,000 square miles in southwestern Colorado

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PREFACE

PLAN OF THE PROJECT AND COURSE OF THE WORK

A study of the geology of the San Juan Mountains was begun by Whitman Cross in 1895. The project was originally planned as an areal survey on folio scale (1:62,500) for presentation of local detail, with monographic treatment of stratigraphy, igneous geology, and associated economic reports. Early in the work Cross recognized the importance of the physiography and the Quaternary geology and in 1908 he recommended that those subjects be studied under the direction of the best available investigator. Fortunately, it was possible to get Wallace W. Atwood for this study, and in 1932 he and Kirtley F. Mather published a detailed report. Cross began the work in the western part of the area and by 1909 the field mapping of nine 15-minute quadrangles was completed. As shown in the following table, geological maps and descriptions of seven of these quadrangles have been published as folios in the Geological Atlas of the United States. In addition, a geological map and description of the southern part of the Lake City quadrangle has been published as a bulletin by Irving and Bancroft (1911). The early work in the area is summarized in the following table.

Early work in the western San Juan Mountains

Quadrangle	*Field work*	*Workers*	*Date published*
La Plata (folio 60)	1896-97	Whitman Cross, assisted by A. C. Spencer and H. S. Gane.	1899
Telluride (folio 57)	1895-96	Whitman Cross, assisted by H. S. Gane, E. C. E. Lord, and A. C. Spencer.	1899
Rico (folio 130)	1897-99	Whitman Cross and A. C. Spencer, assisted by Ernest Howe, J. D. Irving, and R. D. George.	1905
Silverton (folio 120)	1899-1901	Whitman Cross, Ernest Howe, and A. C. Spencer, assisted by J. M. Clements, G. W. Stose, and R. D. George.	1905
Needle Mountains (folio 131).	1900, 1901-03	Whitman Cross and Ernest Howe, assisted by J. M. Clements, G. W. Stose, and Albert Johannsen.	1905
Ouray (folio 153)	1904-06	Whitman Cross and Ernest Howe, assisted by W. H. Emmons and L. H. Woolsley.	1907
Engineer Mountain (folio 171).	1907-09	Whitman Cross, assisted by A. C. Spencer, Ernest Howe, A. Johannsen, W. H. Emmons, and Howland Bancroft.	1910
Durango	1897-1900	Whitman Cross, assisted by A. C. Spencer, Ernest Howe, and W. H. Emmons.	Not published.
Lake City	1907-08	Whitman Cross, assisted by L. H. Woolsley, Albert Johannsen, Howland Bancroft, W. H. Emmons, and G. F. Kay.	1911, in part.

The seven published folios furnished a practically new formational cartographic section from early pre-Cambrian to Tertiary and this was found to be applicable to a large area to the south and west. As work progressed into the central volcanic area, unanticipated complexities necessitated a restriction of the study largely to the volcanic geology and a reduction of the scale of the mapping to 1:125,000 so that the whole project could be finished. The San Cristobal, Uncompahgre, and the northern part of the Ignacio quadrangles were mapped in detail on a scale of 1:125,000. To expedite the work, the Creede, Summitville, Del Norte, and Conejos quadrangles were mapped only in detailed reconnaissance fashion and, because no suitable base maps of the Cochetopa and Saguache quadrangles were available, these quadrangles were covered only by a rapid reconnaissance study.

In the summer of 1908 Albert Johannsen made a reconnaissance study of parts of the San Cristobal quadrangle. In the summer of 1909 Cross, Larsen, and L. F. Noble worked chiefly in the Ignacio quadrangle and the western part of the San Cristobal quadrangle. In the summer of 1910 Larsen and J. F. Hunter worked in the San Cristobal quadrangle. From 1911 to 1917 Larsen and Hunter worked in the Uncompahgre, Cochetopa, Saguache, Creede, Del Norte, and Summitville quadrangles, and Cross was with the field party for a part of the time. The work was interrupted by World War I, but was resumed in 1920 and 1921 when Larsen and C. S. Ross worked chiefly in the Conejos quadrangle. Cross joined the field party for a time in 1921.

In the summer of 1926 Larsen and J. W. Vanderwilt mapped the small area of volcanic rocks in the Pagosa Springs quadrangle and the igneous rocks of the northern half of the Montrose quadrangle. They also revised the previous mapping in many places. In 1930 Larsen spent six weeks in the field in further revision.

Cross had closely supervised both field and office work until it was interrupted by World War I, and his interest in it continued until his retirement from active work in 1925. The final preparation of the maps and text of this study was therefore left to Larsen who assumes all responsibility for this report and the conclusions herein.

The work was supported in large part by the United States Geological Survey, but from 1924 to 1949 Harvard University contributed liberally by financing some seasons of field work and by furnishing chemical analyses, assistants to Larsen, and other help.

A considerable part of Larsen's time since 1930 has been devoted to detailed laboratory investigation, largely under the auspices of Harvard University. The results of many of these studies have been published as topical reports and are referred to in the body of this text.

ACKNOWLEDGMENTS

In the course of both the field work and the preparation of this report we have worked in close cooperation with W. W. Atwood and K. F. Mather, who have made a study of the physiography and Quaternary geology of the area. We have been generously aided and loyally supported in this work by many associates in the United States Geological Survey who have freely furnished field data, paleontologic and other assistance, and help of innumerable kinds. The Topographic Division has prepared excellent topographic maps covering much of the area. Many of the mining men and other residents of the San Juan region have also aided in the field work, especially the resident members of the United States Forest Service. During much of the field work Arthur Broadhead of Mancos, Colo., acted as packer and camp manager, and his fine personality and efficiency added greatly to the pleasure of all the party and to the effectiveness of the field work. The individuals to whom we are indebted are too many to mention. We wish especially to express our appreciation of the loyal and effective help in the field and in the petrographic study of the large collections of rocks given by the late J. Fred Hunter and by Clarence S. Ross. The chief geologists under whose general direction the work was carried on—C. W. Hayes, Waldemar Lindgren, David White, and W. C. Mendenhall—have supported it so far as was in their power. The section chiefs who have had direct supervision of the work—Arthur Keith, F. L. Ransome, Sidney Paige, and G. R. Mansfield—have aided us in many ways. John C. Rabbitt, while my assistant at Harvard and later after joining the U. S. Geological Survey, reviewed the manuscript critically and contributed considerably both to its technical coherence and its organization. Prof. John B. Lyons of Dartmouth College read a revised version of the manuscript in considerable detail and made many constructive suggestions.

E. S. L., Jr.

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GEOLOGY AND PETROLOGY OF THE SAN JUAN REGION SOUTHWESTERN COLORADO

By Esper S. Larsen, Jr., and Whitman Cross

ABSTRACT

The San Juan Mountains are a dissected dome more than 100 miles across. They are bounded on the north by the valley of the Gunnison River, on the east by the San Luis Valley, and on the south and west by an area of mesas and canyons cut chiefly in Mesozoic and Tertiary sedimentary rocks. The mountains are made up chiefly of Tertiary volcanic rocks, but in the western and northern parts of the mountains and locally elsewhere, bodies of older rocks are exposed. These older rocks include a complex of pre-Cambrian rocks and a section of Paleozoic, Mesozoic, and Tertiary sedimentary rocks.

The oldest rocks of the area are a complex of ancient, highly metamorphosed schists and gneisses, part of which are of sedimentary origin, and a larger part of undetermined origin. They are overlain unconformably by a group of moderately metamorphosed volcanic rocks, the Irving greenstone. These are overlain unconformably by a great thickness of moderately metamorphosed sedimentary rocks, the Needle Mountains group, which has a quartzite conglomerate as a lower formation and interbedded quartzites and schists as an upper formation. Intrusions of granitic rocks took place many times during the pre-Cambrian period, and the chief granitic rocks are granite and granodiorite, with sporadic gabbro and syenite. In the Iron Hill area near Powderhorn there is a small stocklike mass that is made up of marble, coarse melilite rock, pyroxenite, ijolite, nepheline syenite, syenite, nepheline gabbro, and quartz gabbro. The older granitic rocks are highly metamorphosed to granite gneiss, those of intermediate age are somewhat metamorphosed, and the youngest are not metamorphosed.

By Late Cambrian time the older rocks were eroded to a smooth surface, this surface was depressed beneath the sea, and the late Cambrian Ignacio quartzite was deposited. About 6,000 feet of Paleozoic sedimentary rocks overlie the pre-Cambrian. There is no angular unconformity within the Paleozoic section, but there are several disconformities.

In the western part of the mountains the Mesozoic rocks were deposited upon the Paleozoic with apparent conformity, but near Ouray and to the west the Triassic rocks lie unconformably on the Paleozoic and northeast of Pagosa Springs the Jurassic rocks bevel the deformed Triassic and Paleozoic rocks and in large areas rest directly on the pre-Cambrian. Upper Cretaceous rocks rest conformably on the Jurassic and in most places the Paleocene and Eocene rocks rest conformably on the Cretaceous. Locally, Oligocene or early Miocene beds rest unconformably on the older rocks. The Miocene volcanic rocks seem to overlie conformably the Oligocene or early Miocene sediments.

There is no evidence of volcanism in the Paleozoic and Mesozoic rocks up to the uppermost formations of the Cretaceous. The upper formations of the Cretaceous and the lower formations of the Paleocene are made up of sands and gravels whose fragments consist in large part of volcanic rocks. Volcanic material was available to the sediments for only a short time, as most of the Eocene and the Oligocene(?) are free of such material.

The main volcanic eruptions of the area began in middle Miocene time and continued, with interruptions, into the Quaternary.

The older volcanic rocks of the western part of the mountains are different from those of the eastern part. In the eastern part they are chiefly light-colored quartz latites, with some latite, rhyolite, and dark olivine-quartz latite. There are some surfaces of erosion separating formations of this quartz latite series and in the San Luis Hills, east of the southern part of the mapped area, the quartz latites are intruded by stocks of monzonite and syenite. This complex was greatly eroded before the subsequent olivine-quartz latites erupted.

In the western San Juan area the first Miocene eruptions formed a volcano of quartz latite—the Lake Fork quartz latite—with minor amounts of rhyolite and basalt. These eruptions were followed by a thick accumulation of bedded tuff-breccia—the San Juan tuff. In the northern part of the area great bodies of this tuff are made up in very large part of fragments of a uniform glassy, vesicular quartz latite. Only on the flanks of the Lake Fork volcano are fragments of the rocks of the volcano present in the San Juan. In the southern area the tuff contains a greater variety of fragments. Much of the tuff must represent pyroclastic material from a volcano of unknown location, which has been reworked by water. The rocks of the Silverton volcanic series are later than the San Juan. They have been divided into five mapped units which range from dark quartz latite approximating basalt, to rhyolite.

The eruptions of the Potosi volcanic series and Fisher quartz latite which followed the Silverton volcanic series are probably related. They covered an area of more than 10,000 square miles and have an estimated volume of about 4,000 cubic miles. The succession of rocks from bottom to top is: dark quartz latite, erosion of canyons, rhyolite, dark quartz latite, erosion of canyons, rhyolite, dark quartz latite, erosion of canyons, rhyolite, erosion of canyons, quartz latite.

After the eruption of the Fisher rocks the area was depressed and the San Juan peneplain was formed. Low domes of basalt and latite, with some rhyolite, were spread over much of this peneplain during Pliocene time.

In pre-Cambrian time the rocks were deformed, metamorphosed, and intruded by granitic rocks several times.

In the southwestern part of the area no angular unconformity was found within the Paleozoic and Mesozoic rocks, but in the northwestern part the Paleozoic rocks were much deformed before the deposition of the Triassic. In the eastern part of the sedimentary belt, from northwest of Pagosa Springs to Ouray, the Triassic and Early Jurassic rocks were greatly deformed

before the deposition of the Late Jurassic. The major deformation of the sedimentary rocks took place near the end of the Eocene when the Needle Mountains were elevated about 14,000 feet and the rocks were folded and faulted. Most of the faults are steep normal faults; a few are steep reverse faults. In many of these faults the rocks on the downthrown side have been dragged up by the fault so that near the fault they dip steeply and are locally overturned.

A moderate interval of time without eruptions followed the deposition of the San Juan beds, during which canyons were eroded more than 1,000 feet deep. Two similar intervals of canyon-cutting separated formations of the Silverton volcanic series. Thus, there was little movement of the crust beneath the volcano during San Jaun and Silverton time and the volcanic mountains rose much above the general level. The Potosi rocks rest on a mature surface, cut on the older rocks, that is several thousand feet above the bottom of some of the canyons of Silverton age. This indicates that the Silverton volcano was greatly depressed following the eruptions of the Silverton volcanic series.

The deep canyons that were cut in the volcano in four periods of Potosi and Fisher time show that during these eruptions the crust must have remained nearly stationary. The borders of the volcano, especially the eastern and southern borders, must have been gradually depressed during the Potosi and Fisher eruptions. After the Fisher eruptions the San Juan peneplain was developed. It is commonly several thousand feet above the bottom of the canyons of Potosi and Fisher age, showing that the volcanic mass must have been greatly depressed after the Fisher eruptions. The eruption of the lavas of the Hinsdale formation followed, and after the eruption of these lavas the area was domed. The maximum uplift at this time was about 15,000 feet in the Needle Mountains. This makes the total uplift of the Needle Mountains area during Tertiary and Quaternary time about 28,000 feet.

The dip of the volcanic rocks is rarely greater than a few degrees and large areas show no faulting. A few zones and areas have many faults. Horsts and graben are present. Some of the steeply dipping faults with displacements of a thousand feet or more have the beds on the downthrown side dipping into the fault. A few miles from the fault the beds become flat and are at the same altitude as the corresponding flat beds on the upthrown side. The faults must have been formed by tension, with a movement of the hanging wall away from the fault, thus removing the support and causing the collapse of a narrow strip along the hanging wall.

In field mapping, it was recognized that the Tertiary volcanic rocks fall into four major groups: the Lake Fork quartz latite, San Juan tuff, and Silverton volcanic series in the western area; the pre-Potosi of the eastern area; the Potosi volcanic series and Fisher quartz latite; and the Hinsdale formation. Relatively long periods of erosion, during which deformation took place, separated the groups. When the analyses of rocks from any one of the groups are plotted on a variation diagram, about 90 percent of the analyses fall near smooth variation curves. The curves for the different groups are different. The curves of the Lake Forks are very near those of the Potosi. The pre-Potosi rocks are lower in SiO_2 and higher in Al_2O_3 and K_2O than the Potosi. The Fisher rocks are a little higher in SiO_2 and lower in Al_2O_3 and Na_2O than the Potosi. The Hinsdale rocks are even lower in SiO_2 and CaO and higher in Al_2O_3 and Na_2O than the pre-Potosi lavas. The groundmasses of the rocks of each group were plotted on the same variation diagram as the rocks and for each pair—groundmass and rock—the groundmass is nearer the rhyolite, and the curves for the groundmasses fall near the curves drawn for the rocks. This shows that if differentiation within each group was by fractional crystallization, the separation of the actual minerals found in the rocks would quantitatively yield the variation diagram of the group.

To account for the succession of events in the deposition of any of the series, such as the Potosi volcanic series, the following hypotheses are made. As the crust remained nearly stationary during the building of the volcanic mountains of the Potosi, the magma must have come from outside the area; it must have been erupted from the volcanoes about as fast as it moved in, and it must have moved in periodically. The first Potosi eruption followed a long period in which few eruptions took place. They yielded dark rocks, the Conejos quartz latite, and represent magma that underwent little differentiation. There followed a time without eruptions in which the magma differentiated and became more or less stratified, with rhyolite forming in the upper part. When magma was again forced into the area the first eruptions from the upper rhyolite layer yielded the Treasure Mountain rhyolite. As this layer became thin or was broken through by the lower magma, the dark magma of the Sheep Mountain quartz latite was erupted. During the eruption of the rhyolite, small masses of the lower dark magma were occasionally brought to the surface and formed the dark horizons in the rhyolites. While the dark rocks were being erupted local patches of rhyolite were erupted to yield the rhyolites in the dark horizons. There followed a time without eruptions and, after that the process was repeated to yield the Alboroto rhyolite and Huerto quartz latite.

After the eruptions of the Potosi and Fisher rocks the area was depressed, probably by the withdrawal of magma. After a long time a new parent magma that was different from the Potosi magma was brought into the area and furnished the Hinsdale rocks.

It is believed that the rocks of each of the volcanic series, such as the Potosi, were derived by crystal fractionation from a parent basaltic magma of rather uniform composition. The parent magmas for the five series were different. They may have been derived from different layers in the crust.

The slow doming of the mountains in late Pleistocene and Quaternary time may have been due to a new movement of magma into the area without extensive eruptions. A few small eruptions took place in this time.

INTRODUCTION

SPANISH EXPLORATIONS

The Spaniards settled in the Rio Grande Valley near the mouth of the Chama River in 1598 and Governor don Pedro de Peralta founded Santa Fe and made it the capital of New Mexico in 1610 (Northrop, 1942). Despite this, and although the distance from Taos to the southern part of the San Juan Mountains and the San Luis Valley is only about 40 miles by a relatively easy route, there is no record that the Spanish reached the San Juan Mountains or the San Luis Valley before 1765.

The earliest explorations by white men into the San Juan region were made by the Spanish from New Mexico. According to Thomas (1924), Don Juan Maria de Rivera, attracted by reports of mines in the San Juan Mountains, led the first expedition into the mountains. In 1765 his party marched northwestward from Santa Fe along the southern foothills of the San Juan Mountains. In the canyon of the La Plata River they collected some samples of ore and then crossed the Dolores River, then called the San Miguel. They crossed the Uncompahgre Plateau, the Uncompahgre River, and finally reached the Gunnison River.

In 1776 two padres, Dominguez, and Escalantes, unarmed, and with 12 companions, some of whom had gone with Rivera, left Santa Fe in search of an overland route to California. They traveled northwestward, reached the Mancos River, crossed the La Plata Mountains, and reached the Uncompahgre River by Dallas Creek. They went down the Uncompahgre to the Gunnison, then toward the north and west to Utah Lake. The winter snows forced them to return by a more southerly route.

In 1779, Juan Bautista de Anza, then Governor of New Mexico, led an expedition against the Comanche Indians north from Santa Fe, along the western border of the San Luis Valley, as far as the Arkansas River.

EARLY AMERICAN EXPLORATIONS

In 1807 Lt. Zebulon M. Pike crossed the Sangre de Christo Range into the San Luis Valley and down that valley to the Conejos River, where he was captured by the Mexicans. In the fall of 1846, during the Mexican war, after the capture of Santa Fe by the Americans, Maj. William Gilpin led an expedition from Santa Fe against the Navajo Indians up the Chama River and across the mountains to the San Juan River. In the winter of 1849 Col. J. C. Fremont, with Bill Williams as guide and a party of 33 men, attempted to find a route across the Rockies by way of the Rio Grande. He reached Antelope Park but was forced by the snow to turn back to Taos, N. Mex., after suffering extreme hardships. In 1853 Capt. J. W. Gunnison explored the passes of Cochetopa, Mosa, Gunnison, Robedeux, and Poncha in search of a railroad route to the Pacific.

It must be remembered that long before the organized expeditions of such men as Fremont, those hardiest of all pioneers, the hunters and trappers, had worked over most of the mountains but they left little or no record of their explorations. The organized expeditions generally employed these trappers as guides.

EARLY GEOLOGICAL WORK

In 1859 Newberry (1876, p. 74–90), as geologist for the Macomb expedition, traversed along the southern and western base of the San Juan Mountains. He described chiefly the Cretaceous sediments but mentioned the older rocks and the great mass of younger volcanic rocks. The map accompanying Newberry's report shows the lowlands surrounding the San Juan Mountains fairly well, but the mountain mass is shown with north-south drainage and the great Rio Grande is shown as an unimportant stream, reaching only a few miles into the mountains.

In 1873 Lt. E. H. Ruffner surveyed a line from Fort Garland up the Rio Grande to its source, and down the Animas River; then north to the Lake Fork of the Gunnison, down that fork to its canyon, thence eastward to Los Pinos Agency, through Cochetopa Pass, and back to San Luis Valley. Frederick Hawn (1874) was geologist of the party.

In 1873 J. J. Stevenson (1875), as geologist with the Wheeler Survey, examined parts of the San Juan area.

The first organized geological work in the San Juan Region was that of the United States Geological and Geographical Survey of the Territories under Hayden between 1869 and 1875 (1874–77). The work in the eastern part of the San Juan Mountains was done by F. M. Endlich (1874, 1875, 1876, 1877, 1878) and that in the extreme western part by W. H. Holmes (1877) and A. C. Peale (1876). The Hayden Survey published a geological and topographic map of the State of Colorado (Hayden, 1877) and reports on the area, chiefly descriptions of the routes traveled. Inevitably, the maps and the reports do not meet the standard set today but, considering the time devoted to the area, the difficult conditions under which the work was done, and the development of the science of geology of that time, the map is remarkably good. It shows approximately the areas underlain by the pre-Cambrian rocks and by the major members of the sedimentary strata up to the base of the volcanic rocks. It shows but a few subdivisions within the volcanic rocks and those are lithologic rather than stratigraphic. The San Juan tuff and part of the Conejos quartz latite are mapped as trachytic breccia, the basalt and latite of the Hinsdale formation and some other dark basaltic rocks as basalt, and most of the other rocks as trachorheite.

EARLY PROSPECTING

In 1860 Charles Baker with six men went to the San Juan Mountains in search of placer gold. They reached the vicinity of Silverton, found some gold, and sent out glowing accounts of their find. They made their headquarters at Animas City, and prospected the heads of the Gunnison, Uncompahgre, and San Miguel Rivers. Others joined them, but this find proved disappointing, and in 1861 they were driven out by Indians. In 1868 Baker returned to the San Juan country and was killed by Indians. In 1869 and 1870 Adnah French and seven companions came from Arizona to prospect in the area. They prospected at the head of the Mancos River and found some ore. They were constantly harassed and threatened by the Indians.

Ore was found at Summitville in 1870 and in the next few years many prospectors came into the mountains. Many of the mines in the area were located in the decade from 1870 to 1880. In 1874, Enos Hotchkiss, who had charge of the construction of the Toll Road from Saguache to the Animas, found rich float near Lake City and started a mining boom in that locality.

Ore was not found at Creede until 1890 when N. C. Creede located prospects near Sunnyside. The Creede area soon had a great boom and in 1891 the Amethyst vein was found.

EARLY SETTLEMENTS

Probably the first permanent settlement by white men made in or near the San Juan area was at Costella, in the southern part of the San Luis Valley, in 1849. San Luis was settled in 1851. In 1852 Fort Washington was built near the present sight of Fort Garland. In 1854, fifty Mexican families from New Mexico, led by Lafayette Head, settled at Guadalupe, near Conejos. Settlers soon spread north and in 1864 four Mexican families settled on San Francisco Creek near Del Norte, and in 1871 a few Americans moved to this area. The settlement was known as Loma. Following the discovery of gold near Summitville, the town of Del Norte was organized and grew rapidly as a main gateway to the mines of the San Juan area. The first settlement near Saguache was on Kerber Creek, above Villa, in 1865 and Saguache was established the following year. The Los Pinos Indian Agency was established in 1868 and soon the valleys of the Gunnison River drainage basin were occupied by white settlers. Most of the other towns of the area were established between 1870 and 1890.

The Denver & Rio Grande Western Railroad Company completed a railroad to Alamosa in July 1878, extended it to Espanola, N. Mex., by way of Antonita in 1880, and built the line up the Rio Grande to Wagonwheel Gap in 1883.

About 1875 a wagon road was constructed up the Rio Grande and across the Continental Divide to Silverton. The upper part of this road in the head of the Rio Grande has been impassable for many years. In 1874, Enos Hotchkiss constructed a toll road from Saguache to Lake City and in 1880 Otto Mears constructed a wagon road across Dallas divide to Telluride.

GEOGRAPHY

The San Juan Mountains area lies in southwestern Colorado, as shown on the accompanying relief map (fig. 1). The area included in the San Juan maps (fig. 2 and pl. 1) is about 125 miles in an east-west direction and 105 miles in a north-south direction. The area covered geologically is about 12,000 square miles, about one-eighth of the State of Colorado.

Nearly all of the area included on the map is mountainous and the only large area of flat land in or adjoining the mapped area is the San Luis Valley, which borders the San Juan Mountains on the east.

In the eastern part of the mapped area southwest of Antonita, a range of mountains which is an arm of the San Juan Mountains extends for many miles into New Mexico. However, in most of the southern part of the area the high San Juan Mountains give place on the south to a surface of moderate relief cut in nearly flat-lying Cretaceous and Paleocene and Eocene sedimentary rocks and characterized by rounded slopes, with canyons and mesas. The main mountain front rises sharply in cliffs several thousand feet high above this area of soft sedimentary rocks, and the streams emerge abruptly from deep, rugged canyons in the mountains to broader, more open valleys with gentler slopes cut in the softer rocks.

On the west the high mountains are formed of gently dipping sedimentary rocks and they grade westward into a terrain of less relief, characterized by canyons and plateaus. To the north the San Juan Mountains are bounded by the Gunnison River and Tomichi Creek, which flow in a gentle syncline bordered by high mountains to the north and south. Thus they differ from most of the mountain masses of Colorado which are elongated mountain ranges. The San Juan Mountains are quadrilateral, with their eastern side longer than the western. The mountain mass has the general form of an undulating plateau and an altitude that in most places is about 12,000 feet. The plateau is deeply dissected, and ends abruptly in cliffs to the south, less abruptly to the west, and has relatively gentle slopes on the north and east. The high mountains are underlain by volcanic and pre-Cambrian rocks, and the bordering lower land by Cretaceous and younger sediments.

CONTINENTAL DIVIDE

The Continental Divide, as shown in figures 1 and 2, winds in a sinuous but general southwesterly course from a point near the northeast corner of the region to the head of the Rio Grande, about 30 miles west of the center of the region. Thence it swings around to the south and southeast and leaves the region at a point about 30 miles west of the southeast corner.

DRAINAGE

This region furnishes water to the three great river systems of the Southwest. A very small area near the northeast corner drains into the Arkansas River and thence southeastward into the Mississippi. The remainder of the area east of the Continental Divide, including most of the eastern part of the region, is drained by the Rio Grande, which heads near the

FIGURE 1.—Relief map of Colorado showing the relations of the San Juan Mountains to the other mountain masses of the State. The area within the white line is included in the geologic map (pl. 1).

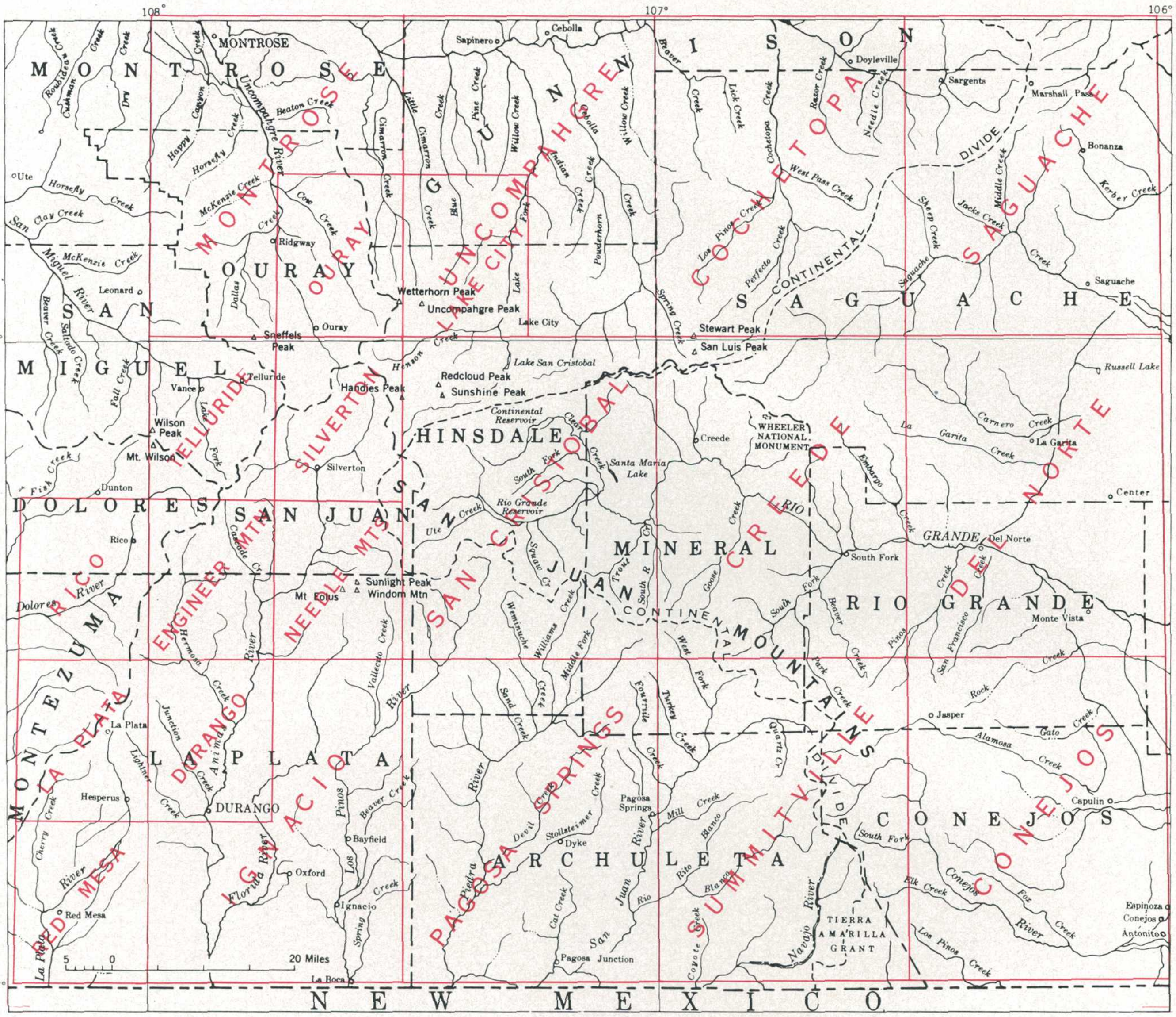

FIGURE 2.—Map of the San Juan region, Colorado, showing the outline of quadrangles.

center of the mountains and flows east for about 100 miles and thence south to the Gulf of Mexico. In the area west of the Continental Divide are the headwaters of many of the main branches of the Colorado River, which flows southwestward into the Gulf of California. The major branches of the Colorado heading in the region are the Gunnison River, which drains the northern part, the Dolores River, which drains the western part, and the San Juan River, which drains the southern part.

ALTITUDES

The lowest point on the mapped area is near the southwest corner and is a little below 5,000 feet in altitude. Only a few of the streams leave the region at altitudes much below 6,000 feet. The total area below 6,000 feet is very small, and the area below 7,000 feet is much less than 1 percent of the whole. The great San Luis Valley is nearly 7,500 feet above sea level. Only about a quarter of the area is below 8,000 feet, and most of that is in the extreme southern, eastern, or northwestern parts.

The highest point in the region is Uncompahgre Peak, in the southwestern part of the Uncompahgre quadrangle, which is 14,306 feet above sea level. The 14 peaks that rise above 14,000 feet are shown on plate 4 and are listed below.

TABLE I.—*Peaks higher than 14,000 feet in the San Juan region*

Name	*Altitude (feet)*	*Location*
Handies Peak	14,008	East of center of Silverton quadrangle.
Wetterhorn Peak	14,017	Southeastern part of Ouray quadrangle.
Sunshine Peak	14,018	Northwestern part of San Cristobal quadrangle.
Wilson Peak	14,026	West of center of Telluride quadrangle.
Unnamed peak near Mount Eolus	14,030	Near center of Needle Mountains quadrangle.
Stewart Peak	14,032	Southwestern part of Cochetopa quadrangle.
Redcloud Peak	14,050	Northwestern part of San Cristobal quadrangle.
Sunlight Peak	14,053	Near center of Needle Mountains quadrangle.
Mount Eolus	14,079	Do.
Windom Mountain	14,084	Do.
Sneffels Peak	14,143	Near south border of Montrose quadrangle.
San Luis Peak	14,149	Northwestern part of Creede quadrangle.
Mount Wilson	14,250	West of center of Telluride quadrangle.
Uncompahgre Peak	14,306	Southwestern part of Uncompahgre quadrangle.

Hundreds of peaks and ridges, some of them 6 or 7 miles long, rise about 13,000 feet. Timberline is at about 11,500 to 12,000 feet, and many long, broad, relatively flat stretches, covered with grass or low alpine vegetation, lie above timberline. About 5 percent of the whole region is above 12,000 feet. The highest mountains are in the western part. High peaks and ridges, in large part above timberline, are also present north of the Rio Grande, and are fewer to the south, chiefly about the head of the Conejos River.

Notwithstanding the high altitude, the range of altitude within the region is not as great as might at first be expected. The difference between the lowest and the highest points in the region is a little more than 9,000 feet. In general, the main mountain mass begins at an altitude of 8,000 feet. In few places is the climb from the main valleys to the crest of the highest peak more than 5,000 feet, but it is nearly 5,000 feet in many places.

VALLEYS

The San Luis Valley is the only large valley in the region and it lies chiefly east of the mapped area. This valley is about 80 miles long in a north-south direction and averages about 30 miles in width. It is nearly flat but has some hills that rise as much as 2,000 feet above the floor of the valley in its southern part. The Rio Grande flows into the valley from the San Juan Mountains on the west, follows the valley west and south in a shallow trench, and near the Colorado-New Mexico line it plunges into a sharp canyon. The old floor of the valley continues for many miles southward into New Mexico on both sides of the canyon of the Rio Grande. Northward, the flat valley ends with a rounded border east of Saguache, and San Luis Creek flows in a narrower strip of low hills that extend to Poncha Pass where its valley is abruptly truncated by the canyon of the Arkansas River. On the east, the San Luis Valley gives place abruptly at a steep fault scarp to the Sangre de Cristo Range. On the west the volcanic rocks of the San Juan Mountains rise gradually above the floor of the valley. The valley is underlain by a thick deposit of sands and gravels and all except a few of the large streams sink into these beds before reaching the Rio Grande.

Small valleys parallel many of the streams, but few of them are more than 1 or 2 miles in width. Mesas are common in the sedimentary area below the high mountains in the southern and western parts of the region. They are few and small in the high mountains and where present are commonly underlain by lava flows of basaltic or hard layers of rhyolitic rock. Except for the few valleys and mesas nearly all of the region is occupied by rough, rugged mountians.

CLIMATE

The following description is taken largely from Sherier (1925). The climate varies with the altitude and exposure, but the country is nearly everywhere so high that the summers are short and relatively cool and the winters long and severe. The climate of the lower lands is well illustrated by that of San Luis Valley, which has an altitude of a little over 7,500 feet and is rather arid, the average annual precipitation being only abut 7 inches in the main valley and 8½ inches at Saguache. The precipitation is greatest in the summer. July and August have frequent thunder storms and are the wettest months. June is commonly dry. The snowfall is light. The summer temperatures are moderate, the average for July and August being a little over 60°. Temperatures as high as 100° F. have been recorded, but the altitude is so great and the air so dry that it is comfortable in the shade even on the hottest day. The nights are always cool. The average temperature in January is from 13° to 20°, but temperatures as low as −34° have been recorded. At the higher altitudes the summer temperatures are below average, but the winter temperatures may not be. The lowest temperatures are in mountain valleys or parks where the air drainage is poor. The highest night temperatures during cold spells occur at places where the wind is strong, usually below the larger canyons. The sky is nearly always clear, and the sunshine is much brighter than at lower altitudes. Extremes of temperature are therefore less trying, because it is nearly always cool in the shade, and the sun is unusually warming. The summers are short, though longer in the lower parts of the region than in the higher parts. Frosts are not uncommon in June and September, and they have been recorded for every month of the year. The summer period without frost ranges from 48 to 178 days.

Owing to the influence of the mountains, weather conditions are much more uniform from day to day than in most other places. Severe cold waves are comparatively rare.

The winds are usually light and blow toward the mountains in the afternoon. After sunset the wind subsides, but toward morning a light breeze blows from the mountains. At the summits of the mountains the prevailing winds are from the west and are frequently very strong.

Along the southern and western slopes of the mountains the precipitation is somewhat higher than elsewhere. It averages about 20 inches at Durango. In the mountains the precipitation is higher, reaching 40 inches or more, and more uniformly distributed throughout the year. The snowfall averages 250 inches at Cumbres, in the southwestern part of the Conejos quadrangle, at an altitude of 10,011 feet, and snowfalls as great as 40 feet have been recorded in other parts of the mountains. In the higher mountains the winter snows remain in patches well into July, and in a few protected places snow banks may remain throughout the year. Severe thunderstorms occur nearly every day throughout most of July and August. After the first real snowstorm they cease, and a month or more of clear weather without precipitation may be expected. The roads in many of the high passes are not open much before July 1, and they may be blocked again by snow before the end of September.

TIMBER AND VEGETATION

The vegetation varies with the altitude. In the lower, drier parts there are no trees, but only grass, herbaceous plants, sagebrush, and other low shrubs. On the western border of San Luis Valley a like flora prevails up to an altitude a little above 8,000 feet, but the growth varies greatly with the soil, exposure, and other factors. On the southern slopes scattered pines grow among the sagebrush at a much lower altitude. In some places piñon and cedar grow at lower altitudes than the pines.

The timber continues up to an altitude of about 12,000 feet. On some southern lower slopes pine is the only tree, but on the mountains as a whole spruce is the chief tree and it forms great forests. Fir is less abundant. Dense growths of aspen cover the slopes where the spruce has been removed by forest fires or otherwise. Scrub oak forms almost impenetrable thickets in places, chiefly on the lower, southern slopes. Near timberline the spruce is small and much deformed by the wind, and within a short distance it ceases. Above this the slopes are covered with grass, flowers, and low shrubs of alpine types. Willow is probably the chief shrub.

Wild flowers are present in great variety, with the alpine types at high altitudes and more familiar types on the slower slopes. Above timberline the alpine flora forms a delicate carpet of the greatest beauty. On the lower slopes, in any place where the timber is not too dense, the profusion of flowers gives to fields and hills solid masses of color. The dainty blue Colorado columbine (*Aquilegia caerulea*), the State flower, is one of the most attractive though not the most common. Great fields of blue larkspur are common on the southern and northwestern slopes below the timber. Paintbrush, monkshood, lupine, and many other flowers grow in the greatest profusion.

POPULATION AND INDUSTRIES

The population of the San Juan region is about 58,000. It is distributed chiefly in the valleys near the borders of the mountains and in the mining towns. In the mountain valleys are scattered ranches. A few prospectors live among the mountains, and in the summer the cattle and sheep herders and the forest rangers travel nearly everywhere. The summer population is greatly increased by tourists who come from the hot lowlands to enjoy the beauty and coolness of the mountains.

The chief industries of the region are farming and stock raising, together with mining and lumbering. Care for the increasing number of tourists is becoming an important item.

Sheep are raised in great numbers, commonly from 1,000 to 3,000 to a herd. The usual practice is to graze them in the higher mountains, in part above timberline, during a few months in the summer, but they must be out before the first heavy snow and taken to the lower countries for the winter. Great numbers of cattle also graze in the mountains during the summer, chiefly on the lower slopes. For many months in the winter they must be fed in the valleys.

Hay for the stock is probably the largest agricultural product, but many other crops are raised. Fruit is grown in the low valleys near Durango and Montrose. San Luis Valley is too high for the growing of fruit, but many carloads of potatoes, summer lettuce, peas, cauliflower, and other cool-weather vegetables are shipped from the valley each year.

The chief mining products are coal, lead, zinc, silver, gold, copper, fluorite, bentonite, and building stone.

Spruce timber is cut throughout the mountains, chiefly for local use or for railroad ties. Pine was formerly sawed in large mills near Pagosa Springs.

RAILROADS, ROADS, AND TRAILS

A single standard-gage railroad enters the region from the east—the Denver & Rio Grande Western Railroad, from Denver, Pueblo, and Alamosa to Creede, near the center of the region. A standard-gage railroad barely enters the area from the north at Montrose. A group of narrow-gage railroads, all belonging to the Denver & Rio Grande Western system, formerly encircled the region.

Good automobile roads cross the mountains in many places. In some places where 20 years ago a difficult saddle trail was the only means of travel there is now a fine automobile road. All these roads lead through picturesque country, and many of them follow impressive canyons and cross high divides where they afford many attractive views. The road from South Fork, on the Rio Grande, over Wolf Creek Pass, more than 10,800 feet above sea level, to Pagosa Springs takes the traveler over high mountains and along deep canyons. That from Durango to Silverton and Ouray is equally picturesque and crosses the divide at an altitude of more than 11,000 feet. The road from Lake City to Creede crosses the divide at the head of Slumgullion Gulch at an altitude above 11,300 feet and two other divides at nearly 11,000 feet.

Besides the main roads there are roads to ranches, mines, or sawmills in many places. Yet much of the country is inaccessible to the automobile, and one who is not familiar with handling an automoblie in rough country had best stick to the main roads or to roads of which he has reliable information.

The higher mountains and rougher country are in national forests, and the Forest Service has built excellent trails nearly everywhere, so that by horse the area is rather accessible. In spite of the ruggedness of the mountains and the timber, an experienced mountaineer with a horse trained in mountain work can ride over much of the country without a trail.

CONTEMPORARY WORK

Most of the published reports dealing with the geology of the volcanic rocks of the San Juan Mountains have described small areas around mining camps. In such studies the volcanic rocks are separated into much smaller units than those used in this report and the mapping is much more detailed. However, it is not possible to recognize the broader features of the volcanism from the study of small areas. Reports on the Bonanza and the Platoro-Summitville districts have been made for the Colorado Geological Survey by Patton (1916, 1917). Burbank studied the Telluride and Silverton areas (1933, 1941), the Ouray district (1930, 1940) and the Bonanza District (1932) for the United States Geological Survey. Emmons and Larsen (1923) have described the Creede District.

As outgrowths of the San Juan studies, many papers have appeared. Some of the longer papers are:

1. Hunter's (1925) description of the pre-Cambrian rocks of the Gunnison Canyon.
2. Larsen's (1942) description of the alkalic rocks of Iron Hill.
3. The description of the minerals of the lavas of the San Juan Mountains by Larsen, Irving, Gonyer, and Larsen (1936, 1937, 1938).
4. The descriptive geology of the Lake City area by Cross (1911).
5. A preliminary report on the area by Cross and Larsen (1935).

Seven folios of the Geological Survey Atlas of the United States describing the area have been published.

The most important recent publications on the stratigraphy of the area are a paper by Baker and Reeside (1929) on the Permian, one by Baker, Dane and Reeside (1936) on the Jurassic, and another by Reeside (1924) on the Upper Cretaceous and the Tertiary. Knowlton (1923, 1924) has given a detailed description of the flora from different collections made by the authors of this report from the San Juan volcanic rocks, thus establishing the age of the volcanic rocks.

PLAN OF THE REPORT

The main subject of this report is the igneous rocks of the San Juan Mountains. The largest areas of pre-Cambrian and sedimentary rocks are in the western and southern part of the area. The largest bodies of such rocks in the western part of the mountains are either in or near areas that have been described in the published reports.

The San Juan tuff and the Silverton volcanic series are best exposed in the western part of the area and, because they have been already described, they will be described only briefly in this report.

Throughout this report, in order to reduce its length and to avoid tedious detail, much material that would be required on a report in a small area has been omitted. Nevertheless, in order to furnish some detail to the few who might be especially interested in a particular area or a particular problem, much detail that will have little interest to the general reader has been included.

FIELD WORK

At the time most of the field work was done there were roads near the towns and up the main valleys but much of the area was many miles from a road. A large part of the area is in National Forests and the Forest Service maintains many good trails; not many parts of the area were more than a few miles from such trails.

In recent years the old roads have been much improved and many new roads have been constructed. Some of these traverse beautiful rugged mountains and cross high divides. Even now, some parts of the area are many miles from a road.

We camped in the mountains in places convenient to our work. Beautiful campsites were common, excellent water was abundant in nearly all parts, and wood could be found nearly everywhere below timberline. Feed for stock was excellent in most parts of the mountains and most of the time our stock kept in fine condition with no feed other than the grass they could find near camp. We moved camp by a pack train of mules. So far as possible we worked from horseback and it is remarkable how large a part of these rugged mountains can be traversed, without trail, by a good horse that is trained to mountain work. Of course, much work had to be done on foot, as the local relief is commonly several thousand feet.

Topographic maps were used as bases for mapping except in the Cochetopa and Saguache quadrangles. Location was established by pace-and-compass traverses wherever possible. But in the rugged areas it was established largely by the use of barometer to check elevation with reference to drainage. A barometer works well if used with discretion and checked frequently with points of known altitude. A pocket level is helpful. In places the contacts were traversed, especially those of the pre-Cambrian and intrusive rocks, because such contacts are commonly very irregular. In many places where cliffs make it impossible to traverse the contacts, the contacts were crossed at places rather closely spaced and the contacts sketched in between. Commonly, this can be done satisfactorily, as most of the contacts can be seen in the cliffs for some distance, and they can be located from the topography or by leveling with a pocket level along the cliffs or across a canyon.

Many thousands of specimens were collected in the course of the work and several thousand thin sections were prepared. In the volcanic formations, where the thickness and sequence of rocks change rapidly, many of our collections represent systematic sections from good cliff exposures of a formation, and such systematic collections and sections are very useful. Some specimens were collected less systematically and were found to be of little value.

For so large a study as this one, it is highly desirable that the geologists hold frequent conferences while in the field and discuss the problems that have recently arisen in the work, the conclusions that seem to be justified, and the hypotheses that seem to be worthy of further consideration as the field work progresses. Concise, complete records should be made of these and of the distribution and character of the rocks, the relations among the various rocks, the structure, and other features. At such a time it would be well to study and compare megascopically the specimens that have been collected and to discard many of the duplicates.

ROCK CLASSIFICATION

For classifying the rocks, the system of Johannsen has been followed. To make the fine-grained rocks strictly comparable to the granular rocks, all the available data have been used—such as texture, chemical analyses, and in some rocks X-ray data—to interpret the composition. Thus, if a granular rock is called a granodiorite, a lava flow from the same magma would be a quartz latite. In doing this, many rocks that were originally called andesites or even basalts are called quartz latites, as the available evidence shows that the rocks must have both a silica mineral and orthoclase. From a study of rocks that are coarse enough to analyze with the microscope, it is found that most rocks of the type found in the San Juan area will have about the same amount, or somewhat more, quartz than is shown in the norm. They will have orthoclase or microcline if the norm shows more than 10 percent of orthoclase.

QUANTITATIVE MINERAL DETERMINATIONS

For all of the rocks analyzed since 1909 careful determinations of the amounts of each kind of phenocrysts have been made and the probable error of these determinations is believed to be ± 1 percent. To attain so high a degree of accuracy great care must be taken, because some of the phenocrysts in many of the rocks occupy areas as great or greater than 25 square millimeters. Rosiwal determinations made for such rocks, using ordinary thin sections, may be in error by several percent. Large thin sections with an area of at least 500 sq mm were used in this work, and for many of the rocks two or more such sections were used. For many of the rocks a further check was made by separating the minerals by an electromagnet and heavy liquids and carefully estimating with the microscope the small amounts of contaminating minerals in each fraction. For most lavas the groundmass is strongly magnetic and can be separated from the phenocrysts with an electromagnet. A few of the rocks are seriate porphyritic and for these it is not possible to estimate accurately the amount of the phenocrysts. However, for most of the rocks the phenocrysts and groundmass are rather sharply distinct.

COMPOSITION OF THE GROUNDMASS

A careful study of the phenocrysts of the lavas of the San Juan area, including many chemical analyses, has been made (Larsen, Irving, Gonyer, and Larsen, 1936, 1937, 1938). By use of these data and the mineral analyses, the compositions of the groundmasses of the analyzed rocks have been calculated. The chemical compositions of the groundmasses are believed to be only a little less accurate than are those of the rocks themselves. The groundmasses fall nearly as close to the curves of the variation diagrams as do the rocks. For several rocks the original analyses did not fit the variation curves, and the calculated groundmass did not fit the curves in about the same way. Corrected analyses fit the curves, and the groundmass calculated with the new analyses also fit the curves.

VARIATION DIAGRAMS AND CHEMICAL ANALYSES

Variation diagrams (Larsen, 1938) made in the early part of this study have most of the points very near smooth variation curves. A point was considered satisfactory if it fell within 0.4 percent of the curve for most of the oxides and a little farther from the curve for SiO_2 and Al_2O_3. Alumina is especially erratic. If, for a rock, one of the oxides does not fit its curve, many of the other oxides are likely not to fit their curves. All of the rocks that were erratic were carefully examined to determine whether alteration or some unusual feature would account for the erratic composition. Where no reason for the erratic composition was found and where material was available, a new sample was prepared and a new analysis made by F. A. Gonyer. A new sample was used, because the erratic character of the analysis may have been due to improper sampling. Thirteen new analyses were made and, as the alkalies were the most erratic oxides, 8 additional determinations of the alkalies were also made. The duplicate analyses of these 13 rocks, together with duplicate analyses of 2 other lavas of the San Juan area, are given in table 2. Column 14 gives for each oxide the average difference between the duplicate analyses for that oxide. Table 3 gives the additional 8 duplicate determinations of the alkalies and, in column 9, the average difference between the duplicate analyses for the 16 rocks for which duplicate alkali determinations were made.

It should be emphasized that the difference between the duplicate analyses and the original analyses is in part due to sampling and that it is greater than the average for check analyses, because duplicate analyses were made only where there was reason to doubt the accuracy of the original analysis.

In tables 2 and 3 Gonyer is low in all but one CaO determination and in most of the TiO_2, H_2O, and K_2O determinations; he is high in most of the Fe_2O_3 determinations. The average difference between the duplicate analyses for Fe_2O_3+FeO is 0.48.

When the 60 analyses of rocks from the Potosi volcanic series are plotted on a variation diagram, about 20 percent of the points for SiO_2 and Al_2O_3 fall off the curves by 1 percent or more; about 25 percent of the points for FeO, 20 percent of those for MgO, K_2O, and Na_2O, and 10 percent of those for CaO fall off the curves by more than 0.4 percent. About half of the erratic points represent altered rocks or tuffs. One rock that falls very far from the curves is a welded tuff, with abundant tridymite as a cement. If 30 percent of SiO_2 is deducted from the analyses and the corrected analyses are calculated to 100 percent, the rock fits the diagram very well. A few of the fresh, typical rocks (for one — DN. 68 — a duplicate analysis is available) fall far from the variation curves. The variation curves show that most of the rocks of a restricted petrographic province fall on or near smooth variation curves but that a few of the rocks do not. The groundmasses fall about as near the curves as do the rocks.

ROCK FORMATIONS AND THEIR RELATIONS

The rock formations and the chief geologic events of the area are arranged, like a columnar section, from youngest to oldest so far as is known, and are briefly characterized in the following pages.

CENOZOIC

QUATERNARY

Alluvium. Landslides, rock streams, glacial deposits, sands, and gravels. They are of small extent except in the San Luis Valley. Slight to moderate thickness.

Latite and basalt. Local flows and associated pyroclastic material, found only in the central part of the Conejos and southwestern part of the Summitville quadrangle. Thickness, 50 feet.

Elevation of the area more than 3,000 feet to a dome or warped plateau. The slopes were relatively steep near the borders of the dome and undulating in the main part. Elevation took place throughout the early Pleistocene and was nearly complete at the time of the last glaciation. Erosion accompanied and followed the elevation to form the present mountains.

TERTIARY

Pliocene (?)

Hinsdale formation. Spread over the San Juan peneplain.

- Basalt and latite. Basalt formed a plateau many miles across in the southern part of the area. Low domes, chiefly of latite, formed in the mountains. Common thickness, 200 feet.
- San Antonio Peak volcanic domes. Several volcanic domes of cristobalite latite rise above the plateau of basalt of the Hinsdale formation in New Mexico, southeast of Antonito. Maximum height, 2,000 feet.
- Rhyolite. In the San Cristobal and Uncompahgre quadrangles rhyolite is a welded tuff with conspicuous phenocrysts of smoky quartz and glassy sanidine (moonstone variety). In the Summitville and Del Norte quadrangles it is made up of flows, breccias, tuff, and small volcanic cones of felsitic rhyolite and is, in places, interlayered with the basalt. Thickness, as much as 500 feet.

TABLE 2.—*Comparison of duplicate analyses* (b) *with original analyses* (a) *of rocks from the lavas of the San Juan area*

	1 Sa. 483		2 DN. 68		3 SC. 2585		4 Con. 16		5 Sv. 9		6 DN. 311		7 SC. 2889	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
SiO_2	60.67	60.34	54.84	54.40	66.39	66.57	55.21	55.55	55.86	56.28	59.95	60.25	52.09	50.82
TiO_2	.80	.86	1.40	1.16	.50	.50	1.45	1.40	1.66	1.26	1.38	.94	1.47	1.63
Al_2O_3	17.50	17.44	18.28	18.74	15.45	15.58	15.72	14.89	13.71	15.76	14.62	16.26	21.35	19.06
Fe_2O_3	3.86	4.13	3.98	4.58	2.50	2.43	4.56	4.28	5.55	5.62	5.30	5.31	2.26	3.84
FeO	.95	.77	2.97	2.53	1.13	1.38	4.58	4.22	3.67	3.09	1.28	1.77	5.82	6.18
MnO	-----	.06	.08	.05	.06	-----	.06	.12	-----	.08	-----	.11	.18	.07
MgO	1.79	1.78	2.55	2.58	.85	1.03	4.17	3.90	4.26	3.86	2.76	2.18	2.57	3.49
CaO	4.05	4.02	7.24	7.22	3.71	3.40	6.67	6.35	6.34	6.04	5.35	5.28	8.17	8.32
Na_2O	4.45	4.35	4.10	3.59	3.65	3.61	3.88	4.35	3.40	3.12	4.06	4.07	3.28	3.51
K_2O	4.19	3.81	3.38	2.89	4.59	4.74	3.31	3.36	2.94	2.76	3.52	3.23	1.81	1.79
H_2O-	1.09	}1.70	.99	}1.35	.56	.61	.13	.72	.99	}1.48	1.13	}.95	.53	}.86
H_2O+	.43		.41		.66	.49	.61	.42	.60		.55		.57	
CO_2	-----	-----	-----	-----	-----	-----	.00	-----	-----	-----	-----	.21	-----	-----
P_2O_5	.38	.34	.49	.54	.36	.20	.00	.98	.82	.27	.45	.09	.61	.09
Trace oxides	-----	-----	-----	-----	.15	-----	.04	.14	-----	-----	-----	-----	.10	-----
Total	100.16	99.60	100.71	99.63	100.56	100.54	100.39	100.68	99.80	99.62	100.35	100.65	100.81	99.66

	8 Lag. 1221		9 Lag. 1120		10 C. 299		11 Con. 532		12 U. 3027		13 SC. 1471		14 Average difference
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	
SiO_2	64.27	64.82	61.80	61.58	70.93	71.55	64.28	63.95	72.94	73.14	56.40	56.11	0.41
TiO_2	.48	.46	1.00	.75	.30	.26	.90	.72	.25	.22	1.31	1.02	.17
Al_2O_3	17.89	17.62	16.13	16.54	15.87	15.14	17.16	17.21	13.06	13.96	16.17	16.84	.79
Fe_2O_3	2.38	2.81	6.40	6.95	.85	1.36	3.84	3.70	.72	1.44	4.19	4.56	.43
FeO	.58	.42	.32	.72	.33	.36	.52	.56	1.45	.14	4.30	3.83	.36
MnO	.07	.04	-----	.07	-----	.09	-----	.07	-----	None	.12	.09	-----
MgO	.57	.65	1.32	.86	.08	.16	.55	.12	.21	.15	3.55	3.30	.29
CaO	2.82	2.38	4.08	3.80	1.28	.80	1.85	1.71	1.08	.64	7.07	6.62	.26
Na_2O	4.32	4.42	3.50	3.81	4.21	4.17	3.94	4.36	3.70	3.35	1.22	3.42	.24
K_2O	4.67	5.08	3.82	3.36	5.32	4.79	5.38	4.92	6.15	5.48	2.79	2.22	.37
H_2O-	.46	}.77	.89	1.24	1.19	.82	1.05	2.03	.69	1.56	.47	.99	}.29
H_2O+	.75		.79	-----	.15	-----	1.03	-----	.39	-----	.51	-----	
CO_2	.15	-----	-----	.14	-----	None	-----	-----	-----	None	-----	.13	-----
P_2O_5	.10	.11	.32	.24	tr.	.12	.20	.23	.05	.09	.29	.30	.22
Trace oxides	.36	-----	-----	.09	-----	.13	-----	.17	-----	.11	-----	.17	-----
Total	99.87	99.58	100.27	100.15	100.51	100.75	100.70	99.75	100.69	100.28	98.39	99.63	

1. Sa. 483. Sheep Mountain quartz latite: *a* by J. G. Fairchild, 1925; *b* by F. A. Gonyer, 1942.
2. DN. 68. Conejos quartz latite: *a* by J. G. Fairchild, 1923; *b* by F. A. Gonyer, 1942.
3. SC. 2585. Alboroto quartz latite, mouth of Texas Creek: *a* by W. T. Schaller, 1915; *b* by J. G. Fairchild, 1924.
4. Con. 16. Hinsdale formation (basalt and latite), Green Mountain: *a* by Glen V. Brown, 1920; *b* by George Steiger, 1919.
5. Sv. 9. Sheep Mountain quartz latite: *a* by R. K. Bailey, 1923; *b* by F. A. Gonyer, 1942.
6. DN. 311. Sheep Mountain quartz latite, canyon of Carnero Creek: *a* by R. K. Bailey, 1923; *b* by F. A. Gonyer, 1943.
7. SC. 2889. Conejos quartz latite, Trout Creek: *a* by W. T. Schaller, 1915; *b* by F. A. Gonyer, 1943.
8. Lag. 1221. Piedra rhyolite, Farmers Creek: *a* by George Steiger, 1925; *b* by F. A. Gonyer, 1943.
9. Lag. 1120. Conejos quartz latite, Creede quadrangle: *a* by J. G. Fairchild; *b* by F. A. Gonyer, 1944.
10. C. 299. Sheep Mountain quartz latite, Cochetopa quadrangle: *a* by J. G. Fairchild, 1925; *b* by F. A. Gonyer, 1945.
11. Con. 532. Conejos quartz latite, Conejos quadrangle: *a* by J. G. Fairchild, 1923; *b* by F. A. Gonyer, 1944.
12. U. 3027. Alboroto rhyolite, east of Pine Creek, Uncompahgre quadrangle: *a* by J. G. Fairchild, 1927; *b* by F. A. Gonyer, 1945.
13. SC. 1471. Sheep Mountain quartz latite, Carson Pass, San Cristobal quadrangle: *a* by J. G. Fairchild, 1926; *b* by F. A. Gonyer, 1945.
14. Average difference between the duplicate analyses.

TABLE 3.—*Comparison of duplicate analyses* (b) *of alkalies with original analyses* (a)

	1 Lag. 1540		2 PRC. 164		3 NM. 707		4 Lag. 1027		5 Con. 320		6 Con. 262		7 SV. 514		8 SC. 1315		9 (See notes)	10 (See notes)
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*		
Na_2O	3.32	3.78	2.82	3.12	2.42	2.76	2.40	3.69	2.76	3.30	4.02	3.69	3.24	3.10	3.41	3.33	0.31	}0.48
K_2O	2.50	2.00	4.65	5.49	4.04	3.47	3.68	3.80	4.26	3.76	2.64	2.64	6.58	6.00	4.39	3.44	0.38	

1. Lag. 1540. Fisher quartz latite: *a* by J. G. Fairchild, 1923; *b* by F. A. Gonyer, 1942.
2. PRC. 164. Alboroto rhyolite near Del Norte: *a* by L. G. Eakins; *b* by F. A. Gonyer, 1942.
3. NM. 707. Welded tuff of Treasure Mountain rhyolite, New Mexico: *a* by J. G. Fairchild, 1923; *b* by F. A. Gonyer, 1942.
4. Lag. 1027. Fisher quartz latite: *a* by R. K. Bailey, 1923; *b* by F. A. Gonyer, 1942.
5. Con. 320. Conejos quartz latite, Bennett Peak: *a* by J. G. Fairchild, 1923; *b* by F. A. Gonyer, 1942.
6. Con. 262. Conejos quartz latite: *a* by R. K. Bailey, 1923; *b* by F. A. Gonyer, 1942.
7. SV. 514. Treasure Mountain rhyolite, Sheep Mountain: *a* by J. G. Fairchild, 1923; *b* by F. A. Gonyer, 1942.
8. SC. 1315. Fisher quartz latite: *a* by Chase Palmer, 1913; *b* by F. A. Gonyer, 1942.
9. Average difference between duplicate analyses for 21 determinations of Na_2O and of K_2O, from tables 2 and 3.
10. Average difference between duplicate analyses for 21 determinations of total alkalies, from tables 2 and 3.

San Juan peneplain. Depression of the main mountain mass by about 4,000 feet. The southeastern part of the area remained nearly stationary.

Pliocene(?) and Miocene

Los Pinos gravel. A local volcano and the surrounding outwash and pyroclastic beds present in the Conejos quadrangle and to the east and south. The rocks resemble those of the Fisher quartz latite. It is probable that the Los Pinos is Fisher in age, but the upper part may be of Hinsdale age.

Miocene

Fisher quartz latite. Spread over a surface characterized by deep canyons are several volcanoes that erupted quartz latites characterized by larger phenocrysts than those of the common rocks of the area. Maximum thickness, 1,000+ feet.

Erosion.

Creede formation. Local lake deposits near Creede, well-bedded tuff, with remains of plants and insects, gravel, talus, and some flows of rhyolite. Upper Miocene.

Erosion. Canyons were developed as deep as the present canyons.

Potosi volcanic series:

Piedra rhyolite. A rather regular succession of lava flows and tuff beds containing local lenses of dark quartz latite. The common succession from top to bottom is:

1. Flows as much as 200 feet thick and associated tuff beds of a latitic rhyolite characterized by phenocrysts of plagioclase, biotite, augite, hornblende, and, in some rocks, quartz and sanidine. Maximum thickness, 400 feet.
2. White tuffs with some associate flows. Maximum thickness, 800 feet.
3. Local lenses of dark quartz latite. Maximum thickness, 500 feet.
4. One or more flows of tridymite rhyolite. Forms a cliff and bench. Maximum thickness, 500 feet.
5. Rhyolite. Chiefly very thick flows of cavernous rhyolite, some beds of tuff, and dark quartz latite. Very irregular in thickness because it was deposited in canyon topography. Thickness in central part, 2,500 feet.

Erosion to canyons several thousand feet deep.

Huerto quartz latite. Two low volcanic domes, for the most part in the San Cristobal quadrangle. The larger center was near Huerta Peak and was about 40 miles across. It is made up predominantly of dark pyroxene-quartz latites near basalts with some hornblende rocks in its northeastern part. Thickness in central part, 2,500 feet. The smaller is east of Lake San Cristobal and contains more light-colored rocks. Thickness in central part, 2,200 feet.

Alboroto rhyolite. The largest rhyolite formation of the Potosi volcanic series. Latitic rhyolite is in very thick flows and tuff bed with very little bedding. Rock uniformly contains phenocrysts of plagioclase, sanidine, quartz, biotite, hornblende, and sphene. Common thickness, 2,000 to 3,000 feet.

Rhyolite with few phenocrysts. Regular thin flows and tuffs. In part tridymite rhyolite, in part cavernous rhyolite. Found only near northern and eastern border of dome. Maximum height of local domes, 2,000+ feet. Thickness, chiefly less than 500 feet.

Erosion to canyon 3,000 feet deep.

Sheep Mountain quartz latite. Erupted from at least four centers:

1. A volcanic cone, 12 miles across, near Carson in the San Cristobal quadrangle. Made up chiefly of breccia with some flows and intrusive rocks. Rock is chiefly dark quartz latite with pyroxene, some rocks have hornblende and some are rhyolites. Maximum thickness, 2,000 feet.
2. A low cone in the Summitville quadrangle, 6 miles across. Made up of quartz latite, near basalt, with tabular feldspar and pyroxene. Thickness, 600 feet.
3. Bodies in the Del Norte quadrangles. Chiefly hornblende-quartz latites, with large phenocrysts. Thickness, 400 feet.
4. In the Saguache quadrangle. A flow of biotite rhyolite at the top, below is dark pyroxene quartz latite, and at base light-colored quartz latites. Total thickness, about 1,000 feet.

Treasure Mountain rhyolite. Alternating flows and tuff beds of rhyolite. A characteristic rock is a latitic rhyolite, with phenocrysts of plagioclase, biotite, and augite. Contains some layers, mostly less than 100 feet thick, of dark quartz latites. Present in three domes. The thicknesses in the central part of the domes are:

1. Dome in Conejos quadrangle, 1,500 feet.
2. Dome in San Cristobal quadrangle, 1,200 feet.
3. Dome in Saguache quadrangle, 300 feet.

Erosion to canyon topography.

Conejos quartz latite. This is the largest subdivision of the Potosi volcanic series and the body is 120 miles across. It is made up of flows and breccia beds in the central part of the mass and grades to sandy or gravelly tuff toward the margins. Erupted from several vents and contains several volcanic necks. The rocks are chiefly dark quartz latites, with phenocrysts of plagioclase and pyroxene and lighter colored hornblende-quartz latites. It has several local bodies of rhyolite. Thickness, in the central part, 3,000 feet.

Erosion to mountain topography nearer to maturity than the canyon topography developed later in the time of the Potosi volcanic series.

In the eastern part of the mountains:

Latite of the San Luis Hills. Several flows of dark basaltic rocks that form prominent mesas.

Tracy Creek quartz latite. A fine-grained quartz latite. Its relation to the latite of the San Luis Hills is unknown.

Erosion.

Beidell quartz latite and quartz latite of the San Luis Hills. Flows and breccia of porphyritic quartz latite.

Stocks of syenite, monzonite, and diorite in the San Luis Hills.

In the western part of the mountains:

Subsidence of several thousand feet.

Silverton volcanic series. Found only in the western part of the mountains overlain by the Potosi volcanic series but its relation to pre-Potosi rocks of the eastern part of the mountains is not known.

Henson tuff. A fine-grained, well-bedded, nonfossiliferous tuff made up of fragments of quartz latite. Greatest development in the southwestern part of the Uncompahgre quadrangle. Thickness, 100 feet.

Pyroxene-quartz latite. A group of dark rocks with tabular feldspar and pyroxene, chiefly in flows. Resembles a common rock in the Potosi. Maximum thickness, 1,000+ feet.

Erosion.

Burns quartz latite. Fine-grained, dark green tuff, breccia, and flows of quartz latite, containing lenses of impure limestones. Scanty remains of leaves and shells in the calcareous layers. Thickness, 1,200 feet.

Erosion.

Eureka rhyolite. Flows, dikes, and well-bedded tuff. The rocks are characterized by many small fragments of rhyolite of various textures and of andesitic rocks. Thickness, 1,800 feet.

Erosion in the Silverton quadrangle. The rhyolites are interlayered with the Picayune quartz latite in the San Cristobal quadrangle.

Picayune quartz latite. Flows, tuffs, breccias, and agglomerates of a quartz latite of intermediate silica content. Some rhyolite of the Eureka type. Thickness, 1,800 feet.

Erosion.

San Juan tuff. Poorly bedded tuff, for the most part reworked by water. Fragments are chiefly of quartz latite of intermediate composition. In the northern part of the mass the fragments are predominantly of one kind of rock, a light-colored, vesicular, hornblende-quartz latite, with a glassy groundmass. They probably represent pyroclastic eruptions from a vent nearby. To the south, a greater variety of fragments is present. Few rocks from the underlying Lake Fork quartz latite are represented. Thickness, 3,000 feet.

Lake Fork quartz latite. A local volcanic pile of flows, brecciated flows, intrusive bodies, breccias, and tuffs. Contains a variety of rocks, chiefly quartz latites and a few rhyolites, and some rocks near basalt. Underlies an area of about 200 square miles. Maximum thickness of the remnant of this volcano is about 3,000 feet.

Erosion (?) but not appreciable deformation.

Oligocene(?)

Blanco Basin formation. Nearly white sandstone and pink and green sandy shales. Rare fragments of bones. No fragments of volcanic rocks. Relation to Telluride conglomerate is not known. As thick as 600 feet.

Telluride conglomerate. Predominantly coarse conglomerate containing pebbles and boulders of schist, granite, quartzite, limestone, and other rocks derived from the Paleozoic sediments. Local bodies of sandy limestone. It increases in thickness from east to west, and in the western exposures it contains abundant beds of sandstone and shale. No fossils and no pebbles of unmetamorphosed volcanic rocks. As thick as 1,000 feet.

Deformation and erosion, to a rather smooth surface with mountains of the resistant rocks.

Eocene

Wasatch formation. Massive, persistent gray to brown, resistant conglomeratic sandstone, interbedded with variegated shale; red shale abundant. In the extreme northern rim of the San Juan Basin variegated shale chiefly, with beds of coarse arkose that contain an abundance of pink feldspar. Fluviatile. As thick as 1,400 feet.

Paleocene

Torrejon formation. Lenticular gray to brown conglomeratic resistant sandstone interbedded with red and gray shale; underlain by gray and greenish-gray shale and soft white to yellow conglomeratic sandstone. Fluviatile. As thick as 1,450 feet.

Unconformity.

Ridgway till. Near Ridgway, an upper till derived from the east and separated by erosion from a lower till derived from the northeast. Contains fragments of volcanic rocks.

Paleocene and Upper Cretaceous

Animas formation. At base, coarse beds with weathered and waterworn andesitic debris and pebbles and siliceous rocks. Rest of formation shale and sandstone, with much andesitic debris and occasional beds of fine conglomerate. Whole formation pistachio-green to tan, with very rare reddish layers. Fluviatile. As thick as 2,700 feet.

Erosion after some deformation.

MESOZOIC

CRETACEOUS

Upper Cretaceous

McDermott formation. In the north, andesitic tuff and tuffaceous sandstone and shale, mostly purple with a small amount of conglomerate of pebbles of siliceous rocks. The proportion of purely volcanic material decreases southward. As thick as 400 feet. Volcanism must have occurred during the McDermott time and probably continued into Animas time. The only remnants of this volcanism are the intrusive bodies near Ouray and possibly some intrusive bodies in the western part of the area.

Local unconformity.

Kirtland shale. Light-gray to blue-gray shale, with some black carbonaceous and brown shale and soft white sandstone. Fluviatile. As thick as 475 feet.

Farmington sandstone member; gray to brown indurated sandstone lenses separated by gray shales. Fluviatile. As thick as 500 feet.

Fruitland formation. Gray sandy shale, gray-white, crossbedded, soft sandstone, brown indurated sandstone, carbonaceous shale, and coal. Of fresh- and brackish-water origin. Thickness, 75 to 450 feet.

Pictured Cliffs sandstone. Buff to light-yellow and gray sandstone, interbedded in the lower part with thin gray shale. Marine. Thickness, 100 to 400 feet.

Lewis shale. Greenish-gray and dark-gray sandy shale, with a few lenses of brown sandy limestone and buff concretions. Marine. Thickness, 1,600 to 2,000 feet.

Mesaverde group:

Cliff House sandstone. Yellow to red-brown sandstone, with some sandy shale. Some beds massive. Cliff-forming. Marine. Thickness, 90 to 400 feet.

Menefee formation. Gray shale, with some sandstone and coal. Coal beds grouped near top and base of formation; barren interval between. Rocks of fresh- and brackish-water origin, with only a few marine beds. Thickness, 270 to 340 feet.

Point Lookout sandstone. Massive buff or cream-colored to red-brown sandstone. Marine. Thickness, 60 to 300 feet.

Mancos shale. Dark-gray and drab sandy shales with a sandstone lentil 35 feet thick 735 feet above base. Contains thin, discontinuous, fossiliferous limestone layers. Marine. Thickness, 1,200 to 2,000 feet.

Dakota sandstone. Gray or rusty-brown quartzose sandstone with shale lenses and coal. Variable conglomerate of small chert pebbles at base. Forms cliffs and mesas. Thickness, 100 to 500 feet.

JURASSIC

Morrison formation. The base is commonly a thin layer of thin-bedded limestone, in part brecciated. Over that is a bed of nearly white, crossbedded but well-bedded sugary sandstone. The main part is alternating, thin, friable fine-grained yellowish or gray sandstones and variegated shales and some thin limestones. The shales are mostly green, but some are pink, dark red, or chocolate brown. Nonmarine. Thickness, 150 to 1,000 feet.

Entrada sandstone. A massive, friable, crossbedded pinkish to white quartzose sandstone. Forms cliffs. Probably terrestrial. Thickness, 0 to 200 feet.

Profound deformation, followed by erosion to a very flat surface. No angular unconformity in the western part of the area.

Dolores formation. The upper part is very fine, even-grained, poorly bedded sandstone and bright-red shale. The lower part consists of reddish sandstone, somewhat shaly, with thin beds and lenses of fossiliferous conglomerate, made up chiefly of small limestone pellets and fragments. Terrestrial. Thickness, 0 to 2,000 feet.

Unconformity, only locally angular.

PALEOZOIC

PERMIAN (?)

Cutler formation. Bright-red sandstone, lighter red or pinkish grits and conglomerates, alternating with sandy shales and earthy or sandy limestone; nonfossiliferous. Thickness, 1,500 feet.

Rico formation. Dark reddish-brown sandstones and pink grits, with intercalated greenish or reddish shales and sandy fossiliferous limestone. Thickness, 300 feet.

Disconformity.

PERMIAN AND CARBONIFEROUS

Maroon formation. In the northeast area. Micaceous sandstone, arkose, shale, and gray fossiliferous limestone. Chiefly sandstone and shale in the upper part; conglomerate in the middle part; and reddish shale in the lower part. Top not exposed. Thickness, 3,400+ feet.

CARBONIFEROUS

PENNSYLVANIAN

Kerber formation. In the northeast area. Alternating black shale and coarse-grained to pebbly sandstone, generally crossbedded. Low-grade coal seams. Thickness, 200 feet.

Hermosa formation. Limestones, grits, sandstones, and shales of variable distribution and development. Limestone, in thick, massive beds, predominates in the middle and upper parts of the section; the lower part is mainly sandstones and shales, with a few limestone layers. Many invertebrate fossils occur in the shales and limestones. Thickness, 2,000 feet.

Disconformity.

Molas formation. Shale, red and calcareous, containing many fossiliferous nodules of chert and saccharoidal limestone; becomes more sandy and shaly upward; different strata cannot be distinguished. Rests on a weathered and broken surface of the uppermost Leadville limestone. Thickness, 75 feet.

Disconformity.

MISSISSIPPIAN

Leadville limestone. In the western area a small, uncertain amount of the upper part of the limestone beds mapped as Ouray limestone. In the northeastern area mainly unevenly thick-bedded, blue-gray limestone. Thickness, 350 to 400 feet.

DEVONIAN

Upper Devonian

Ouray limestone:

1. Limestones, similar to the second of the Leadville limestones, without cherts; 20 feet thick.
2. Limestones, thin-bedded, dense, bluish-gray; certain layers extremely fossiliferous; 25 feet thick.
3. Quartzite and sandy limestones; no fossils; 4 feet thick.
4. Sandy limestones containing many crinoid stems and a few cup corals; 25 feet thick.

Chaffee formation. In the northeastern area (equivalent of Ouray limestone).

1. Limestone, dark-gray to grayish-white, fine-grained, commonly thin and evenly bedded, weathers yellowish or brownish. Thickness, 90 to 100 feet.
2. Sandstone, fine to coarse, white, associated with variegated argillaceous sandstone, shale, and impure limestone. Thickness, 10 to 50 feet.

Elbert formation:

1. Clay shale, fine, red, not forming distinct outcrops. Thickness, 10 feet.
2. Limestone, dense, gray, conchoidal fracture in several beds, variable in development and absent in places; not fossiliferous. Thickness, 0 to 35 feet.
3. Sandstone or quartzite, variable in character; extremely fossiliferous in places. Thickness, 1 foot.
4. Limestones or calcareous shales, thin, containing pseudomorphs of salt crystals. Thickness, 30 feet.
5. Limestones, dense, gray with thin shale partings; in lower part fish scales have been found locally; form ledges. Thickness, 30 feet.
6. Limestones, sandy and impure, with thin fossiliferous quartzites and shale layers; red and yellow. Thickness, 25 feet.

Disconformity.

ORDOVICIAN

Fremont limestone. Limestone, lower part gray, dolomitic, becoming less dolomitic and finer toward top. Brownish chert in upper part. Thickness, 300 feet.

Harding sandstone. Quartzite, gray, bedded. Thickness, 60 to 90 feet.

Manitou dolomite. Limestone, thin-bedded, gray, dolomitic, with beds and lenses of gray to white chert. Found only in the northeastern area where it directly overlies the pre-Cambrian. Thickness, 90 to 200 feet.

CAMBRIAN

Upper Cambrian

Ignacio quartzite:

1. Quartzite, massive, fine-grained, in beds 2 to 5 feet thick. Total thickness, 25 feet.
2. Quartzite, thin-bedded, fine-grained, in places with reddish shaly parting or sandy layers. Thickness, 20 feet.
3. Quartzite, conglomerate, fine-grained, in places giving way to red crumbling shales and sandstones, resting unconformably on pre-Paleozoic rocks. Thickness, 5 to 50+ feet.

Great unconformity.

PRE-CAMBRIAN (?)

Dikes of different ages. Diabase, lamprophyre, granite porphyry, olivine gabbro, augite syenite, shonkinite, pegmatite, and aplite.

Complex of Iron Hill. Includes, from youngest to oldest:

1. Dikes of theralite.
2. Dikes and larger bodies of syenite.
3. Dikes and larger bodies of nepheline syenite.
4. Ijolite, coarse.
5. Pyroxenite, chiefly diopside and biotite.
6. Uncompahgrite, a coarse melilite rock.
7. Limestone, probably hydrothermal.

Granodiorite of Needle Mountains. Coarse gray rock with hornblende, biotite, and some augite. Intrudes Eolus granite.

Gabbro of Engineer Mountain. Contains augite and hypersthene. Intrudes Eolus granite.

Trimble granite of Needle Mountains. Moderately fine-grained biotite granite. Intrudes Eolus granite.

Leucogranite of Florida River area. Pink biotite granite. Intrudes Eolus granite.

Batholith of Pine River area. Intrudes Uncompahgre formation and Tenmile granite.

Porphyritite leucogranite. Intrudes Eolus granite.

Eolus granite. Coarse pink biotite-hornblende granite. Intrudes granodiorite.

Granodiorite. Dark hornblende rock.

Syenite of Ute Creek. Coarse syenite with some quartz. mildly metamorphosed.

Leucogranite of Rio Grande. Pinkish biotite granite mildly matamorphosed.

Whitehead granite of Needle Mountains. Rather coarse pink biotite granite.

Tenmile granite of Needle Mountains. Coarse pink biotite granite. Many sills and dikes parallel to the contact intrude the bordering schists. Intrudes Eolus granite.

Twilight granite of Needle Mountains. Medium-grained and distinctly gneissoid. Intimately injects and carries many inclusions of schist. Intrudes Uncompahgre formation.

Granite of Lake Fork of Gunnison River: Pink or gray biotite granite rich in soda. Mildly metamorphosed.

Needle Mountains group:

Uncompahgre formation. Chiefly quartzite in thick beds and with several horizons of interbedded schists, derived from shales. Thickness, 5,500+ feet.

Vallecito conglomerate. A quartzite conglomerate with well-rounded pebbles and boulders of vein quartz, quartzite, and hornblende schist. In the upper part it has some pebbles of jasper, hematite, and magnetite. Thickness, 3,000+ feet.

Irving greenstone:

Includes both intrusive and extrusive rocks. Chiefly dark quartz latite. Metamorphism has largely recrystallized some parts but much of it still retains some of its original minerals and textures. Amphibole, epidote, and chlorite are the chief metamorphic minerals.

Metagabbro south of Powderhorn in the Uncompahgre quadrangle. Dark-green rock made up of hornblende, epidote, and sodic feldspar.

Gneissoid granite:

Highly metamorphosed granites found in the Conejos River, the Cochetopa and Saguache quadrangles, and elsewhere.

Dubois greenstone of Uncompahgre quadrangle:

Hornblende gneiss, chlorite schist, amphibolic schist, amphibolite.

River Portal mica schist (Gunnison Canyon):

Finer textured, less fissile, less metamorphosed, and younger than Black Canyon schist. Some parts are of sedimentary origin. Mica schists, quartz mica schists.

Black Canyon schist (Gunnison Canyon):

In part of sedimentary origin.

Amphibolite schists. Probably from a quartz diorite intruded into other rocks after they were partly metamorphosed.

Quartz-muscovite schists.

Biotite schists.

Mica schists.

Ancient schists and gneisses:

Highly metamorphosed and injected and range from mica schist to amphibolite. In part derived from sediments and in part from igneous rocks. Most of these schists are of unknown origin.

PRE-CAMBRIAN ROCKS

DISTRIBUTION

Pre-Cambrian rocks are widely distributed in the San Juan Mountains but have small areal extent. Most of the outcrops are in the extreme northern part and in the southwestern part. A few small outcrops in the extreme southeastern part are outliers of much larger bodies to the south in New Mexico.

The largest mass of pre-Cambrian rocks cropping out in the area included on the map of the San Juan Mountains is in the extreme northern part. It is largely in the drainage basin of the Gunnison River and will be called the Gunnison mass. It extends from the northeastern part of the Montrose quadrangle, eastward across the northern parts of the Uncompahgre, Cochetopa, and Saguache quadrangles for a distance of more than 80 miles. To the northwest it forms the Black Canyon of the Gunnison River, extending 20 miles beyond the limits of the map. To the east it continues for many miles beyond the mapped area and connects with the great masses of the Sangre de Cristo ranges. To the north it connects with the great masses in the Elk and Sawatch ranges. On the map it is separated into two areas by the overlying Mesozoic sedimentary rock near Doylesville.

Pre-Cambrian rocks probably directly underlie the volcanic rocks in much of the area for some distance south of the outcrops, for abundant pebbles of pre-Cambrian rocks were found in the lowest exposed beds of the volcanic breccias west of Razor Creek, in Slone Gulch, Lost Gulch, and South Pass creeks. Moreover, small bodies of pre-Cambrian rocks crop out from under the volcanic rocks in the following places south of the main mass:

1. In Alder Creek northeast of Bonanza in the eastern part of the Saguache quadrangle.
2. In Squirrel Creek, a few miles north of Bonanza.
3. Several bodies on both sides of Lower Kerber Creek southeast of Bonanza.

4. In Finley Gulch, a few miles northwest of Saguache.
5. North of the Saguache River and above the mouth of Finley Gulch.
6. North of Saguache River and near the mouth of Poison Gulch.
7. In the east fork of Ford Creek, south of the center of the Saguache quadrangle.
8. West of Middle Creek, just west of the center of the Saguache quadrangle.
9. In the drainage areas of Cross and Jacks Creeks; three separate bodies.
10. North of Saguache Creek and east of Antelope Creek; a very small outcrop of granite and Morrison formation overlain by volcanic rocks.
11. Northeast of the center of the Cochetopa quadrangle, north of Razor Creek and a few miles southeast of Razor Creek Dome.

The body in the southwestern part of the mountains is chiefly in the Needle Mountains and will be referred to as the Needle Mountains mass. The actual outcrops in this area may be nearly as large as those of the mapped part of the Gunnison mass, but they are less than 30 miles across, are confined to the San Juan Mountains mapped area, and show few outliers. The mass is rudely circular and is bordered on the east by volcanic rocks and in other directions by Paleozoic sedimentary rocks. It represents a huge dome from which the younger rocks have been removed. Small outliers are mapped to the east and south in the Weminuche and Piedra Canyons and to the northeast in the head of the Rio Grande.

Other much smaller outcrops of pre-Cambrian rocks are mapped:

1. In the northwestern part of the San Cristobal quadrangle in the Lake Fork valley of the Gunnison River.
2. In the northern part of the Silverton and southern part of the Ouray quadrangles in the Uncompahgre Canyon.
3. In the northeastern part of the Rico quadrangle near Rico.
4. In the extreme northeastern part of the Telluride quadrangle.
5. In the southern part of the Conejos quadrangle in the Conejos River valley.

GENERAL CHARACTER AND SUBDIVISIONS

On the small-scale geologic map of the San Juan Mountains (pl. 1) the pre-Cambrian has been subdivided as follows: ancient (?) schists and gneisses; Irving greenstone; Needle Mountains group; granitic rocks.

In the published folios, in Hunter's report (1925) on the Gunnison River area, the rocks have been further subdivided. The ancient schists and gneisses form the greater part of both the large pre-Cambrian bodies and some of the smaller bodies. These rocks are all so highly metamorphosed and injected by igneous material and so prominently schistose or gnessoid that all traces of the original rock have been obliterated. The only clue to their origin is the chemical composition. They range from mica schists or granitic gneiss to amphibolites and may have been derived from rocks ranging from granite to diabase or gabbro. Some have a high silica content and may have been derived from arkosic sandstones. They probably represent a complex of intrusive rocks, possibly with some sediments and volcanic rocks. They include, no doubt, rocks of very different ages.

In the eastern part of the Needle Mountains mass, partly overlying and partly intruding the schists and gneisses, there is a group of less metamorphosed volcanic rocks, the Irving greenstone. They are now amphibolites retaining only occasional relicts of their original texture and character. The original rocks ranged from quartz latite to basalt, granodiorite, or gabbro.

Overlying the Irving greenstone and the older schists there is a great thickness of metasedimentary rocks, the Needle Mountains group. The lower part, called Vallecito, is chiefly conglomerate. A thick layer of interbedded quartzites and schists, the Uncompahgre formation, overlies the Vallecito conglomerate. The Needle Mountains group is best exposed in the Needle Mountains mass but it forms much of the pre-Cambrian to the west and north; similar quartzites have been found in New Mexico, south of the Conejos quadrangle.

Granitic rocks were intruded repeatedly in pre-Cambrian time and such intrusions were both the earliest and latest recorded events. These rocks differ considerably in character and represent a number of periods of intrusions; some are gneissoid, some show no metamorphism. The granitic masses range in size from very small bodies to those 20 miles or more across. No body of granitic rock comparable to the great masses of the Sierra Nevada of California and elsewhere is present and with one exception the bodies are only a few miles across. The masses in the Gunnison River drainage basin are all small.

The chief rock is a granite, in part rich in soda, but the one large batholith is chiefly a granite (near a granodiorite). In general, granodiorite is not abundant. Diorite, gabbro, syenite, shonkinite, and other rocks are represented. Many subdivisions, however, have been mapped in detail (pl. 1) and even the granites differ in texture, composition, degree of metamorphism, and age.

The following descriptions have been taken largely from the published folios and from Hunter's report.

ANCIENT SCHISTS AND GNEISSES

Schists and gneisses are widely distributed in the San Juan Mountains and are present in most places where any large body of pre-Cambrian rocks are exposed. These rocks are highly metamorphosed and, wherever their relations to other pre-Cambrian rocks can be determined, they are older. They are very ancient rocks. They are a complex of bodies of widely different ages, compositions, origins, and degrees of metamorphism. Some probably derived from sediments but most were clearly derived from granitic to gabbroic igneous rocks.

THE NEEDLE MOUNTAINS AREA

DISTRIBUTION

The largest exposed body of these intensely metamorphosed rocks (with the exception of the mass in the drainage area of the Gunnison River) extends from the north-central part of the Ignacio quadrangle, north across the southeastern part of the Engineer Mountain quadrangle, then northeast across the Needle Mountains quadrangle and for a few miles into the Silverton quadrangle. It then extends to the north and as a wedge down the Rio Grande, and for a few miles east into the San Cristobal quadrangle. This mass is rudely wedge-shaped. It narrows to the south and comes to a point in the Ignacio quadrangle but widens in the Needle Mountains quadrangle and, in its northern part, is 12 miles across. It is broken in the northern part of the Needle Mountains quadrangle by a strip of quartzite of the Uncompahgre formation and to the south of this is divided into two arms by a body of the Tenmile granite. The schist mass is nearly 30 miles in its maximum dimension (northeast-southwest). The following description is taken in part from the Needle Mountains and Silverton folios.

DESCRIPTION

The complex varies in petrographic detail from place to place, but it possesses no clearly marked divisions which it is practical or desirable to recognize as cartographic units. Although certain zones are lighter or darker in color than others, the schists as a rule are a uniform gray, but the tricks of weathering may cause them to have a distinctly banded appearance, even when seen from a distance. This banding is due to alternations of nearly black amphibolites with rocks richer in quartz and the feldspars, the various bands being only a few feet or yards in thickness.

The general character of the complex is made still more varied by the presence of granite bodies which have intruded the schists and which have sent out irregular arms and dikes, in some places coinciding with the direction of schistosity, elsewhere crosscutting. [In addition there are a few dikes of olivine diabase.]

When examined in detail the schists show great diversity both in composition and texture. The commonest variety is a moderately fine-grained, well-laminated rock of a dark-gray color which on weathered surfaces assumes a lighter shade of reddish brown. Quartz and feldspar can be distinguished in fine grains and with them is hornblende or a dark mica. [Bands of such rock may be found at almost any point in the schist area, but in a number of places this type predominates.] Distinct from these schists are rocks which are coarse-textured and irregularly foliated rather than banded. They are as a rule very light gray in color and contain greater amounts of quartz and the feldspars in proportion to the dark minerals than do the finer-grained schists which have been described. [They are believed to represent granitic rocks whose original structure has been largely destroyed by compression and mashing and are distinct from the later intrusive and slightly metamorphosed granitic rocks.]

Nearly black amphiboles are very common in the schist complex of the Needle Mountains and Silverton quadrangles but are uncommon in the San Cristobal quadrangle. They have a fine fibrous or banded texture and are made up largely of prisms of hornblende, with some biotite, feldspar, quartz, and accessory minerals. They are believed to represent mashed basic intrusive rocks, the origin of which is clear for some of the similar bodies in the adjacent areas. The principal types are biotite schists, gneisses, and hornblende schists.

BIOTITE SCHISTS

The biotite schists are compact, fine-grained, well-laminated rocks with alternating dark and light bands which combine to give a generally dark greenish-gray color to the whole. The microscope shows that they consist of quartz and feldspar in about equal proportion, with less biotite. Green hornblende and muscovite are commonly present, as are accessory apatite, magnetite, and sphene. In some specimens the feldspar is almost entirely sodic plagioclase, and in others microcline equals or exceeds the plagioclase in amount. It is not possible to determine the original character of these rocks with any certainty; they may well have been either sedimentary or igneous.

GNEISS

The gneisses are lighter in color and coarser in texture than are the biotite schists. They differ greatly in the degree of banding but are never as well banded as are the schists. Microscopically they are made up chiefly of quartz and feldspar, with considerable biotite and accessory apatite, magnetite, sphene, and zircon. Horneblende, epidote, and muscovite are rather abundant in some specimens. In some the feldspar is largely microcline; in others plagioclase equals or exceeds the microcline in amount. The rocks were probably derived from the metamorphism of granites and granodiorites.

HORNBLENDE SCHISTS

Hornblende schists are less abundant than biotite schists. They are nearly black and commonly have a fine-fibrous texture. Less often they are banded or massive. They are made up very largely of hornblende and contain considerable quartz, orthoclase, and plagioclase, some biotite, and accessory magnetite, sphene, and apatite. These rocks represent metamorphosed diorites, dikes of diabase, and related rocks. In tbe southern part of the mass, in the Ignacio quadrangle, the rocks are less metamorphosed quartz diorites.

In the Animas Canyon in the Durango quadrangle the dark schists are less metamorphosed. They are now mostly amphibole and plagioclase but some still retain relicts of the original augite, indicating that the rocks were derived from diorites. The amphibolite is interlayered with granite gneiss representing metamorphosed granite that intruded the amphibolite. Some of the dark amphibole-rich parts may have been derived from gabbro.

Garnet in irregular grains as much as an inch across is an abundant and conspicuous constituent of a few bands in the hornblende schists east of the Molas mine in the Silverton quadrangle. In part it is altered to chlorite and crumbles when removed from the rock. Garnet was also found in bands in the amphibolite in the canyon about 2 miles north of Needleton. It is rare as an accessory constituent of the amphibolite in other places.

WEMINUCHE CREEK

A small outcrop of quartz monzonite gneiss is exposed north of Weminuche Creek about 5 miles north of the south boundary of the San Cristobal quadrangle. It is not so greatly metamorphosed as the schist to the west.

RICO QUADRANGLE

Near the northeastern corner of the Rico quadrangle just north of the town of Rico, is a very small outcrop of dense, bluish-gray schist containing biotite and amphibole. Intruding the schists, generally parallel to the structure but locally crosscutting, are many thin dikes of porphyritic rock which are much crushed and metamorphosed. They do not cut the quartzite of the Uncompahgre formation. They carry hornblende and epidote and subordinate feldspar, chiefly plagioclase.

THE GUNNISON RIVER REGION

LOCATION AND SUBDIVISION

The large mass of pre-Cambrian rocks in the Gunnison River region is formed mostly of ancient schists and gneisses intruded by various granitic rocks. Hunter (1925) has mapped this pre-Cambrian area in detail for the Montrose and Uncompahgre quadrangles and has subdivided the schists and gneisses into nine mapped units. In much of the Cochetopa and Saguache quadrangles the schists and gneisses have not been separated from the younger intrusive rocks and the pre-Cambrian is mapped as a single unit.

The following description of the schists and gneisses is taken largely from Hunter's report, supplemented by data from the areas to the east. For more detailed descriptions the reader is referred to Hunter's report.

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 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

The Black Canyon schist makes up by far the greater part of the schists and gneisses and most of the pre-Cambrian rocks of the area. On his map Hunter divided this schist into four mapped units: amphibole schists, quartz muscovite schists, biotite schists, and mica schists, including granite, gneiss, quartz-rich rocks, and other rocks.

The best and most accessible exposures of the schists are in the walls of the Black Canyon from Sapinero to Curecanti Needle and in Lake Fork Canyon. The exposures in Cebolla Canyon are less accessible. Hunter (1925, p. 11–12) says:

> 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
>
> * * * * *
>
> 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.

BIOTITE SCHIST

The biotite schists occupy at least half of the exposed pre-Cambrian area of the region and "* * * the other rocks of the group occur as relatively narrow and more or less indefinite bodies." The rocks are gray to black and have a conspicuous schistosity. They consist chiefly of quartz and feldspar in nearly equal but variable amounts. Microcline and either albite or oligoclase are both present and either may predominate; biotite is the chief mica but muscovite is common. Hornblende is rare. Magnetite is the commonest accessory mineral, and apatite, sphene, and garnet are usually present. Zircon is rare; calcite, sericite, epidote, and zoisite are present locally. The grains mostly range from 0.05 to 1 mm across. The mineral composition and texture of the rocks indicate that they are metamorphosed granites or quartz monzonites. Locally these schists grade into granite gneiss with less conspicuous banding and less mica.

QUARTZ-MUSCOVITE SCHIST

The quartz-muscovite schists form a zone about half a mile wide and 5 miles long, separating the mica schists from the Dubois greenstone. There are several small isolated bodies within the greenstone, and the wedge-shaped area mapped as chlorite schist half a mile southwest of Spencer contains zones of this schist.

These schists are fissile and some are almost slaty. Their grain size ranges from submicroscopic to 0.5 mm. Quartz is commonly the most abundant constituent and forms as much as 50 percent of the rock. Plagioclase, microcline, and muscovite are also abundant; biotite is less common. Colorless to pale green chlorite is in variable amount, and magnetite, apatite, zircon, and rarely tourmaline are accessories. Sericite, epidote, and calcite are secondary. This schist is rich in silica and is believed to have been derived from a granite porphyry or similar rock.

AMPHIBOLE SCHIST

The only mapped mass of amphibole schist is chiefly in the drainage of Cebolla Creek below the mouth of Wolf Creek. Rocks of this character are scattered through the schists, mostly as small layers paralleling the foliation of the schist. The mapped strip is a few miles long and a fraction of a mile wide. The rocks are dark and range from metadiorites to amphibolites.

The grain sizes of schists differ greatly but are commonly 0.5 to 1 mm. The chief minerals are hornblende and feldspar and the proportion of hornblende ranges from 25 to 90 percent. Rarely quartz is one of the chief minerals. The plagioclase is chiefly andesine, less often oligoclase; and microcline and microperthite are present in small amount. Biotite in small plates is present in about half the rocks. Augite is very rare. Chlorite, sericite, epidote, calcite, and iron ores are secondary minerals after hornblende and feldspar. Apatite, magnetite, sphene, rutile, and zircon are accessory.

The rocks were derived from the metamorphism of a variety of rocks that intruded the schists, largely parallel to the foliation of the schist. These rocks were closely akin to quartz diorite. They were probably intruded after the schists had undergone most but not all of their metamorphism.

Local small bodies of dark rock much like the amphibolites in composition, but massive and less metamorphosed and made up largely of amphibole, were found on the north slope of Stumpy Creek, on the point of the ridge south of Crystal Creek, and elsewhere. They were derived from rocks related to gabbro or pyroxenite.

RIVER PORTAL MICA SCHIST

Hunter gave the name River Portal mica schist to a broad band of schists of the Black Canyon of the Gunnison River for several miles on both sides of the portal of the Gunnison Tunnel. He subdivided them into the quartz-mica schist of Mesa Creek and mica schist.

The River Portal mica schist is well exposed. For 12 miles it forms the walls of the wildest and most picturesque part of the Black Canyon in the northeastern part of the Montrose Canyon and for about 8 miles to the northwest.

Outcrops of these schists are much like outcrops of the Black Canyon schist though in places the prominent jointing gives picturesque spirelike forms in the canyon. Exposures are somber, gray, or drab. Close examination shows that these schists have a much finer texture and as a rule are less fissile than is the Black Canyon schist. The mica is also in smaller grains and is relatively obscure. The quartz-mica schist that forms the extreme eastern part of the River Portal mica schist is well laminated and closely resembles the biotite schists of the River Portal schist but is much richer in quartz.

These schists are intruded by the granitic rocks and they are so greatly metamorphosed as to destroy completely their original character; yet they are not so much metamorphosed as the Black Canyon schist and were believed by Hunter to be somewhat younger than the latter.

MICA SCHIST

A widespread type of the River Portal mica schist resembles the quartz-mica schist of the Black Canyon schist near Spencer. In the hand specimen it suggests a graywacke. The microscope shows it to be very fine grained and having a tendency toward a porphyroblastic texture. The grains range mostly from 0.05 to 0.5 mm in length. Quartz is the chief mineral. Albite exceeds microcline in abundance. Biotite and muscovite are both present in variable amounts and biotite usually exceeds muscovite. Chlorite is present in some specimens and hornblende is very rare. Garnet, apatite, sphene, epidote, zoisite, zircon, and magnetite are the commonest accessory minerals. Sericite is common and tourmaline is rare.

A chemical analysis by George Steiger of the U. S. Geological Survey of a typical specimen of this schist from three-fourths of a mile south of Nyswanger Spring, just north of the Montrose quadrangle, is given below. The composition is that of a granite or rhyolite. Small vaguely outlined patches of the mica schist are lighter-colored and contain more quartz, locally as much as 60 or 80 per cent.

SiO_2	71.06	TiO_2	0.60
Al_2O_3	13.23	ZrO_2	.02
Fe_2O_3	1.17	P_2O_5	.16
FeO	3.57	S	.02
MgO	.95	MnO	.13
CaO	1.48	BaO	None
Na_2O	3.98	SiO	None
K_2O	2.74	Li_2O	None
H_2O-	.32		
H_2O+	1.16	Total	100.59

QUARTZ-MICA SCHIST OF MESA CREEK

Along the east border of the mica schists described above and grading into them is a zone of quartz mica schist about 1.5 miles wide. This rock is coarser grained than the mica schist, and the typical rock contains from 50 to 75 percent of quartz. Muscovite is more abundant than biotite. East of the mouth of Cimarron Creek and on the slopes north of Mesa Creek are bands of quartzose schists containing large flakes of sillimanite. These schists may well have been derived from sedimentary rock.

DUBOIS GREENSTONE

The Dubois greenstone of Hunter is present chiefly in the Uncompahgre quadrangle east of Lake Fork and near the center (north-south) of the quadrangle. It extends for a short distance east into the Cochetopa quadrangle. It crops out as an east-west strip ranging from 1 to 4 miles in width and is about 18 miles long. It contains many large and small bodies of schist and intruded granitic rocks. It is bounded on the north chiefly by Black Canyon schist, on the south by intrusive granitic rocks, and to the west and east it passes under younger volcanic rocks and probably pinches out.

The Dubois greenstone, unlike most of the pre-Cambrian formations of the Gunnison area, chiefly underlies the rolling upland country and crops out mostly as irregular cliffs and bluffs. Only in the Lake Fork and Cebolla Creeks does it form important canyons.

Mineralized quartz veins are more abundant in the Dubois greenstone than in any of the other pre-Cambrian rocks. The old mines at Dubois, Spencer, Midway, and Vulcan are chiefly in the greenstone.

Hunter divided this greenstone into hornblende gneiss, chlorite schist, and amphibole schist and amphibolite.

AMPHIBOLE SCHIST AND AMPHIBOLITE

Amphibole schists and amphibolites form nearly the whole of the mass of Dubois greenstone west of Goose Creek and they are the prevalent type throughout the mass, although there is more variation to the east. They are dark green to black, schistose rocks. Rarely have they a fibrous structure. They resemble the amphibolite schists that make up a part of the Black Canyon schist although most of them are finer and more homogenous in texture.

They are uniformly fine- and mostly even-grained, with individual grains averaging 0.1 to 0.2 mm long. Hornblende makes up most of the rocks. The felsic minerals, oligoclase or andesine, and quartz, rarely make up as much as half the rock and they range down to less than 10 percent of it. A little biotite is present and some of the more felsic rocks show chlorite. Magnetite, ilmenite, apatite, and sphene are the chief accessories. Epidote and clinozoisite are common and have been in part derived from feldspar.

Associated with the amphibolites are several small bodies of less metamorphosed mafic rocks. They are made up of about the same minerals as the other amphibolites but are richer in amphibole and were probably derived from rocks related to gabbro.

HORNBLENDE GNEISS

Hornblende gneiss was found in small bodies in various parts of the greenstone but the largest body lies just east of Cebolla Creek. It is about 2 miles long and 0.2 mile wide. These rocks are lighter in color and less schistose than the amphibolites and were probably derived from quartz diorite and quartz-diorite porphyry. The rocks are made up chiefly of quartz and plagioclase, with subordinate muscovite and varying amounts of hornblende. Biotite is present in more than half the rocks but it is nearly always subordinate to hornblende. The quartz is commonly in lenses that suggest drawn out phenocrysts. The plagioclase is commonly andesine, rarely ablite. Epidote, clinozoisite, sericite, magnetite, and apatite are present.

CHLORITE SCHIST

The chlorite schists are present in narrow zones parallel to the foliation of the schist. The largest body is east of Cebolla Creek and is about 3 miles long and half a mile wide. It contains much hornblende schist into which it grades. A second body occurs northeast of Vulcan. It contains an abundance of quartz-muscovite schist. These chlorite schists are well foliated. Chlorite is less conspicuous in the thin sections than in the hand specimens and it makes up from less than 10 to more than 50 percent of the rocks. Hornblende is common, quartz is always present and rarely makes up half the rock. Sodic plagioclase is in small amount; biotite in small scales is usually present; garnet, muscovite, epidote, magnetite, apatite, and sphene are in small amount.

COCHETOPA AND SAGUACHE QUADRANGLES

The extensive outcrops of pre-Cambrian rocks in the northern parts of the Cochetopa and Saguache quadrangles are parts of the great mass of rocks in the Gunnison River drainage basin. They are much like the rocks of the Uncompahgre quadrangle that have already been described. The rocks of the Uncompahgre quadrangle continue east with little interruption as far as Cochetopa Creek. Mica schist is the chief rock and it is intricately intruded by granite. Granitic rock is abundant in the drainage area of Beaver Creek, and in Cochetopa Creek it is common. The strip of Dubois greenstone continues, its width somewhat diminished, east of the Uncompahgre quadrangle for about 6 miles, where it goes under younger rocks. It does not reappear in the canyon of Cochetopa Creek.

Farther east, in the northwestern part of the Saguache quadrangle granite and granite gneiss, with subordinate schist, make up most of the pre-Cambrian. Still farther east, near Shawano Siding on the north side of Marshall Creek, there are hornblende-rich gneisses and schists cut by many pegmatitic and granitic intrusive rocks. Near Poncha Pass, schists are well exposed.

Farther south in the Saguache drainage, many small outcrops of pre-Cambrian rocks were found. These are chiefly of granitic rocks but some are schists. The small outcrop in Alder Creek, west of the head of the San Luis Valley, is made up of schist and gneisses. Those near Bonanza are hornblende-mica schist and mica schist intruded by coarse porphyritic granite, aplite, and pegmatite. The small outcrop just north of the road up the Saguache River and about a mile above Findley Gulch is of feldspathic gneisses and amphibolite cut by granite. The several small bodies a few miles to the west in the drainage of Cross and Jacks Creeks are of similar rocks and of mica schists.

CONEJOS AREA

Pre-Cambrian rocks have not been found in the Summitville, Creede, and Del Norte quadrangles. In the southern part of the Conejos quadrangle two small bodies of pre-Cambrian rocks crop out near the Conejos River. One of these, situated just below the River Springs ranger station, is a highly metamorphosed gneiss, and the other, a mile above the Elk Creek ranger station, is a coarse-grained gneissic granite.

Just south of the Conejos quadrangle, in New Mexico, mica schists and gneisses, intruded by pegmatite and granite form the canyon of Los Pinos Creek near Osier and Sublette. Their laminations strike about north-south and their dip is nearly vertical.

South, in New Mexico, pre-Cambrian rocks make up large areas, and schists and gneisses are abundant.

IRVING GREENSTONE

NAME AND DISTRIBUTION

The name Irving greenstone was proposed in the Needle Mountains folio (Cross and Howe, 1905a) for "* * * a complicated series of schists, greenstones and subordinate quartzites, a portion of which is prominently exposed in Irving Peak, in the southeastern part of that quadrangle." These rocks were derived largely from gabbro and diabase and from volcanic rock, chiefly andesitic, and are now more or less metamorphosed to amphibolites. A single body of these rocks is exposed in the southeastern part of the Needle Mountains quadrangle and southwestern part of the San Cristobal quadrangle and extends for a short distance into the Ignacio quadrangle. The mass measures about 8 miles in a north-south direction by 5 miles east-west. It is everywhere separated from the other pre-Cambrian rocks by faults and is overlain by the Cambrian. Its exact position in the section is therefore unknown but it is much less metamorphosed than the "Archean" gneisses and schists nearby and about as much as the schists of the Needle Mountains group. The folio says:

> The lower portions of the Vallecito conglomerate, however, are largely made up of greenstone pebbles and boulders, with many of quartzite and this is sufficient to prove the greater age of the Irving and indicates the former abundance of quartzite in it.
>
> No other rocks of similar character are known to occur in the San Juan Mountains, but similar schists have been found by Cross near Salida, in the Sangre de Cristo Range, concerning the occurrence and distribution of which there is very little information. Petrographically these rocks and those of the Irving formation appear to be practically identical.

The formation has been described by Howe (1904, p. 501–509).

GENERAL DESCRIPTION

The following description is taken from the Needle Mountains folio (Cross and Howe, 1905a, p. 2):

> The rocks which make up the Irving complex possess a great variety of textures, but a composition that is very uniform in the different groups. The majority may be broadly described as greenstones; some resemble massive granular rocks, others are porphyritic with a dense groundmass, while still others are finely liminated schists. Hornblende, chlorite, epidote, and rarely biotite can be recognized megascopically in nearly all, and usually these dark minerals appear to be in excess of the lighter silicates. What feldspar there is has evidently been much altered.
>
> The greenstones are dark greenish brown or black and give a somber tone to the hillsides and canyon walls where they are exposed. The most significant features of the rocks in different

parts of the complex are the variations in texture and structure, which are conspicuous in the field and still more so when the rocks are examined microscopically. These variations are due partly to original textural differences in the rocks themselves and partly to the dynamic metamorphism that has produced in some instances finely laminated schists, in which all traces of original structure have been obliterated, and in others breccias, in which the fragments have been welded together by pressure, with a rude schistosity, not well marked as a prevalent structure, but sufficient to modify the massive appearance.

With the greenstones are a few lighter colored rocks, generally much mashed, which seem to have been granitic intrusions; there are also more recent granite porphyries and pegmatites. "In the Needle Mountains quadrangle there are a few bands of extemely siliceous rocks which were formerly sandstones or quartzites." They have not been observed in the San Cristobal quadrangle.

PETROGRAPHY

The greater part of this complex consists of dark-colored rocks which vary greatly in the degree of metamorphism but were probably all derived from similar rocks. They may be classed together as greenstones. There are some dikelike or irregular bodies of lighter colored granitic rocks.

GREENSTONES

In the southeastern part of the area, especially at the head of Bennett Creek, much of the greenstones is only slightly banded and still shows the relicts of the large, tabular plagioclase crystals of the original rock. However, the minerals have been completely recrystallized and the original texture of the groundmass obliterated. The original plagioclase phenocrysts still extinguish as units under the microscope and are now of a sodic variety. They are filled with secondary inclusions of biotite and clinozoisite and were no doubt originally a calcic feldspar. The balance of the rock is a rather fine, uneven-textured mass of sodic plagioclase, biotite, sericite, and quartz, with more or less epidote, chlorite, opacite, and green hornblende. These rocks were probably derived from an andesite or dacite. Where metamorphism has been more intense they have completely lost their original texture and have become fine-grained schists.

In the northern part of the mass the rocks have been intensely metamorphosed and may have been derived from somewhat mafic rocks, such as diabase. They are completely recrystallized, well-banded schists, made up of variable amounts of sodic plagioclase, quartz, green hornblende, biotite, white mica, chlorite, epidote, zoisite, magnetite, pyrite, and accessory apatite and sphene.

GRANITIC ROCKS

Closely associated with the greenstones are rather abundant dikelike or irregular bodies of a granodiorite or granodiorite porphyry which it is impracticable to show separately on the map. The rock was originally rather uniform in its character but metamorphism has given rise to considerable diversity. In general it has resisted metamorphism somewhat more than the primary rock of the greenstones, and some of it to the west of Bennett Creek still shows much of the original textures and mineral composition. The better preserved rocks have abundant fairly well-formed crystals of andesine feldspar and some quartz in a rather fine-grained mass of quartz and orthoclase, with some plagioclase and secondary minerals. Recrystallization of the feldspars to mica and zoisite has begun and no trace of the original dark mineral remains. Secondary chlorite, biotite, zoisite, amphibole, and sericite are abundant, and accessory apatite, iron ore, zircon, and sphene are present. This rock was originally a granodiorite porphyry. More complete metamorphism gives rise to rather dark-green amphibolite schists which are with some difficulty distinguished from the greenstones. In general they show abundant large quartz grains and more light-colored minerals than the greenstones. This granodiorite porphyry was intruded into the greenstones before their metamorphism. In most places no parallelism between the elongation of the granodiorite bodies and the laminations of the schist was recognized, but west of Moon Lakes, a strip of the granodiorite seems to follow the laminations of the greenstones.

NEEDLE MOUNTAINS GROUP

NAME AND SUBDIVISIONS

The name Needle Mountains group was proposed in the Needle Mountains folio for the conformable series of pre-Cambrian conglomerates, quartzites, and interbedded schists that are extensively exposed in the Needle Mountains and in Uncompahgre Canyon in the northern part of the Silverton and adjoining parts of the Ouray quadrangles. The lower part of this group is a thick conglomerate that has been called the Vallecito conglomerate. The upper part is chiefly quartzite with interbedded schists and is called the Uncompahgre formation. In the small-scale map of the San Juan Mountains the Needle Mountains group has been mapped as a unit but on the maps of the published folios and on other large-scale quadrangle maps the group has been divided into units: schist and quartzite of the Uncompahgre formation, and Vallecito conglomerate.

DISTRIBUTION

The largest mass of the Needle Mountains group extends from the southwestern part of the San Cristobal quadrangle, near Emerald Lake, westward across the northern part of the Needle Mountains quadrangle and for a short distance into the Engineer Mountains quadrangle. This body extends for 20 miles in an east-west direction and is more than 8 miles wide in its eastern part, becoming much narrower to the west. It is everywhere separated from the older gneisses and Irving greenstone by faults and from the younger granitic rocks by faults or contacts with intrusive rocks, and it is in part overlain by younger sedimentary or volcanic rocks. This body is made up of the quartzites and interbedded schists of the Uncompahgre formation.

A few miles to the south in the extreme southwestern part of the San Cristobal quadrangle and in the adjoining parts of the Pagosa Springs, Ignacio, and Needle Mountains quadrangles there is an exposed mass of the Vallecito conglomerate that is about 7 to 8 square miles in area. It is separated from the other adjoining pre-Cambrian rocks by faults and is overlain by Paleozoic sediments. The type locality for this conglomerate is in the western part of this mass, in the drainage basin of Vallecito Creek. An apparent thickness of 3,000 feet is indicated west of the Lake Fork of Pine River. This and the small body northwest of it in the San Cristobal quadrangle are the only mapped masses of the Vallecito conglomerate.

In the northwestern part of the Pagosa Springs quadrangle, in the canyon of Piedra River are two small outcrops of the Uncompahgre formation—one just above the mouth of First Fork and the other near the mouth of Weminuche Creek.

In New Mexico, just south of the Conejos quadrangle, in the drainage of Tusas and Brazos Creeks, a pre-Cambrian quartzite that may belong to this group underlies considerable areas. This is about 75 miles east of southeast of the nearest outcrop in the Pagosa Springs quadrangle.

West of the great Needle Mountain mass, in the extreme northeastern part of the Rico quadrangle, in the drainage of Silver Creek, are two bodies of quartzite only a fraction of a mile across. They are bounded by faults.

In the extreme northeastern part of the Telluride quadrangle in the drainage of Canyon Creek there is a body of quartzite less than half a mile across. It is partly intruded by Tertiary gabbro and partly overlain by San Juan tuff. It carries an intercalated sheet of rhyolite.

The fairly large body of quartzites and schists from which the Uncompahgre formation received its name lies a few miles to the east, in the drainage of Uncompahgre Creek, partly in the Silverton and partly in the Ouray quadrangles. This mass is a little more than 3 miles in largest dimension. A small outcrop lies a few miles to the south, east of Ironton Park.

THICKNESS

Only an estimate of the minimum thickness of the Needle Mountains group can be made, as the base is nowhere exposed and the top is everywhere a surface of erosion. Moreover, the two members of the group are nowhere seen in contact and the beds have been intensely folded, metamorphosed, and faulted. The Vallecito conglomerate has an estimated exposed thickness of more than 3,000 feet west of Pine River, and neither the base nor top is exposed (figs. 3 and 4). The Uncompahgre formation was estimated to have an exposed thickness of 8,500 feet in Uncompahgre Canyon, with neither base nor top exposed. The total thickness of the formations is no doubt greater than these figures, and it is probably much greater.

VALLECITO CONGLOMERATE

The Vallecito conglomerate is best seen in the cliffs west of Pine River and Lake Fork of Pine River and in Vallecito Canyon. In Vallecito Creek in the neighborhood of the Quartz Mill the rock is a very compact conglomerate. The well-rounded, water-worn pebbles and boulders range from ½ inch in diameter to 12 inches in rare instances and are composed of vein quartz, purplish quartzite, and many varieties of schist, mostly dark amphibolites and rocks rich in chlorite, clearly derived from the Irving series of greenstones. A few granular fragments have also been observed. The cement is a fine-grained, dark-gray quartzose material, exceeding in quantity at some places the pebbles and boulders that it encloses.

Generally the rock has the appearance of having been compressed or sheared. Many of the pebbles are fractured and the cracks are filled with vein quartz; others are bent or welded into their neighbors, the cement looking as if it had flowed about the pebbles.

Higher up in the section the conglomeratic character becomes less pronounced. Coarse grits or finer-grained, cross-bedded sandstones and arkoses begin to appear and form an important part of the series but in no place, so far as observed, to the exclusion of the conglomerate beds. In the upper parts greenstone pebbles are much fewer, most of the materials being quartzites with a considerable amount of jasper, gray hematite, and magnetite (Cross and Howe, 1905a, p. 3).

In the San Cristobal quadrangle most of the fragments are of white sugary quartzite, some are of dark-gray quartzite, jasper, banded jasper, hematite, greenstone, and fine-textured red granite.

UNCOMPAHGRE FORMATION

The Uncompahgre formation is made up of alternating quartzites and metamorphosed shales. The quartzite layers are relatively thick but the schist members are much thinner, though some are hundreds of feet in

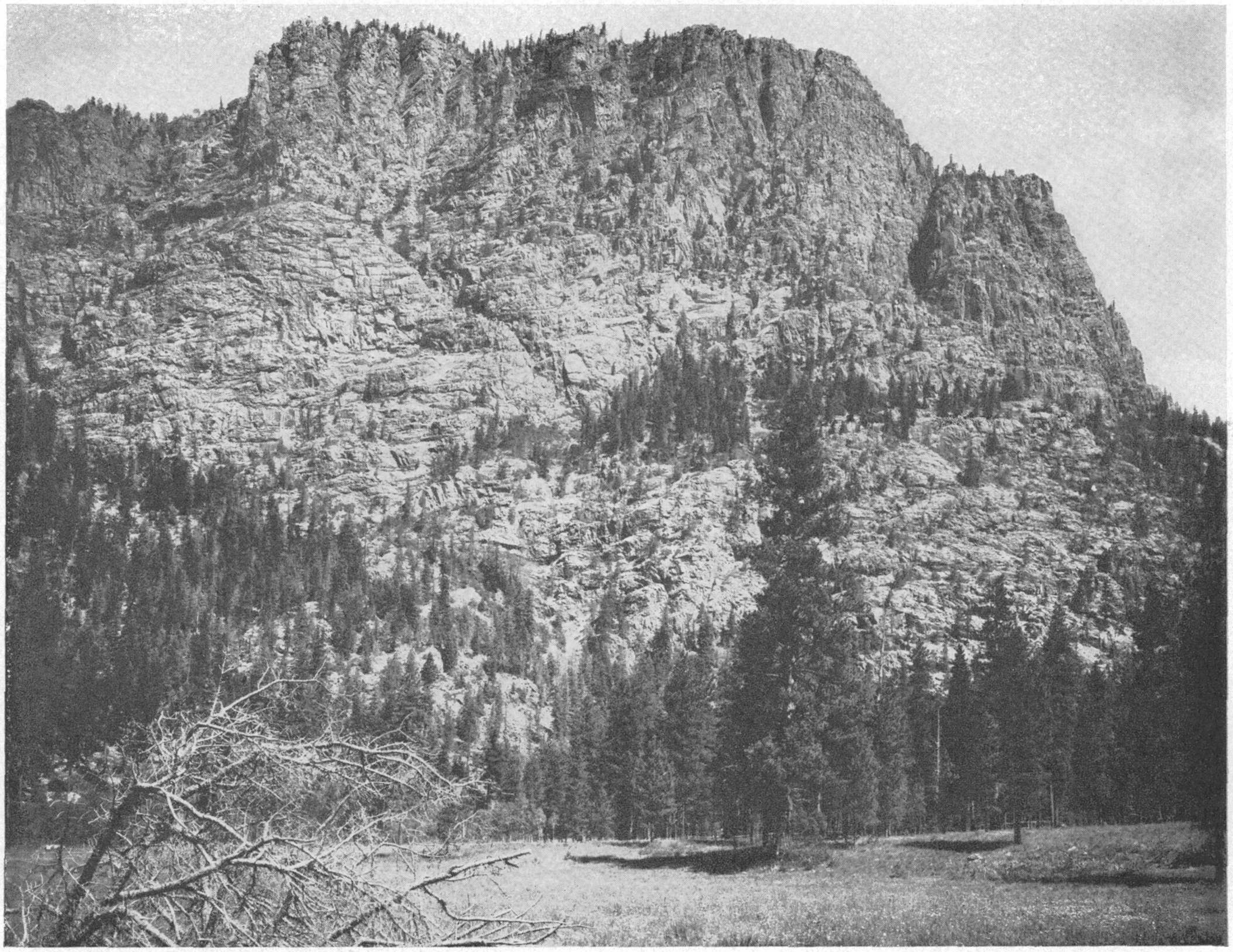

FIGURE 3.—Cliffs of Vallecito conglomerate west of Mount Rumlett, as seen looking west from the Porter ranch in Pine River Valley, near the west border of the Piedra quadrangle.

thickness. In the section in the San Cristobal quadrangle are five distinct schist (originally shale) layers, although some of them may be repeated by close folding or faulting. Farther west toward the Needle Mountains the two lower schist layers pinch out and the lowest exposures show 1,500 feet of massive quartzite which is light gray or white and, except for occasional pebbly layers, is uniformly fine grained and compact.

The quartzites range in color from white to red, purple, gray, or black. They are mostly nearly pure quartz. Some are rather thin bedded and even the more massive beds show some shale partings. They commonly show crossbedding and ripple marks. They are thoroughly indurated. The quartzites are traversed by joints now filled with secondary quartz.

The original shaly beds have been subjected to varying degrees of dynamic and contact metamorphism that has caused the development of secondary minerals and structures and a variety of rocks. At one extreme are soft black slates; on the other are the compact massive argillites and the schists.

Metamorphic minerals, such as andalusite, garnet, chlorite, and sericite, are common in the schists, and laminations have been developed both parallel and transverse to the bedding.

The lithologic character of the rocks and the deformation to which they have been subjected have had a material influence on the topography. The Grenadier Range of the Needle Mountains owes the ruggedness of its jagged peaks and their 2,000-foot precipices to a massive quartzite, dipping steeply to the north, which extends in a great bow from the Animas Canyon across Vallecito Creek to the region about Mounta Oso at the head of Pine River. The slates, however, generally occupy gentle slopes and saddles, or have influenced streams in the carving of their valleys.

In the Silverton and Ouray quadrangles the hard

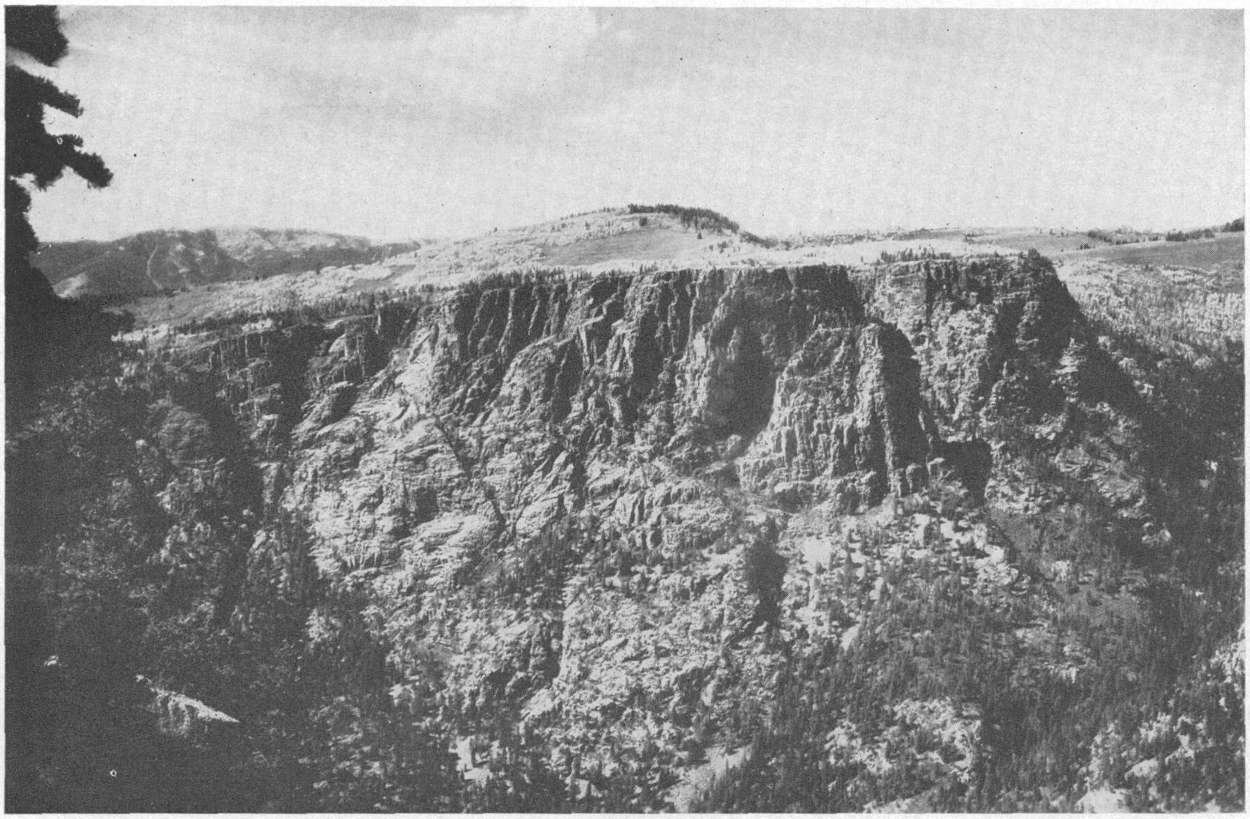

FIGURE 4.—Paleozoic rocks exposed on a nearly level bench at the top of cliffs of Vallecito conglomerate, as seen looking west from the Porter ranch in Pine River Valley, Piedra quadrangle.

quartzites and the slates protected by them form the precipitous walls of a canyon of unusual grandeur, through which the Uncompahgre River flows to the outskirts of the town of Ouray.

GRANITIC ROCKS

The ancient schists and gneisses, the Irving greenstone, and the sediments of the Needle Mountains group have all been intruded by granitic rocks so that no body of these older rocks more than a few miles across is free from such intrusion. The granitic rocks make up somewhat less than half the area occupied by the pre-Cambrian in the San Juan Mountains.

Except for the Pine River batholith which is in two masses separated by a fault block, none of the masses of granitic rock is large—none more than 15 miles across and most are only a few miles across. The largest bodies are in the southwestern part of the area in the Needle Mountains and adjoining quadrangles.

These granitic rocks are varied in character. They include pegmatite, aplite, granite, quartz monzonite, granodiorite, quartz diorite, diorite, gabbro, syenite, shonkinite, and others, and have a great variety of textures. Some are distinctly gneissic but most show little or no metamorphism. They no doubt represent many separate intrusions and several distinct epochs of igneous activity.

NEEDLE MOUNTAINS MASS

The large pre-Cambrian body that centers in the Needle Mountains has some of the largest bodies of granitic rocks. These represent a number of separate intrusions and 15 have been recognized as of sufficient importance to be separately mapped on the quadrangle maps. Most of these are best shown in the Needle Mountains quadrangle and have been described in the Needle Mountains folio, but five are best shown in the San Cristobal quadrangle and one in the Ignacio quadrangle. The description of these granitic rocks is taken in part from the published folios. The following granitic rocks have been distinguished on the quadrangle maps. They are arranged so far as possible from oldest to youngest.

Name	*Quadrangles in which exposed*
1. Twilight granite	Needle Mountains and Engineer Mountain
2. Tenmile granite	Needle Mountains
3. Whitehead granite	Needle Mountains and Silverton
4. Granite of the Rio Grande Canyon.	San Cristobal
5. Syenite	San Cristobal

Name	*Quadrangles in which exposed*
6. Granodiorite of the Pine River area.	San Cristobal and Ignacio
7. Eolus granite	San Cristobal, Ignacio, Pagosa, Needle Mountains, and Engineer Mountain.
8. Porphyritic leucokaligranite.	San Cristobal and Ignacio
9. Leucogranite of the Florida River area.	Ignacio and Needle Mountains
10. Trimble granite	Needle Mountains
11. Gabbro	Engineer Mountain
12. Granodiorite	Needle Mountains
13. Diabase and other basic dikes.	All quadrangles
14. Lamprophyre dikes	All quadrangles
15. Granite porphyry	Needle Mountains

TWILIGHT GRANITE

DISTRIBUTION AND MANNER OF INTRUSION

The Twilight granite forms much of the rugged West Needle Mountains in the western part of the Needle Mountains quadrangle and adjoining part of the Engineer Mountain quadrangle. The mass is about 5 by 9 miles in dimensions. It is separated on the north from the quartzites of the Uncompahgre formation by faults, on the west it is overlain by Paleozoic sediments, on the south it is intruded by gabbro, and on the east it intrudes the ancient schists and gneisses. The granite intrudes the dark schists in a most intricate way. In the Engineer Mountain quadrangle between Cascade and Little Cascade Creeks the granite dikes or sills from a few inches to 20 feet or more in width intrude the schists parallel to the laminations. These dikes are numerous and rather evenly spaced, with bands of dark schist about the same width as the dikes they separate. To the south the granite shows a greater tendency to more continuous intrusion. Fragments of schist are included in the granite. The granite of the West Needle Mountains and south of Potato Hill is the central mass and it is relatively free from inclusions though slabs of the dark schist are rarely absent from any large area.

Cross and Howe (1905a, p. 7) wrote:

> The gradual decrease in volume of the granite away from the central mass is well shown in the Animas Canyon from the western boundary of the Needle Mountains quadrangle eastward for about a mile and a half. Here there are a number of bands of granite 200 to 300 yards in thickness, separated from each other by narrower areas in which schists predominate, but which also contain the Twilight granite. Finally, the outermost zone is essentially like that described near Cascade Creek, where the granite and schist alternate in narrow bands until the granite disappears altogether.

T. S. Lovering (personal communication) found:

> On the Silverton-Durango road 16 miles from Silverton and about 0.3 mile south of the east-west fault shown crossing Lime Creek in the Needle Mountains folio, altitude about 9,200 feet, the flow structure in the Twilight granite is parallel to the contact with the Uncompahgre quartzite to the north. On the east side of Lime Creek about a half mile northeast of this locality where the contact between the Twilight granite and the Needle Mountains group runs almost north and south, the flow structure of the Twilight granite swings with the contact, and in many places apophyses from the main mass of the Twilight granite break into the Uncompahgre quartzite clearly showing the intrusive character of the granite. The linear structure in the Twilight granite is consistent in this region and dips east-northeast at about 35°. This suggests that the Twilight granite rose at a low angle from the east along the steep southerly dipping Uncompahgre quartzite series. The general absence of shattering of the quartzites is explained by their dip, strike, and competence. Where there was a marked southerly jog in the contact, the shoulder of quartzite opposed the direction of upward movement of the magma and shattering took place with the consequent intrusion of numerous dikes of Twilight granite parallel to the bedding of the quartzite.

PETROGRAPHIC DESCRIPTION

The Twilight granite is light gray, in marked contrast to the dark schists which it intrudes. In the larger dikes it is distinctly gneissic with the banding parallel to the walls, whether this is parallel to the laminations of the older rocks or irregular and across it. The smaller dikes show no foliation, nor do the bodies where inclusions of schist predominate. The change from the gneissic rock to massive, more or less pegmatitic rock is abrupt. These relations show that the banding is a primary flow structure.

The rocks are medium-grained and for the most part are distinctly gneissic. The principal constituents are feldspar, quartz, biotite, and hornblende. Their relative proportions are extremely variable. Commonly feldspar is in excess of quartz. Muscovite is commonly present and locally is as abundant as biotite. Such rocks are granodiorite or quartz monzonites or even quartz diorite. The dark minerals are subordinate; biotite is the chief mineral but hornblende is abundant and locally is more abundant than biotite. The accessories are magnetite, garnet, apatite, sphene, and zircon.

The prevalent gneissic texture is a primary fluidal texture but in places a secondary gneissic texture parallel to the older lamination of the schists is developed.

TENMILE GRANITE

LOCATION AND METHOD OF INTRUSION

The Tenmile granite occupies an area about 3 by 4.5 miles on both sides of Animas Canyon in the northern part of the Needle Mountains quadrangle. It intrudes the schists and gneisses, except for a part of its northern border where it is intruded by the Eolus granite. Its relation to the schists is characteristic. Beyond the main mass there is a series of granite bodies elongated parallel to the general boundary of the granite. These bodies decrease in size outward from the main mass.

At the north and south ends arms of granite extend into the schist in places for nearly half a mile. These outlying masses are finer-grained and carry lesser amounts of dark minerals than the main granite. In most places the apophyses, which are countless, are parallel to the laminations of the older rocks.

PETROGRAPHIC DESCRIPTION

Cross and Howe (1905a, p. 8) give the following description of the Tenmile granite in the Needle Mountains folio:

> The Tenmile rock as a whole is a rather coarse light-pink or gray granite, but there is an intricate mingling of granite of other textures, shades, and colors, ranging from coarse pink pegmatites to fine dark-gray gneissoid rocks rich in biotite, that resemble some mica-diorites. The association of these rocks is most intimate, but notwithstanding the diversity of their megascopic characters, their mineralogical compositions show no marked differences.
>
> The lighter-colored rock closely resembles the Whitehead granite, both megascopically and microscopically. The feldspars are orthoclase, microcline, and a very little plagioclase; quartz is abundant, while biotite is nowhere prominent, and there is generally a little muscovite. Accessory magnetite, apatite, and titanite are found in nearly all the specimens. The darker rock, which appears to be quite distinct in the field, is more variable in texture, ranging from coarsely granular to finely banded gnessic, and contains a greater percentage of the dark silicate, biotite. In many places unmistakable transitions of one rock into the other have been found and a comparison of thin sections has proved that they are essentially the same. The principal differences seem to be the greater amount of biotite in the dark rock, together with a slight increase in the quantity and basicity of the plagioclase. Hornblende also is occasionally found in the darker rock.
>
> That there has been more than one period of eruption is evident, and the differences between the lighter and darker rocks are to be attributed to the lack of uniformity in composition of a single magma. A more acid portion, possibly contemporaneous with the Whitehead intrusion and derived from the same source, was erupted first and before its complete consolidation the slightly more basic portion was forced into the first intrusion. In places fissures formed in the older granite and these were filled by the younger rock as dikes; in other places the lighter-colored rock was fractured and coarsely brecciated, the fragments being included in the darker granite, while at some points the older rock was still so nearly liquid that no sharp boundaries are seen and the two rocks seem to blend into one another. The banded or gneissic texture characteristic of the darker rock and occasionally found in the lighter granite shows no evidence of having been induced secondarily through pressure after the consolidation of the rock, but rather is primary, produced while the magma was still in a viscous condition, and probably corresponds to flow texture like that of the Twilight gneissose granite. Inclusions of schist are not uncommon in the Tenmile granite. As a rule the included masses are large, 20 to 50 feet in diameter, with sharp contacts with the granite and at many points cut by pegmatite veins or dikes which enter from the granite.

WHITEHEAD GRANITE

The Whitehead granite is mapped as a number of small bodies cutting the schists in the extreme northern part of the Needle Mountains quadrangle and extreme southern part of the Silverton quadrangle. The chief bodies are north of Whitehead Gulch on the opposite side of the Animas River, and near the head of the north fork of Elk Creek. None of the bodies is much more than a mile in length and they are much less than a mile in width. The total area underlain by this granite would be less than 2 square miles.

In many places no very sharp boundaries can be drawn for this granite, because it sends out into the schists a multitude of dikes which branch repeatedly until they gradually disappear. As this granite does not intrude the quartzites of the Uncompahgre formation, it is believed to be older than they.

The Whitehead granite is a rather coarse rock, pink or light red, in which biotite is not conspicuous. Near contacts with schist the granite is much finer-grained, locally somewhat gneissic in structure, and darker-colored on account of the greater abundance of biotite; in the Molas body the rock is often coarsely porphyritic. Microscopically the rock is found to be a very typical biotite granite with the usual granular texture. The essential minerals are the feldspars (orthoclase, microcline, and a little oligoclase), quartz, and biotite; the last-named mineral, though uniformly present, in some places is of almost secondary importance and occurs as minute flakes sparingly disseminated through the rock. In addition to these principal constituents muscovite is occasionally found as an original mineral. The usual accessories are almost lacking, magnetite and apatite being the commonest, with a little sphene and zircon (Cross and Howe, 1905a, p. 8).

GRANITE OF THE RIO GRANDE CANYON, IN THE WESTERN PART OF THE SAN CRISTOBAL QUADRANGLE

In the western part of the San Cristobal quadrangle, the Rio Grande forms a canyon in a body of granite that is exposed beneath the Treasure Mountain rhyolite and older volcanic rocks for a distance of nearly 4 miles. The granite is rather coarse-grained and is light-brownish vinaceous. In the hand specimen it shows rough pinkish tablets of microcline, some of which are as much as 15 mm long and 5 mm thick but most are about 5 mm long. It also shows some dark quartz, small white plagioclase, and some biotite. The microscope shows that the rocks consist of about 33 percent quartz, 40 percent microcline perthite, 20 percent plagioclase, 1 percent biotite, and 2 percent secondary muscovite. The microcline includes small scattered oriented tablets of plagioclase, a little plagioclase in a perthitic network, and some grains of quartz. The microcline is fairly fresh. The plagioclase is oligoclase, is clouded with a clay mineral, and contains some sericite. There is a little myrmekite. The muscovite is in irregular grains between and penetrating the feldspar. Much if not all of it is probably secondary. The rock is a leucogranite.

SYENITE

A body of rather dark syenite is exposed beneath the lavas of the Potosi volcanic series just below the forks in Ute Creek basin south of the Rio Grande in the western part of the San Cristobal quadrangle. Another small outcrop of the same rock occurs several miles farther up on the west fork of Ute Creek. The large body is about 2 miles long and is surrounded by younger rocks. The rock is uniformly dark, and it is usually fairly coarse. Abundant subhedral Carlsbad twins of feldspar in pinkish-gray to bluish-gray, thick, tabular crystals are characteristic; they are commonly a centimeter or more long and are imbedded in a finer grained mass of feldspar and abundant hornblende and biotite. The texture is generally distinctly porphyritic but in some places the rock is coarse, even grained. The original pyroxene has all been altered to amphibole and locally, near the southern boundary of the mass, the rock has been crushed and metamorphosed into a banded gneissoid rock. Under the microscope the rock is made up largely of microcline-microperthite, considerable biotite and secondary green hornblende, some quartz and plagioclase, and the accessories apatite, sphene, zircon, and iron ore. The rock is a quartz-bearing soda syenite. The rock of the small body on the west fork of Ute Creek is somewhat lighter colored and is finer and more evenly grained. It contains a little more quartz and plagioclase, and remnants of the original augite are present.

PINE RIVER BATHOLITH

DISTRIBUTION AND AGE

A composite batholith occupies a large area in the southwestern part of the San Cristobal quadrangle and adjoining parts of the Pagosa Springs quadrangle. It is well exposed in the drainage basin of Pine River. There are nearly continuous exposures north and south for a distance of about 15 miles, and isolated outcrops were found in the canyons of Weminuche Creek and Piedra River, about 6 miles farther south. The body is bounded on the north, east, and south by younger rocks, and on the west is in fault-contact with other pre-Cambrian rocks.

Another mass of this batholith, called the Eolus granite in the Needle Mountains and Engineer Mountain folios, lies chiefly in the southern part of the Needle Mountains quadrangle, but extends for a mile or so to the west into the Ignacio quadrangle. This body is about 14 miles across, and extends under younger rocks for an unknown distance to the south and west. Two smaller bodies lie a few miles to the north. The two main bodies are separated by a block about 6 miles wide and bounded by faults of other pre-Cambrian rocks. The total area of the exposed masses of this batholith is between 200 and 300 square miles.

In the Needle Mountains quadrangle, Eolus granite of this batholith intrudes the quartzites of the Uncompahgre formation, and apophyses of it cut the Tenmile granite southwest of Mount Garfield. It is overlain by the Ignacio quartzite of Late Cambrian age. It shows no appreciable metamorphism and is believed to be of late pre-Cambrian age.

GENERAL CHARACTER

The batholith is made up of rock types which are the results of four separate intrusions. The types follow the usual chronology for batholiths. The earliest was a dark granodiorite approaching a diorite in composition, next came a granite near a granodiorite (Eolus), and then the leucogranite of the Florida River area and finally the porphyritic leucokaligranite. The Eolus granite makes up the greatest part of the outcrops. In the Needle Mountains quadrangle only the Eolus granite and the granite of the Florida River area were found and mapped separately. On the San Cristobal quadrangles all but the Florida granite, and in the Ignacio quadrangle all but the porphyritic granite are well exposed and separately mapped. The four rocks have many features in common. All show blue quartz and conspicuous pink microcline crystals.

GRANODIORITE OF THE PINE RIVER BATHOLITH

In the San Cristobal quadrangle on the northwestern side of Pine River southwest of Divide Lakes, there is a large body of dark granitic rock which is entirely surrounded by Eolus granite. No other body of this rock crops out in the San Cristobal quadrangle but several irregular bodies of the same rock were found in the Eolus granite west of Vallecito Creek in the Ignacio quadrangle about 13 miles to the southwest. The rock makes up only a very small part of the Pine River batholith. The contacts of this body are usually fairly sharp, but the similarity of the two rocks and the lack of exposures make it impracticable to show the smaller details of the boundaries. The granodiorite is clearly older than the quartz monzonite which may represent a great inclusion in the Eolus. Many dikes of aplite and pegmatite cut the dark rock.

The granodiorite differs considerably from specimen to specimen in texture, general appearance, and mineral composition. In general it is medium-dark gray with a fairly coarse texture; it characteristically carries irregularly distributed pinkish feldspar crystals as large as an inch across. These feldspars are microcline-microperthite commonly bordered by plagioclase. The distribution of these microcline crystals in streaks and their association with intrusions of Eolus granite that have similar crystals indicate that they were introduced by "soaking" from the granite. Large plagioclase crystals are less common. In addition to the large feldspar crystals, the rock contains andesine feldspar, blue quartz, biotite, green hornblende, some microcline, accessory apatite, iron ore, sphene, and zircon, and secondary epidote, calcite, and chlorite. The hornblende is partly derived from pyroxene; the dark minerals are abundant. Where the microcline phenocrysts are absent the rock generally has the composition of a quartz diorite but on the whole it should be called a granodiorite. Some light-colored facies have less dark mineral and abundant microcline in the groundmass. The large pink feldspars are the most striking characteristic of the rock.

EOLUS GRANITE

By far the greatest part of the Pine River batholith—probably more than 90 percent—is made up of a uniform granite, called the Eolus granite in the published folios. It is a remarkably uniform rock with only slight and local variations in texture and composition and is by far the largest mass of uniform granitic rock in the San Juan Mountains, underlying at least 200 square miles. In sharp contrast to many of the older granites of the region, this granite has relatively sharp and regular contacts with the older rocks, and it is comparatively free from inclusions.

The Eolus granite is a light pink or pinkish-gray, coarsely porphyritic rock. Large Carlsbad twins of pink feldspar, commonly 2 cm long, make up a considerable part of the rock and are imbedded in a coarsely granular aggregate of bluish quartz, feldspar, biotite, and hornblende. In thin sections the large feldspars are seen to be microcline, with a little perthitically intergrown plagioclase; the feldspar of the groundmass is largely andesine but there is a variable amount of microcline; the hornblende is green and the biotite brown. The most abundant of the accessory minerals is sphene which occurs in large, pleochroic crystals; apatite, zircon, and an opaque mineral are also present. The rock is a granite.

Near the borders of the mass the rock is commonly somewhat banded or it may be finer grained and richer in plagioclase and dark minerals and in a few places it carries augite.

Inclusions, some a foot or more across, of a darker-colored rock are common. These differ considerably both in texture and mineral composition, but they are characteristically much richer than their host in the dark minerals, especially hornblende, and in the accessory minerals, especially sphene; they are poorer in microcline and are finer textured and less porphyritic. They are sharply bounded from their host. Their origin is uncertain but their mineral composition indicates that they represent a concentration of the minerals of earlier crystallization from the granite. They probably represent inclusions that have been reacted on by the magma and more or less completely reworked, following Bowen's reaction principle.

The sphene and other accessory minerals which are commonly much concentrated in such inclusions are not easily explained, although they may have been concentrated into the inclusion from a rather large body of the granite.

PORPHYRITIC LEUCOKALIGRANITE

In many places in the San Cristobal quadrangle, the Eolus granite is intruded by a coarsely porphyritic red granite. The contacts are very sharp, but the two rocks are so much alike that accurate mapping is impracticable. In general, these contacts are irregular and the porphyritic granite sends out many dikes and apophyses into the Eolus granite. Pegmatitic and aplitic facies are usually abundant near the contacts. The accurate, detailed separation of these two rocks would require a careful examination of every outcrop in the granite area. Most of the bodies are comparatively small and seem to be dikes or irregular stocks, but the masses about 2 miles west of Divide Lakes seem to be the remnants of a sheetlike body which has been eroded through by a small gully.

This rock varies considerably in texture but is more uniform in its composition. Most commonly it is very similar to the Eolus granite, as it has the conspicuous phenocrysts of feldspar in a coarsely granular mass of bluish quartz, feldspar, and biotite; hornblende is characteristically absent. The large feldspars are microcline microperthite, but the feldspars of the groundmass are chiefly microcline with only subordinate oligoclase-albite. This granite differs from the Eolus chiefly in the small quantity of dark minerals and absence of hornblende, the small amount of plagioclase, and lack of large sphenes. The color is usually bright red but it is locally pale pink or even white. In some of the larger bodies the phenocrysts are more abundant and the groundmass coarser, giving the rock a coarsely granular texture with a porphyritic tendency. However, at some of the borders and in the smaller bodies the phenocrysts are less abundant and the groundmass finer textured. The rock is a leucokaligranite.

LEUCOGRANITE OF THE FLORIDA RIVER AREA

In the Ignacio quadrangle a light-colored granite cuts the Eolus granite. The contacts are sharp but the lighter-colored rock sends many long dikelike apophyses into the Eolus. This light-colored rock makes nearly all of the drainage area of the Florida River that is occupied by the granitic batholith except the extreme northern strip. It extends across the divide to the east and underlies the large basin north of West Mountain. The outcrop is about 5 miles across and on the west and south it is overlain by younger sediments, so that it probably has a much larger extent. To the north and east it intrudes the Eolus. It is therefore much larger than any of the subdivisions of the Pine River batholith except the Eolus granite.

The granite of the Florida River area is a light pinkish-gray rock with a porphyritic tendency. It varies somewhat in texture but it commonly has many centimeter-sized crystals of pink feldspar twinned after the Carlsbad law, imbedded in a millimeter-grained matrix of quartz, feldspar, and biotite. The large feldspars are microcline, with some intergrown albite. The groundmass is made up of oligoclase, microcline, and quartz. The dark minerals are in small amount and biotite is the only one in many of the rocks, but green hornblende is present in about half the thin sections examined and in a few it exceeds the biotite in amount. The accessories are apatite, zircon, magnetite, and millimeter-sized sphene. The secondary minerals—epidote, sericite, chlorite, and calcite—are in small amount. In many respects the rock is intermediate between the Eolus granite and the porphyritic leucokaligranite. It is a leucogranite.

TRIMBLE GRANITE

In the Needle Mountains quadrangle a granite that has less in common with the members of the Pine River batholith than the granites previously described intrudes the Eolus granite. According to Cross and Howe (1905a, p. 8):

> In the region northeast of Missouri Gulch and including Vallecito Basin a fine-grained gray granite is found intruded in the Eolus. The contacts between the two rocks are very sharp and, except in the southwestern part, there are almost no apophyses. The rock is uniform in texture, except near contacts with the Eolus, where a faint banding may be made out. At these places, also, a porphyritic appearance is not uncommon, due to a slightly finer texture of the rock as a whole and the development of large phenocrysts of feldspar which are in many instances arranged with their greater diameters parallel to the contacts.

With the exception of the contact facies, the Trimble granite has an even texture and is of a moderately fine grain; the color is light gray with a pinkish tinge. There is a very uniform sprinkling of fine specks of a dark mica and lath-shaped crystals of feldspar 2 to 3 mm. long. The rock consists of microcline with relatively subordinate amounts of orthoclase and plagioclase, quartz, biotite, and locally a little muscovite, with magnetite or apatite as accessorites. The structure is very characteristically hypidiomorphic-granular. The contact phases differ from the ordinary rock only in the presence of phenocrysts of feldspar, many of them 1 inch long, and in the color, which is slightly pinker.

GABBRO

Southeast of the center of the Engineer Mountain quadrangle, a body of gabbro is exposed over an area about 3 miles across. It continues to the west under younger sediments. Small arms and tongues of the gabbro project 20 feet or more into the surrounding schists and Twilight granite. Cross and Hole (1910, p. 3) say of it:

> The gabbro mass varies a great deal in composition and texture, but shows no sharp changes indicating intrusive relations of any of the varieties. Texturally the rock is granular, ranging from medium to very coarse grain. In some places the crystals of feldspar or diallage are from 1 to 2 inches in diameter. Such large individuals generally inclose many small grains of other minerals and the resulting poikilitic fabric is pronounced.
>
> A primary banded or gneissic texture is present in certain parts of the contact zone and also in portions of the interior of the mass. A dark dense phase of the rock was observed near the contact in a few places but is by no means a characteristic of the border zone.
>
> The portion of the mass east of the Ignacio reservoir is chiefly made up of lime-soda feldspar (labradorite), diallage, and hypersthene, with subordinate amounts of biotite, hornblende, quartz, and orthoclase, variably developed. In some places, especially where a banded texture appears, hypersthene replaces diallage almost entirely and the rock becomes a norite.
>
> On the west side of the reservoir the mass is richest in quartz, hornblende, and biotite, and some specimens from this portion of the mass are nearly free from diallage and hypersthene.
>
> In intimate association with the gabbro occur many dikes or veins consisting mainly of microcline, orthoclase, and quartz. These are commonly only a few inches wide and a few yards long. They cut both gabbro and schist, with sharp contacts. Some dikes have the fine, even grain of typical aplite; others are pegmatitic; and some are partly of one and partly of the other character. Biotite is the only dark silicate observed. In many places quartz and feldspar occur in intricate micrographic intergrowth. The essential minerals of the gabbro are entirely absent from these associated aplite and pegmatite dikes, so far as they have been examined.

GRANODIORITE

In the extreme southern part of the Needle Mountains quadrangle just west of Florida River, a body of dark granodiorite three-quarters of a mile long and half a mile wide, cuts the Eolus granite. Cross and Howe (1905a, p. 8) describe it:

> The rock is moderately coarse-grained, even-textured, and of a clear-gray color; a noteworthy feature is the large quantity of the darker silicates present. The microscope shows that plagioclase, ranging from oligoclase to andesine, is more abundant than orthoclase or microcline, and that hornblende, biotite, and rarely a little augite nearly equal the feldspars; a very little quartz may also be present. The accessories are magnetite, apatite, and titanite. The rock is to be regarded as a granodiorite containing a rather unusual amount of the dark silicates.

MINOR INTRUSIVE ROCKS

Many small dikes and less regular bodies of a great variety of granite, granite porphyry, syenite, lamprophyre, diabase, aplite, pegmatite, and other rocks cut the pre-Cambrian rocks. For the most part they have not been separately mapped even on the large-scale quadrangle maps. Lamprophyres are abundant in the northern part of of the Needle Mountains quadrangle. They are chiefly minettes and quartz-bearing mica syenites. Diabase dikes are common in the southern part of the Silverton quadrangle. They are partly fresh and partly altered to amphibolites.

THE GRANITE OF LAKE FORK

OCCURRENCE

Near the head of the Lake Fork of the Gunnison River in the high mountains of the northwestern part of the San Cristobal quadrangle, that stream has cut through the volcanic rocks and, in places, nearly 4,000 feet into an underlying mass of granite.

From the irregular primary contacts of different volcanic rocks resting on or abutting against this granite (illustrated on pl. 1 and discussed in the part on volcanic rocks), it is evident that the granite of Lake Fork formed a high and rugged mountain mass before the beginning of the San Juan volcanic activity. The main area of the granite begins about 4 miles above Lake San Cristobal and extends westerly up the valley to Sherman and beyond that up the canyon of Cottonwood Creek and its southwestern branch, Cuba Gulch, nearly to the line of the Silverton quadrangle. The area is from 1 to 3 or 4 miles in width and about 10 miles in length.

On the south of Lake Fork and Cottonwood canyons the granite disappears under volcanic rocks, the contact having a general southerly or southwesterly dip. On the north the great faults separate the granite from the volcanic rocks.

A second smaller mass of this granite occurs at the head of Lake Fork and its western tributary Grizzly Gulch. Its culminating point is Whitecross Peak (13,550 feet) and northwest of that summit the rock extends a short distance into the Silverton quadrangle. This mass is wholly bounded by faults and is of very irregular shape. The two granite areas are separated by a narrow mass of Picayune quartz latite on the ridge between Campbell and Grizzly Gulches.

PETROGRAPHIC DESCRIPTION

The granite of Lake Fork is normally pink or gray and usually shows large microcline crystals in a medium-grained groundmass. In some parts of the mass the rock is coarse and nearly even-grained. Large pinkish feldspar grains, some gray or greenish feldspar, much quartz, and a little biotite can be recognized. The thin sections show that the large feldspars are microcline, with the twinning so developed that much of the material resembles plagioclase with albite twinning; the crystals are clear and fresh but are microperthitically intergrown with a little plagioclase. The plagioclase is nearly as abundant as the microcline and is albite; it is always much clouded with sericite flakes, calcite, and other alteration products. The quartz is always much strained. Biotite is present in small amount but is largely bleached or altered to chlorite; muscovite is also present and possibly some of it is primary although much is clearly secondary. The usual accessory minerals are present. The rock as a whole is very uniform and is essentially a biotite granite rich in soda. The rock has been considerably and uniformly metamorphosed by dynamic processes accompanied by development of secondary muscovite and straining of the minerals. Because the granitic rocks of Pine River show little or no evidence of such metamorphism, they are believed to be younger than the granite of the Lake Fork. The syenite of Ute Creek shows nearly as much metamorphism and as it is also similar in that it is a highly sodic rock the two may be closely related.

MAFIC DIKES IN GRANITE OF LAKE FORK

Near Sherman the granite of Lake Fork is cut by three nearly parallel, dark dikes which run a little north of west. They are granular rocks and are metamorphosed to about the same degree as the granite. They are probably pre-Cambrian in age but were not intruded until after the granite was cold, since they show fine-textured borders. A similar dike occurs in Grizzly Gulch. The northernmost dike is about 30 feet across at Sherman and has been followed over much of its length. The center of the dike is a nearly black, medium fine-textured, ophitic rock which is made up largely of labradorite, with considerable diallage, a little micrographically intergrown quartz and orthoclase, and accessory apatite, and iron ore; the diallage is more or less altered to green uralite, chlorite, and biotite; the feldspars are filled with secondary white mica and calcite; epidote and chlorite are also present.

The middle dike is about 100 feet across at Sherman. It is somewhat coarser than the rock of the northern dike, is not typically ophitic, and contains more micropegmatite. The other dike is very similar. These rocks are quartz diabase.

GNEISSOID GRANITE OF CONEJOS RIVER

In the Conejos quadrangle a small outcrop of gneissoid granite, surrounded by volcanic rocks, was found just north of the Conejos River, a little above the mouth of Elk Creek. The rock is very coarse-grained with feldspar crystals 30 mm or more in diameter. It has gneissoid texture with bands of fine-grained dark minerals between the feldspar crystals. Pink microcline and oligoclase are the dominant minerals. Biotite and epidote are the dark minerals.

GRANITIC ROCKS OF THE GUNNISON REGION

GENERAL STATEMENT

The great mass of pre-Cambrian rocks in the Gunnison River drainage and to the east is made up predominantly of schists and gneisses, but granitic rocks are widespread and of great variety. The individual bodies are mostly small. The largest, near Powderhorn, is exposed with interruptions for 13 miles along Cebolla Creek. Few of the other bodies are much more than a mile across and they taper to narrow stringers. No considerable body of the schists is free from intrusions, and locally the intrusive rock is so abundant that it makes up a considerable part of the mass, or even becomes the greater part of the mass that has only inclusions or streaks of the schist.

Hunter (1925) has published an excellent, detailed description of the rocks of the Uncompahgre and Montrose quadrangles and of the Black Canyon; the descriptions to follow are taken largely from his report. He subdivided the less metamorphosed intrusive rocks in this way:

Powderhorn granite
- Granite porphyry
- Gray biotite granite
- Porphyritic biotite granite

Vernal Mesa granite (found only in the Black Canyon north of the area included in the map)
Curecanti granite
Undifferentiated granite
Metagabbro
Quartz diorite (a border zone of the metagabbro)
Quartz diorite and diorite
Olivine gabbro
Augite syenite
Pegmatite and coarse granite
Diabase
Lamprophyre

The subdivisions were made largely on the basis of petrographic character. Different granites were distinguished largely from general appearance and textural features. In composition the rocks differ chiefly in the relative amounts of potash and soda feldspar, biotite, and muscovite. They are characterized by a relatively high content of soda feldspar. For the most part, a particular type of granite is confined to a restricted area. Except in a few places, the different rocks have not been found in contact and their relative ages are not known. In general the syenites and more mafic rocks are later than the major granites.

POWDERHORN GRANITE

The Powderhorn granite in the eastern part of the Uncompahgre quadrangle is made up of three textural varieties representing distinct intrusion. It is exposed with interruptions for about 11 miles along Cebolla Creek and for a width of about 6 miles east and west. Both eastward and westward it goes under later rocks and much of it may be covered.

GENERAL CHARACTER

Hunter (1925, p. 39–40) describes the Powderhorn granite (now classified by the U. S. Geological Survey as a formation of the Front Range granite group):

> The Powderhorn group [granite] 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 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.
>
> The area of the Powderhorn granite is characterized by high hills and rugged canyons. * * * 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.

These granites everywhere cut the Dubois greenstone. Their relation to the gabbro to the south is uncertain. The contact between these rocks is vague and in places almost gradational. Bodies of the granite, believed to be inclusions, were found in the gabbro, and dikes of rock much like the gabbro cut the granite.

The granite also shows more dynamic metamorphism. It is probable that the granite is the older.

GRANITE PORPHYRY

The principal area mapped as granite porphyry lies in the drainage of Cebolla Creek just northeast of the postoffice of Powderhorn. It includes much of the drainage area of Milkranch Gulch and is about 3 by 4 miles in dimensions. A much smaller mass lies about a mile to the northwest on both sides of Cebolla Creek. Another small mass lies to the south, about a mile west of the mouth of Deldorado Creek. Many dikes and less regular bodies cut the Dubois greenstone near the granite porphyry contact.

The granite porphyry is a light to bluish-gray rock that varies from a rhyolite porphyry to a granite porphyry and from a massive rock to a well-banded gneiss. It characteristically has a variable proportion of phenocrysts of quartz and albite or oligoclase as much as 10 mm across in a fine-grained to aphanitic groundmass. Potash feldspar is rare as a phenocryst. The groundmass varies from very fine-grained to 0.3 mm-grained and is made up chiefly of quartz and microcline with some plagioclase, biotite, muscovite, and chlorite. The rock is much altered and contains sericite developed from feldspar. Locally, epidote, tourmaline, calcite, and amphibole are developed.

Everywhere the granite porphyry carries inclusions of the Dubois greenstone. It seems to be older than the porphyritic biotite granite although the relations are not clear.

PORPHYRITIC BIOTITE GRANITE

The porphyritic biotite granite makes up the greater part of the area underlain by the Powderhorn granite. The rock varies considerably from place to place and no doubt represents several more or less distinct intrusions. The prevalent rock is a pink, coarse-grained granite with a porphyritic tendency. A finer and more aplitic gray type intrudes the other in an intricate manner, in part with sharp contacts, in part with gradational contacts.

The typical rock is seriate porphyritic to porphyritic; the largest crystals are 25 mm in length; the normal crystals are from 1 to 5 mm across. Microperthite makes up about a third of the rock, quartz somewhat less, albite or albite-oligoclase usually less than microperthite, and biotite rarely 15 percent. The biotite is in fine equigranular aggregates. Magnetite, apatite, zircon, and rarely sphene are the chief accessories. Allanite was found in one specimen.

GRAY BIOTITE GRANITE

The gray biotite granite underlies about a square mile west and south of the mouth of Beaver Creek. It seems to intrude the porphyritic biotite granite. It is a pepper-and-salt gray. It has a seriate porphyritic texture and few grains are more than 1.5 mm across. The minerals are about the same as those of the porphyritic biotite granite but sodic plagioclase is more abundant.

CURECANTI GRANITE

The Curecanti granite is in the canyon of the Gunnison River in the northwestern part of the Uncompahgre quadrangle, and forms the most rugged part of the Black Canyon traversed by the railroad. The body forms the canyon walls for about 3.5 miles. For the most part, its north and south boundaries are with younger rocks but near the center of the mass its width is about 2 miles. Near the western border of the granite in Black Canyon and the southern limit in Blue Creek, the granite contains many inclusions of schist, and the schists are intruded by granite. On the north and east the granite-schist contact is well defined.

Nearly everywhere the granite contains inclusions of the schists. The inclusions range from a few feet in diameter to bodies several hundred feet thick and three-quarters of a mile along.

The Curecanti granite is a uniform pink to gray sodic quartz-microcline granite of fine to medium grain and of even texture. The texture is seriate and the grains range from 0.5 to 3 mm in diameter. The proportion of the minerals varies somewhat, but on the average quartz makes up a little more than a third of the rock, microcline about a third, sodic plagioclase about a fourth, and muscovite and biotite a few percent each. The plagioclase is partly perthitically intergrown with microcline. Garnet is the most abundant accessory mineral, and apatite, magnetite, and zircon are in very small amount. Irregular pegmatitic patches are present.

OTHER GRANITE BODIES

Hunter (1925, p. 53) describes the undifferentiated granites as follows:

> 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. * * * 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 the 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 * * *.

SODA GRANITE

In many places between Willow Creek in the northeastern part of the Uncompahgre quadrangle, and Cochetopa Creek in the Cochetopa quadrangle there are small irregular bodies of a gray soda-rich granite. The body about a mile north of Vulcan is of this type, as are many of the elongated bodies to the north and northeast that have a northwesterly strike. One of the larger masses crosses South Beaver Creek about 4 miles above its mouth and is about half a mile wide and more than 2 miles long. The Aberdeen granite quarry is on this body. A considerable body is exposed in Lick Creek.

The granite ranges from a quartz diorite to a granite. The typical rock is gray, even-grained, and most crystals are between 2 and 3 mm in diameter. A specimen from the Aberdeen quarry contained the following percents of minerals: quartz 36, feldspar 51, biotite 12, accessories 1. Oligoclase is the chief feldspar.

A fine porphyritic granite is associated with the soda granite but is probably older. It differs from the soda granite chiefly in its texture and larger content of microcline. The largest body of this granite is about a mile wide and extends from the head of Pole Creek, about 5 miles north of Vulcan, to the southeast for several miles.

MICROCLINE GRANITE

Microcline granite much like the Powderhorn granite has been found in many places in the Saguache quadrangle and in small bodies in South Beaver, Lick, and Rock Creeks of the Cochetopa quadrangle. The small, faulted block of granite about 6 miles southeast of Razor Creek dome is a microcline granite. Crossing Cochetopa Creek northwest of Razor Creek dome there is a zone of gneissoid granite with a well-developed banding, which seems to be at least 2 miles wide but has not been examined in detail. A study of one section showed that this gneissoid granite resembles the microcline granite type, but also carries a noteworthy amount of tourmaline.

Gneissoid granite and granite gneiss make up much of the large pre-Cambrian area between Needle and Long Branch Creeks and west of Little Tomiche Creek.

Northwest of Hot Spring Creek is a body, at least a mile long and half a mile wide, of a moderately coarse biotite-microcline granite that is similar to the Powderhorn granite.

A somewhat similar granite forms the small mass east of Middle Creek, north of Saguache River, west of the center of the Saguache quadrangle. Some miles to the east, near the eastern border of the quadrangle, medium-grained granite makes up the granitic mass.

METAGABBRO AND ASSOCIATED QUARTZ DIORITE

The metagabbro and its border zone of quartz diorite crop out in an area 1.5 miles wide by 3.5 miles long in the drainage area of Cebolla Creek about 6 miles south of Powderhorn, in the southeastern part of the Uncompahgre quadrangle. On the south and east the body is irregularly overlain by lavas and on the north and northwest it is in contact with the Powderhorn granite. This contact is straight and may be a fault although the metagabbro is believed to have intruded the granite.

Dark-green metagabbro is the chief rock of the mass. Few of the mineral grains exceed 1.5 mm in mean diameter although amphibole crystals reach an extreme length of 10 mm. Amphibole is the chief mineral. It is mostly massive but partly fibrous, of ragged outline, and full of inclusions. Next in abundance are clinozoisite and epidote. They never exceed 40 percent of the rock. Rarely, traces of plagioclase are still recognizable. Magnetite makes up from 2 to 3 percent of the rocks. Pyrite, apatite, quartz, calcite, and chlorite occur in small amount.

A feldspathic phase of the metagabbro was found in Beaver Creek. It is composed chiefly of plagioclase ranging from bytownite to anorthite, and of hornblende, clinozoisite, and epidote, named in order of decreasing abundance.

The quartz diorite occurs in two bands on the north and south borders of the metagabbro. The northern band is about 3 miles long and as wide as half a mile. The quartz diorite intrudes the metagabbro.

The average grain of the quartz diorite is 2 mm in diameter and the largest 5. Andesine, more or less albitized, is the chief mineral, and microcline occurs in small amount. Quartz is commonly the mineral second in abundance. Hornblende is next in abundance and may equal or exceed the quartz. Biotite, chlorite, epidote, muscovite, and clinozoisite are common. The accessories are apatite, zircon, garnet, and iron ore.

QUARTZ DIORITE AND DIORITE

Many small bodies of diorite and quartz diorite were mapped by Hunter in the eastern part of the Uncompahgre quadrangle. Similar rocks occur to the east. The rocks cut the schists and are cut by granite. They are probably not all of the same age. The principal occurrences are those on Willow Creek between Sugar and Camp Creeks, on the west slope of South Beaver Creek, northeast of Big Mesa, and along the Gunnison River, 1 mile east of Iola. A body of unknown extent was found in the Cochetopa quadrangle on the south side of Tomichi Creek about a mile west of Long Branch.

> 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. (Hunter, 1925, p. 62)

They are composed essentially of plagioclase, hornblende, quartz, and biotite, named in order of abundance. The plagioclase is chiefly andesine but ranges from calcic oligoclase to labradorite. It is commonly altered and locally forms a confused aggregate of sericite, epidote, and albite. The hornblende is in part massive, in part fibrous. In a few places augite is present and is bordered by amphibole. Quartz rarely exceeds the hornblende in amount and in places it is entirely absent. Biotite is highly variable and is more abundant in the quartz-rich rocks. It rarely exceeds the hornblende in amount.

THE IRON HILL COMPLEX

The Iron Hill complex underlies an area of about 12 square miles in the eastern part of the Uncompahgre quadrangle, east of Powderhorn Valley. It has been described by Larsen (1942). The oldest rock of the complex is a marble, and the oldest intrusive rock of the stock is an uncompahgrite. The next and largest intrusive rock is a pyroxenite, which was followed successively by ijolite, nepheline syenite and syenite, and nepheline gabbro and quartz gabbro.

MARBLE OF IRON HILL

The marble of Iron Hill underlies an area of 2.5 square miles. It forms the large mass of Iron Hill and several smaller bodies within the complex. A few small bodies of similar marble are present in the pre-Cambrian granitic rocks near Iron Hill. The marble is cut by the rocks of the Iron Hill stock.

In part, the outcrops of the marble are nearly white but over large areas the weathered surface is yellow or brown from iron stain. No bedding is present in this great body of marble which varies little from place to place. The rock is chiefly dolomite, but part of it is calcite and it contains some apatite and pyrite.

On the southwestern slope of Iron Hill the marble is cut by several veins consisting of calcite, apatite, and martite. Bodies of siliceous limonite are present in the marble. Near the contacts with the pyroxenite the marble locally has been partly replaced by phlogopite, aegirite, apatite, and amphiboles ranging from soda tremolite to glaucophane. The carbonate rocks within the granitic rocks several miles from the Iron Hill stock contain the same silicates.

The marble is believed to be of hydrothermal origin.

UNCOMPAHGRITE

The uncompahgrite is the oldest of the intrusive rocks of the stock and is present in a number of small bodies, chiefly in the drainage area of Beaver Creek. The fresh uncompahgrite is medium- to very coarse-grained and is made up chiefly of melilite, with pyroxene, phlogopite, magnetite, perofskite, apatite, and calcite.

The minerals of the uncompahgrite have undergone a long succession of replacements beginning with those caused by the residual liquid of the crystallizing magma before it separated from the crystal mesh and continuing to those caused by moving hydrothermal solutions that gathered into fractures and were relatively dilute. All of the replacements are unevenly distributed. In the late magmatic stage, rims of light-colored perofskite were deposited around the older perofskite and the magnetite. Following this, titaniferous garnet, with some pale green phlogopite, was deposited as rims around the melilite and in veinlets cutting the rock. This took place partly in the magmatic stage and partly after the solutions left the crystal mesh and moved between the grains of the rock and along fractures.

An unusual vein 10 cm wide north of Beaver Creek replaces the uncompahgrite. Its borders are made up chiefly of titaniferous garnet, with some phlogopite, chlorite, calcite, and fibrous zeolites. Grading inward, the vein is made up chiefly of coarse idocrase in which are embedded crystals of monticellite. The center consists of large grains of cancrinite containing embedded grains of monticellite and some brown garnet.

Following the deposition of the dark garnet, idocrase and colorless diopside replaced the melilite. In some large bodies of the uncompahgrite the melilite has been completely replaced, in others it is unaltered or cut by veinlets of the replacing minerals. A number of later replacements formed many veinlets of hydrous minerals. In the replacement by idocrase and diopside and by the hydrous minerals there was little change in composition except for the addition of water.

PYROXENITE

A pyroxenite intrudes the uncompahgrite and makes up about 80 percent of the intrusive rocks of the stock. It is a medium- to coarse-grained rock, with average contents of 60 percent augite, 15 percent biotite, 10 percent each of magnetite and perofskite, and less apatite and ilmenite. Local parts of the rock contain microcline, albite, nepheline, and sphene. As is common in mafic rocks, the pyroxenite is highly variable in both texture and the proportion of minerals it contains. The textural and mineralogical varieties commonly have sharp intrusive contacts with each other, and a single prospect pit 50 feet long will show many types, one cutting the other. Some are made up largely of biotite, some of magnetite and perofskite, some of apatite with a little perofskite; some are coarse-grained, some fine-grained. A few small dikelike bodies contain much olivine.

IJOLITE

The ijolite cuts the pyroxenite as dikes or less regular bodies and is variable in texture and mineral composition. It is commonly rather coarsely crystalline, and the average rock consists of about equal amounts of nepheline, augite, and titaniferous garnet, and about 3 percent of apatite, 2 percent each of magnetite and biotite, 1 percent of primary calcite and local sphene, perofskite, microcline, wollastonite, primary cancrinite, and zircon. The garnet crystallized late and in part replaces the pyroxene.

SODA SYENITE AND NEPHELINE SYENITE

A soda syenite forms many dikes and a few larger bodies which cut the pyroxenite, ijolite, and the pre-Cambrian rocks that surround the stock. Much of the syenite is a streaked, banded, or granulated rock caused by fracturing during the late stages of crystallization. The typical rock is fine grained and consists chiefly of microcline microperthite that contains much albite. Aegirite-diopside is present, chiefly along fracture and streaks; apatite and sphene are in small amounts; and zircon, fluorite, and quartz are rare.

Numerous dikes and some larger bodies of a nepheline syenite, with conspicuous tabular crystals of microperthite, intrude the soda syenite and older rocks. Many bodies of this rock are present in the drainage area of Beaver Creek. The rock contains about 80 percent of microperthite; next in abundance is nepheline, largely altered to cancrinite, then aegirite, magnetite, biotite, sphene, apatite, zircon, and in a few specimens, titaniferous garnet.

NEPHELINE GABBRO AND QUARTZ GABBRO

A few dikes of nepheline gabbro and quartz gabbro, some as wide as 300 feet, cut all the other rocks of the stock. The two types of gabbro are in subparallel dikes and, in places, practically form a single dike.

The typical nepheline gabbro is a coarse-grained rock that has conspicuous tabular plagioclase crystals in random to subparallel arrangement. It looks like a coarse diabase. The texture of the rock is ophitic. Some olivine and altered nepheline are present and accessory magnetite, with reaction rims of biotite, and apatite.

The quartz gabbro is somewhat finer-textured than the nepheline gabbro. It is made up of labradorite, pigeonite, and 10 percent of interstitial quartz and orthoclase.

HYDROTHERMAL PRODUCTS

Hydrothermal products were formed repeatedly during the activity of the Iron Hill stock and they were of the kind characteristic of alkalic rocks. Dark titaniferous garnet was formed during the late magmatic and early hydrothermal stage in the uncompahgrite and ijolite, and in the hydrothermal stage in the pyroxenite, syenite, and nepheline syenite, and in veins. Aegirite, phlogopite, and sodic amphiboles were formed in the contact metamorphic limestones, and in the limestone bodies in the rocks surrounding the stock. Aegirite and soda amphiboles are also abundant in veinlets and in coatings of and replacements next to the numerous fractures in the older rocks surrounding the stock. These minerals are also common along and adjoining closely spaced fractures in the syenites.

Many veins of dolomite, containing some quartz, alkalic feldspar, galena, sphalerite, pyrite, fluorite, and some silicates cut the rocks of the stock. Some carbonate veins contain augite, others contain hastingsite.

Hastingsite is also present locally as a replacement of augite in pyroxenite and other rocks of the area. Zeolites, chiefly analcite, natrolite, and cancrinite, replace the nepheline in some of the rocks. The replacements of the uncompahgrite and of the marble have already been described.

LAMPROPHYRES

Dikes of altered lamprophyre were found in and near the Iron Hill area. The rocks contained phenocrysts of biotite, pyroxene, and olivine in a fine-grained groundmass. They are greatly altered and contain much carbonate, chlorite, mica, pyrite, and some aegirite and analcime. Similar altered lamprophyres were found near the Lot Mine, which is near Vulcan, and east of the gulch between Camp and Willow Creeks 150 yards above the point where the main road crosses those creeks.

A 3-foot dike of vogesite cuts the hornblende gneiss on the west side of Cebolla Creek, near the south end of the pre-Cambrian area. It is fine-grained and made up chiefly of orthoclase, sodic plagioclase, hornblende, and augite.

A 1-foot dike of altered lamprophyre crosses Black Canyon a mile south of the mouth of Lake Fork.

OTHER DIKE ROCKS

INTRODUCTION

In the area surrounding the Iron Hill stock, the pre-Cambrian rocks are cut by several dikes of syenite and an associated shonkinite, differing from those of the Iron Hill stock, and a single dike of olivine gabbro (Hunter, 1925, p. 63–75). Their alkalic affinities suggest that they may be related genetically to the Iron Hill rocks, but they are high in potash content, whereas the Iron Hill rocks are high in soda content. If they are related to the Iron Hill stock, they determine the age of that stock as late pre-Cambrian, because the syenite and shonkinite are cut by aplite and pegmatite dikes, and such dikes are confined to the pre-Cambrian of this region. Their mineral and chemical compositions, characterized by abundant hypersthene and much K_2O, seem to distinguish them sharply from the Iron Hill rocks.

AUGITE SYENITE AND SHONKINITE

Augite syenite was found in several small bodies in the northeastern part of the Uncompahgre quadrangle. The largest body crosses Wildcat Gulch 1.5 miles above its mouth. It is about 1 mile long and 0.3 mile wide in its southern part and wedges out to the north. Along its western border is a small body of a peculiar olivine-rich shonkinite differentiate. A somewhat smaller body with a similar olivine-rich associate near its border lies west of Goose Creek, 1.25 miles south of Dubois. Near this are several smaller bodies. Smaller bodies were found 0.6 mile above the mouth of Wolf Creek, near Spencer, above the Lot Mine, and on the west side of Willow Creek, 2.5 miles south of Midway. Where the syenite intrudes the schists it cuts across their laminations. It intrudes the granites of the Powderhorn region but is cut by pegmatite and aplite.

The augite syenite is a uniform rock. The typical rock is dark gray to black and contains biotite standing out as large poikilitic crystals. It is seriate to seriate porphyritic, and the average crystal is about 0.8 mm across. Some of the large augite grains reach 2 mm, and some of the poikilitic biotite plates are 8 or even 20 mm across. Microcline, with some perthitically intergrown albite, is the chief mineral. Crystals of albite are present in small amounts. Augite makes up from 20 to 25 percent of the rock and has been partly altered to actinolite. Hypersthene is present in a few of the rocks, and biotite is less abundant than augite. Magnetite, apatite, zircon, quartz, sphene, rutile, and garnet are accessory minerals. In some of the border phases, especially in the lower Wolf Creek body, quartz is more abundant than in the normal rock. An analysis of the augite syenite from the middle of the Wildcat Gulch body is given in column 1 of table 4. The rock is high in potash content, but the related shonkinite has an even higher ratio of K_2O to Na_2O. The syenites of the Iron Hill area nearby are relatively high in soda content. The syenite of the Willow Creek dike appears to have a moderate amount of soda. It is distinctly porphyritic and may have contained nepheline. The augite and biotite are almost completely decomposed, and the rocks contain a secondary amphibole that resembles glaucophane.

The syenite body of Wolf Creek is coarser in texture, contains more hornblende, and shows much differentiation. In its central part crystals of microcline-microperthite as much as 6 mm across include poikilitically albite, hornblende, quartz, and accessory minerals. The hornblende is secondary. Sphene is unusually abundant, and some of the crystals are 1 mm across. The border of the mass is a fine-grained rock in which the mafic minerals exceed the feldspar. The perthite includes the other minerals. Hornblende is the chief dark mineral and augite and biotite are also present. The border and central types grade into each other. This border rock is similar to the most abundant rock of the Wildcat Gulch and Goose Creek areas, and the coarse central part is like the quartzose rock along the border of the Wildcat Gulch mass. The body in Wildcat Gulch is about 50 feet wide and 200 feet long; that of Goose Creek is smaller. It weathers in rounded forms and is characterized by a rough uneven surface and gives characteristic outcrops. The shonkinite is a tough, dark, medium- to coarse-grained rock, containing large glistening brown micas. The rock has a seriate porphyritic fabric, and the grains range from 0.5 to 5 mm in diameter. Orthoclase having a small axial angle approximates the augite in amount. Olivine is less abundant, biotite still less, and magnetite and apatite are accessory.

An analysis of the shonkinite from Wildcat Gulch is shown in table 4 column 2.

TABLE 4.—*Analyses and norms of augite syenite* (1) *and shonkinite* (2) *from Wildcat Gulch*

[George Steiger, analyst]

Analyses	*1*	*2*	*Norms*	*1*	*2*
SiO_2	54.99	50.86	or	42.26	35.03
Al_2O_3	12.98	11.14	ab	20.96	9.43
Fe_2O_3	3.13	2.93	an	1.39	5.00
FeO	3.92	5.21	ne	1.70	2.84
MgO	5.50	11.26	di	17.63	20.29
CaO	5.67	6.97	ol	5.98	17.47
Na_2O	2.83	1.73	mt	4.41	4.41
K_2O	7.08	5.85	il	1.98	1.52
H_2O-	.41	.64	ap	2.17	1.86
H_2O+	.58	.95			
TiO_2	.99	.84			
ZrO_2	.04	.02			
CO_2	None	None			
P_2O_5	1.00	.79			
S	.05	.02			
Cr_2O_3	.01	.11			
V_2O_3	None	None			
NiO	.04	.04			
MnO	.13	.13			
BaO	.47	.31			
SrO	.17	.22			
Total	99.99	100.12			
Sp gr	2.83	2.94			

OLIVINE GABBRO

A dike of olivine gabbro cuts diorite about 12 miles north of Iron Hill, just east of Willow Creek and above the mouth of Sugar Creek. It is not more than 200 feet across and about three-quarters of a mile long. Its outcrop is distinctive, owing to its peculiar rounded form, its rusty brown color, and its rough pitted surface. Megascopically the rock resembles the shonkinite described above. On the fresh surface it is a black medium-grained rock in which lustrous flakes of biotite and plagioclase, poikilitically including the other minerals, are conspicuous. It is exceedingly heavy and hard to break or trim. The minerals, named in approximate order of abundance, are olivine, augite, labradorite ($Ab_{45}An_{55}$), biotite, hypersthene, and magnetite. Secondary magnetite, serpentine, sericite, and a little chlorite are common.

DIABASE

Several diabase dikes cut all the other pre-Cambrian rocks and several have been mapped in the Uncompahgre Canyon. One in the canyon of the Lake Fork, a little more than a mile north of Madeira Siding, is 150 feet across and cuts across the foliation of the Dubois greenstones. Another in the Black Canyon, a quarter of a mile east of Nelson Gulch, is 250 feet wide and traceable for a mile.

In these rocks labradorite exceeds augite in amount. Biotite is present in small amount in some specimens and olivine is rare. Most of the rocks have a small amount of interstitial micropegmatite.

PALEOZOIC ROCKS

INTRODUCTION

The Paleozoic rocks rest on a remarkably smooth surface cut on the pre-Cambrian rocks. The underlying pre-Cambrian rocks are deeply weathered.

In the western part of the mountains the section includes Cambrian, Devonian, Carboniferous, and Permian rocks. In the map of the mountains (pl. 1) only the major subdivisions of the Paleozoic have been mapped—Cambrian, Devonian, and Carboniferous—but in the published folios the Devonian and Carboniferous have been subdivided as shown in table 5, which is taken largely from the Needle Mountains folio. (Cross and Howe, 1905a, p. 3).

TABLE 5.—*Section of the Paleozoic rocks of the western part of the San Juan Mountains*

	Thickness (feet)
Permian (?):	
Cutler formation:	
Sandstone, bright-red, lighter red or pinkish grits and conglomerates, alternating with sandy shales and earthy or sandy limestones; nonfossiliferous	1, 500
Rico formation:	
Sandstones, dark reddish-brown, and pink grits with intercalated greenish, or reddish shales and sandy fossilliferous limestones	300
Carboniferous:	
Pennsylvanian:	
Hermosa formation:	
Limestones, grits, sandstones, and shales of variable distribution and development. Limestone, in thick, massive beds, predominates in the	

TABLE 5.—*Section of the Paleozoic rocks of the western part of the San Juan Mountains*—Continued

	Thickness (feet)
Carboniferous—Continued	
Pennsylvanian—Continued	
Hermosa formation—Continued	
middle and upper parts of the section, the lower part being mainly sandstones and shales, with a few limestone layers. Many invertebrate fossils occur in the shales and limestone	2, 000
Molas formation:	
Shale, red and calcareous, containing many nodules of chert and saccharoidal limestone which are fossiliferous; becomes more sandy and shaly upward; different strata cannot be distinguished. Rests on a weathered and broken surface of the uppermost part of Leadville limestone	75
Mississippian:	
Leadville limestone:	
A small but uncertain part of the upper bed of the Ouray limestone	Thin
Devonian:	
Upper Devonian:	
Ouray limestone:	
Limestone, dull rusty-brown, earthy, laminated, and wavy; fossiliferous. Yellowish limestone with large rounded cherts near top	25
Limestone, massive, blue, not always continuous	5
Limestones, without cherts	20
Limestones, thin-bedded, dense, bluish-gray; certain layers extremely fossiliferous	25
Quartzite and sandy limestones; no fossils	4
Sandy limestones containing many crinoid stems and a few cup corals	25
(Ouray limestone, total thickness 104 ft)	
Elbert formation:	
Shale, fine red clay, not in distinct outcrops	10
Limestone, dense, gray, conchoidal fracture in several beds; variable in development and not always present; nonfossiliferous	0–35
Sandstone or quartzite, variable in character; extremely fossiliferous in places	1
Limestones or calcareous shales, thin, containing pseudomorphs of salt crystals	30
Limestones, dense, gray, with thin shale parting; in lower part fish scales have been found locally; forms ledges	30
Limestones, sandy and impure, with thin fossiliferous quartzites and shale layers; reds and yellows	25
(Elbert formation, total thickness 100± ft)	

TABLE 5.—*Section of the Paleozoic rocks of the western part of the San Juan Mountains*—Continued

	Thickness (feet)
Cambrian:	
Upper Cambrian:	
Ignacio quartzite:	
Quartzite, massive, fine-grained beds 2–5 ft thick	25
Quartzite, thin-bedded, fine-grained, often with reddish shaly parting or sandy layers	20
Quartzite conglomerate, fine-grained, in places giving way to red crumbling shales and sandstones, resting unconformably or pre-Paleozoic rocks	5–50
(Ignacio quartzite, total thickness 90± ft)	
Total	4, 169±

In the eastern part of the Saguache quadrangle, north of Saguache Creek, several small bodies of Paleozoic rocks, associated with thrust faulting, are exposed. Burbank's subdivision of these rocks (1932a, p. 10), later modified by Johnson (1944, p. 308), is shown in table 6.

TABLE 6.—*Section of the Paleozoic rocks in the Kerber Creek area, the Saguache quadrangle*

	Thickness (feet)
Unconformity.	
Permian and Carboniferous:	
Permian and Pennsylvanian(?):	
Maroon formation:	
Micaceous sandstone and shales and a few thin conglomerate beds, with gray fossiliferous limestone somewhat more abundant than in lower member. Uppermost beds contain very coarse arkosic conglomerate and sandstone. Top not exposed	1, 650±
Conglomerate member, at least of local development; contains thick beds of conglomerate and very coarse sandstone, with interlayered shales like those of the lower part	630±
Mainly micaceous shale, sandy shale, and sandstone, with interbedded conglomerate. A few beds of carbonaceous black shale near base, and a few lenticular limestone beds. Colors range from dark red to yellow and orange or green, reddish predominating. Fossiliferous limestone and shale near base indicate an age corresponding to the lower part of Maroon formation of Anthracite-Crested Butte district	1, 150±
	3, 430±
Carboniferous:	
Kerber formation:	
Alternating beds of black, very thin-bedded carbonaceous shale and coarse-grained to pebbly sandstone, generally crossbedded. Shale contains low-grade coal seams, or carbonized plant remains	200

TABLE 6.—*Section of the Paleozoic rocks in the Kerber Creek area, the Saguache quadrangle*—Continued

	Thickness (feet)
Unconformity.	
Mississippian:	
Leadville limestone (upper part of Ouray):	
Mainly unevenly thick-bedded, blue-gray, fine-grained limestone. Thin-bedded with shale at base, passing up into unevenly bedded limestone with black dolomite layers. Upper part massive, with concretions of black chert	350–400
Unconformity.	
Devonian:	
Chaffee formation (lower part of Ouray):	
Dark-gray to grayish-white fine-grained limestone. Commonly thin and evenly bedded. Contains ferruginous and argillaceous impurities and weathers yellowish or brownish	50–100
Fine to coarse white sandstone and quartzite in places cross-bedded. Associated with variegated argillaceous sandstone and shale and impure limestone	10–50
	130±
Unconformity.	
Ordovician:	
Fremont limestone:	
Lower part gray crystalline dolomitic limestone, becoming less dolomitic and finer toward top. Upper beds with brownish cherts. Contains fossils of Richmond age	300
Unconformity.	
Harding sandstone:	
Gray bedded quartzite of fine to coarse texture, with a few shaly layers. Fragments of fish remains. Corelative with Harding sandstone of Canon City, Colo	60–90
Unconformity.	
Manitou dolomite:	
Thin-bedded gray dolomitic limestone with beds and lenses of gray to white chert. Becomes more massive and less siliceous toward top. Contains fossils of Early Ordovician (Beekmantown) age	90–200
	500±
Unconformity.	
Pre-Cambrian:	
Gneiss, schist, and granite.	

As subdivided on the small-scale map (plate 1) the Cambrian includes only the thin quartzite member of the Ignacio; the Ordovician includes only the rocks of the Kerber Creek area; the Devonian includes the shaly beds of the Elbert and most of the Ouray limestone, including the Chaffee formation in the northeastern part of area; the Carboniferous and Permian have by far the greatest thickness, as they include the Leadville limestone, the overlying thin red beds of the Molas formation, the great thickness of the Hermosa, the Rico

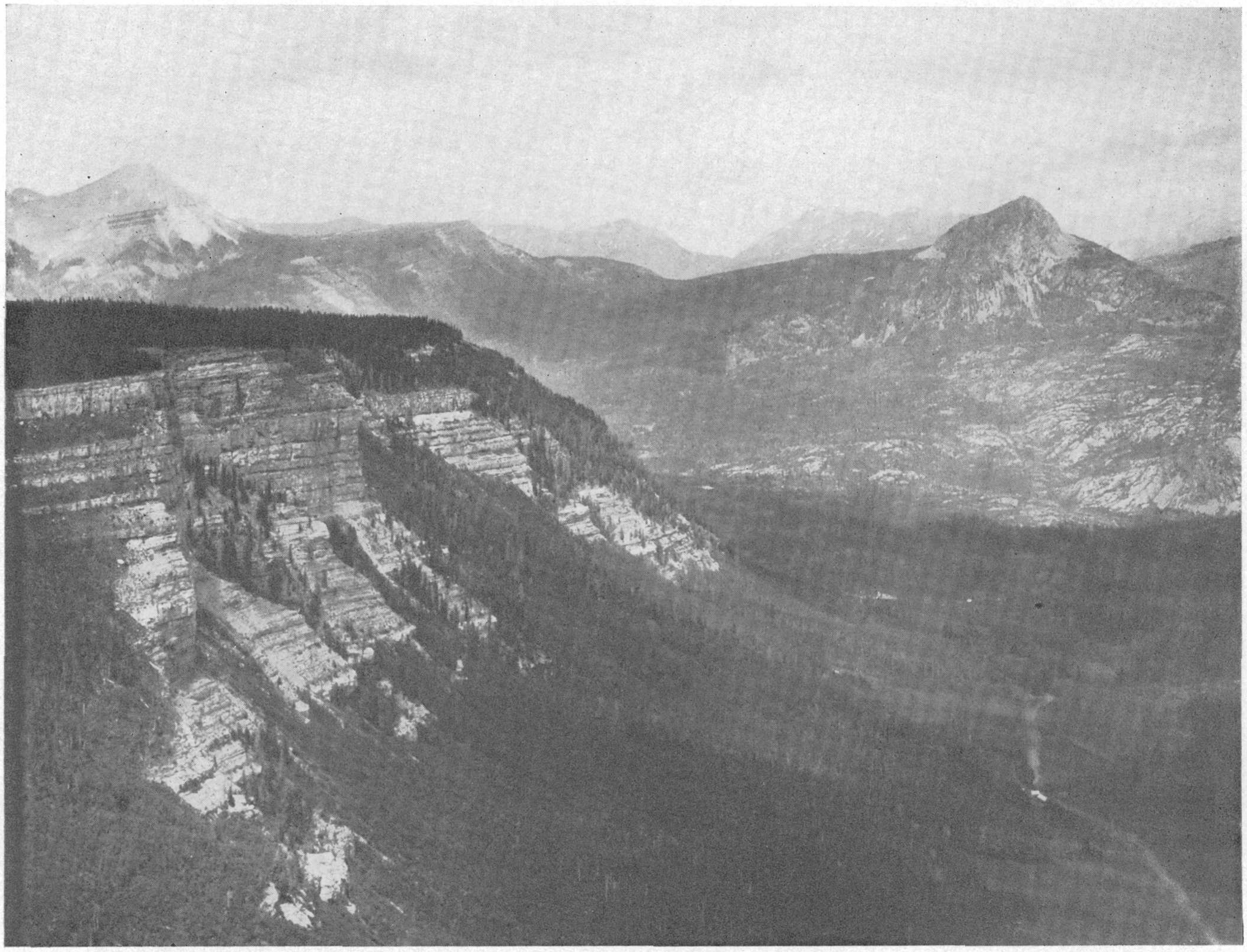

FIGURE 5.—Characteristic scarp of the Hermosa formation, looking north from scarp south of Elbert Creek, Engineer Mountain quadrangle. In the left background is the rhyolite summit of Engineer Mountain; to the right the granite summit of Potato Hill, with *roches moutonnées* surfaces near that hill.

and Cutler formations, and the Kerber and Maroon formations of the Kerber Creek area.

DISTRIBUTION

The Paleozoic rocks are found almost exclusively in the western part of the mountains. The largest body overlies the great mass of pre-Cambrian rocks of the Needle Mountains. It occupies much of the northern part of the Ignacio quadrangle and small areas in adjoining quadrangles to the east, northeast, north, and west. It also occupies much of the Needle Mountains quadrangle, the eastern part of the Rico quadrangle, and extends for a short distance north-northeast and east of these quadrangles. Outliers are present overlying the pre-Cambrian rocks and underlying the Mesozoic rocks in some of the canyons. To the north there are two small exposures near Ouray. In most of the northern area in the Gunnison River drainage basin the Paleozoic rocks were removed by erosion before Jurassic time, and the Jurassic rocks rest directly on the pre-Cambrian. However, a small body of Paleozoic rocks crops out in the extreme northeastern part of the Cochetopa quadrangle, and several others in the eastern part of the Saguache quadrangle, in the drainage area of lower Kerber Creek. The former is an outlier of larger masses to the north and the latter is probably related to the Paleozoic outcrops of the Sangre de Cristo Range to the east.

Probably the most easily accessible, complete, and well-exposed section of the Paleozoic rocks is in the Animas Canyon above Durango. Excellent places to study the section are to the east in the drainage areas of Florida and Pine rivers. Photographs of some outcrops of the Paleozoic rocks are shown in figures 5 and 6.

CAMBRIAN SYSTEM

IGNACIO QUARTZITE

The Cambrian system is represented by a series of quartzites, the Ignacio quartzite, which are from a few feet to 200 feet thick. They are at the base of the

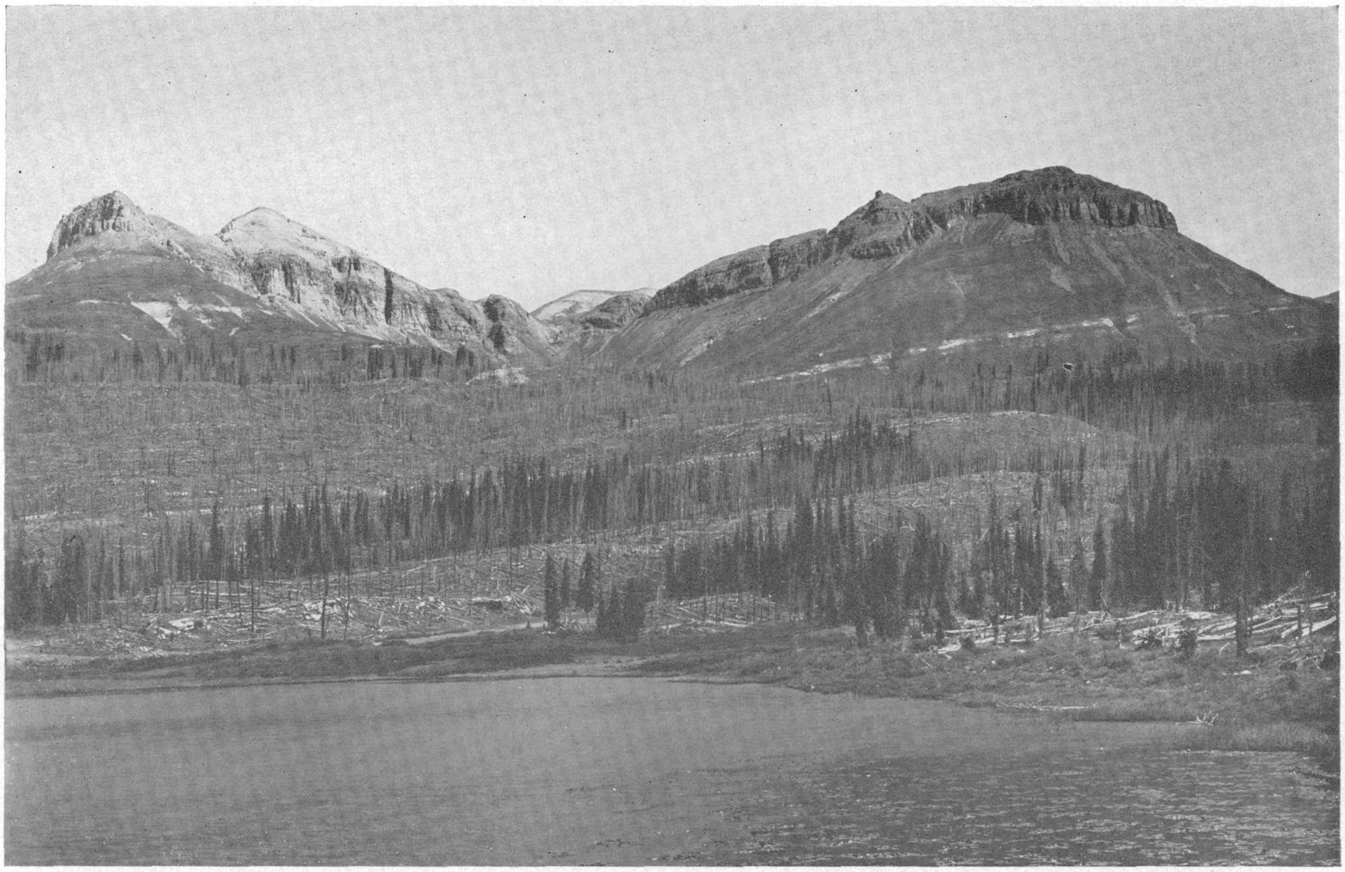

FIGURE 6.—A view in the Silverton quadrangle of the mountains southwest of Grand Turk, taken from the shore of a lake on the divide between Lime Creek and the Animas River. The upper cliff is San Juan tuff, under it is Telluride conglomerate, and the lower slopes are of the Cutler and Hermosa formations.

section in most places around the Needle Mountain pre-Cambrian mass but are locally absent, probably because of erosion preceding the deposition of the Elbert beds. They are absent in the eastern part of the mountains, in the Ouray quadrangle, and locally elsewhere.

The following description of the Ignacio quartzite is taken from the Silverton folio (Cross, Howe, and Ransome, 1905, p. 3):

The Ignacio consists of nearly pure siliceous strata, with some feldspar locally in the lowest beds. The greater part is fine-grained, white, gray, or pinkish, and highly indurated. The lower portion is commonly a massive quartzite of prevalent pink or reddish color, while the succeding strata are nearly white. Distinct bedding is common, as is an irregular jointing. Above this the strata are often wavy in bedding, with shale partings, in which mud cracks, trails, and other markings are common. These layers are friable sandstones in places. More massive quartzite layers generally succeed this series, but not in a thickness equal to those below.

At the very base of the formation a true basal conglomerate is often found, but only in hollows of the granite, schist, or Algonkian quartzite floor. The hard Algonkian quartzites are most abundant among the pebbles, which range in size up to a diameter of (rarely) 1 foot.

Fossils.—The only identifiable fossil invertebrate yet obtained from the Ignacio beds was found on a remnant capping Overlook Point, one of the hills of Mountain View Crest, in the Needle Mountain quadrangle, south of Needle Creek. Specimens of this fossil were found scattered through a hard, dark quartzite above the middle of the formation, which was there 110 feet thick. Mr. Walcott identifies this shell as an *Obolus*, but is unable, from the material at hand, to determine its species. Three forms that are much like this are *Obulus matinalis*, *O. tetonensis*, and *O. loperi*, the latter occurring in the passage beds between the Cambrian and the Ordovician in the Crested Butte quadrangle, Colorado. Since the Cambrian is known in Colorado only in thin representatives of the upper division, it seems best to assume for the present that the Ignacio quartzite also belongs in that series.

A common apparent fossil of the Ignacio quartzite is thought by Mr. Walcott to be Cruziana, a problematic plant remain.

Two sections of the Ignacio quartzite are given below:

Section of Ignacio quartzite near limestone quarries in the Durango quadrangle described by Howe

	Thickness (feet)
Elbert formation.	
Ignacio quartzite:	
Quartzites, thin-bedded	10
Quartzites, well-bedded, but massive, layers 1–2 feet thick which rest at the base of the series on a conglomerate composed of pebbles of Uncompahgre series in a gritty matrix and occasional gritty lenses which are arkose in part	130
Total	140

Section across the Ignacio quartzite measured by Larsen in the gulch heading northeast of Devon Point in the northeastern part of the Ignacio quadrangle

	Thickness (feet)
Elbert formation.	
Ignacio quartzite:	
Grits, with some fine conglomerate	4½
Grits, thin-bedded, purple with thin purple shale partings	3
Quartzite, heavy bedded, with pebbles as large as ¼ inch across	4½
Quartzite, dark red, made up of irregular lenses of quartzite and conglomerate. Pebbles less than 1 inch across	12
No exposures	20
Total	44
Granite.	

ORDOVICIAN SYSTEM

MANITOU, HARDING, AND FREMONT FORMATIONS

The Manitou, Harding, and Fremont formations, were found only in the Cochetopa and Saguache quadrangles, where they directly overlie pre-Cambrian rocks.

DEVONIAN SYSTEM

ELBERT FORMATION

The Elbert formation is a series of thin-bedded shales, quartzites, and limestones, rarely more than 100 feet thick. It regularly overlies the Ignacio quartzite but an important stratigraphic break must be present below the Elbert formation, for the Ignacio quartzite is absent in some places.

A few fossil fish that have been found in the Elbert formation show the age as Late Devonian.

The Elbert formation seems to be present everywhere around the Needle Mountains pre-Cambrian mass but is absent in the northern part of the Silverton quadrangle, and it was not recognized in the Rico quadrangle or in the Cochetopa and Saguache quadrangles.

The following description is taken from the Silverton folio (Cross, Howe, and Ransome, 1905, p. 3):

The formation is mainly composed of calcareous shales and thin sandy limestones that vary in details of development from place to place. The beds are drab, buff, or yellowish in color. The shaly layers break up readily on exposure, so that outcrops are obscured by the resulting scales and thin plates. Quartzites are present, but are always very thin and subordinate to the calcareous and shaly portion.

The shaly beds are in many places characterized by pseudomorphous casts after salt crystals. They occur, as noted by Endlich, on the under side of slabs, as is natural considering their origin. The crystals of salt, it must be supposed, formed on or near the surface of the mud of a desiccating body of salt water, and were dissolved by influx of fresh water, and the crystal space was filled by sand or mud of a new deposit. The crystals are usually more or less clearly skeleton cubes with sunken faces. Some of them are as much as an inch or more in diameter. So abundant are these casts that they may be found at nearly every outcrop, but they are larger amd much more perfect in some localities than in others.

Two sections of the Elbert formation are given below:

Section across the Elbert formation measured by Larsen in the gulch heading northeast of Devon Point in the northeastern part of the Ignacio quadrangle

	Thickness	
	Feet	Inches
Ouray limestone.		
Elbert formation:		
Grits, red, limey, containing some shells and abundant nodules of iron oxide. Some of these iron nodules are due to late mineralization	2	
Limestones, thin, impure and a smaller amount of clay parting. Poorly exposed	8	
Limestone, light-gray to yellow, thin-bedded, carrying much grit and some white finer textured sandy limestone	5	
Limestone, yellow, thin-bedded, soft, impure	1	6
Shale or marl, green. Weathers yellow. Grades into overlying impure limestone		10
Grits, quartose, hard, white, two beds; and fine conglomerates, with some calcite cement. Pebbles ¼ inch in diameter	3	
Shale, green, calcareous, grading into shaly limestone at base	1	9
Sandstone beds, white to gray, calcareous, 5 to 14 inches thick	2	
Shale, dark-red to purple, calcareous, with three beds of green impure limestone, each less than 6 inches thick	8	
Limestone, white, poikilitic, sandy		10
Shale, purple	2	
Limestone, white, sandy, two beds. The lower one is the thinner	1	8
Shale, purple, calcareous, with some very thin beds of limestone	5	3
Grits, white, calcareous, in beds as great as 3 feet thick	7	
Sandstones, thin-bedded, calcareous, and sandy limestones beds separated by dark-red calcareous shale	5	
Sandstones and grits, white, calcareous, three beds, no partings	3	9
Limestones, purplish to light-gray, shaly near base	3	2
Total	63	0

Section of Elbert formation near limestone quarries in the Durango quadrangle described by Howe

	Feet
Ouray limestone.	
Elbert formation:	
Shales, thin-bedded, calcareous, salt pseudomorphs	6
Limestone, dense, bluish, weathering buff	6
Total	12

OURAY LIMESTONE

The Ouray limestone overlies the Elbert formation conformably and, with it, crops out as a band about the crystalline core of the Needle Mountains. It is nowhere known to be absent from the Paleozoic section and is therefore more widespread than the two underlying formations. Locally, in the Uncompahgre Canyon in the northern part of the Silverton quadrangle, it directly overlies the pre-Cambrian. It is a resistant unit and forms prominent cliffs and mesas.

LITHOLOGIC CHARACTER

The following description of the formation is taken from the Silverton quadrangle (Cross, Howe, and Ransome, 1905, p. 4):

The Ouray formation, as at present known, has a thickness varying from 100 to 300 feet. The upper and major part of the formation is massive limestone, either in one bed or with such thin intercalated shales that the ability of the limestones to cause mesas, benches, and prominent cliffs as characteristic topographic forms is always notable. Below the more massive portion, a third or less of the section is made up of beds of limestone with distinct shaly layers and, rarely, thin quartzites between them. Some of the lower layers have a wavy bedding, some are arenaceous or earthy, and large chert concretions, free from fossils, are common at a horizon near the base. The lowest stratum is characterized usually by crinoid stems and rarely by a cup coral.

The greater part of the formation is dense, compact limestone, but portions of the upper ledge are coarsely crystalline. In general the rock is nearly white, straw-yellow, or buff, with local pinkish tones. Some of the lower beds are strongly yellow, and these are commonly more or less sandy. The contrast with the dark-gray, dense limestones of the Hermosa is marked, layers of such color and character occurring only near the base of the Ouray.

The Carboniferous portion of the Ouray, (Leadville limestone) is at present indistinguishable lithologically from the Devonian. Its existence was detected through the presence of Mississippian invertebrate fossils in the chert pebbles of the succeeding formations.

FOSSILS AND CORRELATION

The Devonian invertebrate fauna of the Ouray occurs from near the base to a horizon which in many places is not far below the top of the upper, massive ledge. The greater number of species are found in this upper horizon, but many of them range to within a few feet of the base. * * *

The invertebrate fauna of the Devonian of the Ouray has been fully described by G. H. Girty (Twentieth Ann. Rept., U. S. Geol. Survey, pt. 2, 1900, pp. 25–63), and compared with similar faunas hitherto collected in Colorado, but not separated from lower Carboniferous.

The Devonian fauna of the Ouray limestone has been shown by Dr. Girty to be represented more or less fully in older collections from various parts of Colorado, notably in the Elk Mountains, at Glenwood Springs on Grand River, near the head of White River, and on East Monarch Mountain, Chaffee County. Full correlations of the sections in these localities with the section in the San Juan region will not be possible, however, until further examinations have been made. Dr. Girty says:

"In general the Devonian fauna of the Ouray clearly belongs to upper Devonian time. It is but distantly related to the Devonian faunas of New York, and its relation with those of the Mississippi Valley, or even with other known western Devonian faunas, is not close.

"It shows many points of approximation to the Athabascan fauna described by Whiteaves, and is somewhat strikingly similar to the Devonian of Russia."

A section of Ouray limestone near limestone quarries, Durango quadrangle is:

	Thickness (feet)
Molas formation.	
Ouray formation:	
Limestone, massive, light buff, rather coarsely crystalline above and weathering into nodules becoming more massive below	30
Limestone, dense, pale buff to white, in layers 6 feet 4 inches thick with occasional shale partings. Individual layers are not very persistent but have a tendency to occur as long drawn-out lenses	60
Limestone, nearly white, weathering to a soft powdery marl with included nodules of harder limestone	6
Limestone, massive, light gray, fossiliferous at top—crinoids and brachiopods	6
Limestone, buff, thin-bedded and platy near top, becoming massive below. 30 feet to talus and to foot of talus 30 feet more	60
Nearby in a small pit a thin massive limestone band is exposed, which evidently forms the surface of the bench upon which this talus rests. It probably belongs to the Ouray	5
Total	167

CHAFFEE FORMATION

Burbank (1932a, p. 12) called the Devonian part of the Ouray limestone in the Kerber Creek area the Chaffee formation. It overlies the Fremont limestone with apparent conformity.

CARBONIFEROUS SYSTEMS

LEADVILLE LIMESTONE

The small and uncertain upper part of the limestones that are of Mississippian age but have been included in the Ouray limestone are assigned to the Leadville limestone. In the western part of the San Juan Mountains, Mississippian fossils have been found locally in the upper part of the upper limestone bed of this group of limestones. Most of the Leadville limestone was removed from this area by weathering before the deposition of the Molas formation. In the Kerber Creek area the Leadville limestone is from 350 to 400 feet thick.

MOLAS FORMATION

The Molas formation is the oldest unit of the Pennsylvanian system. Where seen in the San Juan Mountains area it everywhere overlies a surface of erosion underlain by the Leadville limestone.

[It] is distinguished as a cartographic unit on lithologic grounds, being a well-characterized element in the Carboniferous section, and because it records, in certain pecularities of its sediments, important events of the preceding interval of erosion, including the almost total destruction of a Mississippian formation. There may be a further reason for separating the Molas and Hermosa formations in certain observed faunal differences, which are, however, as yet not sufficiently established to warrant laying much stress upon them. (Cross and Howe, 1905a, p. 5.)

LITHOLOGIC CHARACTER

The following description is taken from the Needle Mountains folio (Cross and Howe, 1905a, p. 5):

The Molas formation is specially characterized by its deep-red, friable, sandy strata, which are variably calcareous and often shaly. They are seldom very distinctly bedded and disintegrate so rapidly on weathering that good exposures are rare. In the lower part of the formation dark chert nodules abound, in many cases making a large part of flat lentils or discontinuous layers. Many of these cherts carry a Mississippian invertebrate fauna, the origin of which has already been discussed. In the uppermost part of the formation, on Stag Mesa, some thin limestones contain the fauna described in a succeeding paragraph, which is believed to characterize the Molas beds.

The best section of the formation thus far observed is situated on the southwest slope of the Needle Mountains, on the south side of Tank Creek. At that locality there is a continuous section, about 75 feet in thickness, representing the whole formation, as there developed, between the Ouray limestone and the Hermosa complex. There is no distinct stratification in the section. At the base is a zone of gradation into the Ouray limestone, for the upper zone of the latter is much broken up, with the red calcareous mud of the Molas filling the interstices. This relation of the formation is very common. For some feet above this transition zone there is a chaotic mixture of chert and limestone fragments, with not a few of bluish or white quartzite, but none of granite or schist. In all the lower part of the section much of the material is an impure limestone, reddish in color, but with the saccharoidal texture of the Ouray. It is probably a calcareous sandstone. The matrix in which the fragments of chert, quartzite, and limestone are held is a red marl-like material. There are in places indications that a calcareous mud was broken up before consolidation and was worked over with the fragments of foreign rocks. From the base upward the section becomes more and more sandy, but chert fragments were found almost up to the fossiliferous limestone of the Hermosa.

While the Molas beds exhibit much variability in texture, the section described is in most respects characteristic.

The chert pebbles which are one of the most notable features of the formation are so abundant locally as to form dark conglomerate layers. These are in many places not continuous. The chert is distributed through the whole formation, and on the inclined mesas south of the Needle Mountains, most of which have scarps of the Ouray limestone, the chert pebbles form, over large areas, almost continuous coatings of residual material, mingled with some of the reddish sandy shale. Many small isolated remnants of the Molas also occur on these mesas.

The cherts are, as a rule, well-rounded pebbles up to 6 inches in diameter. They are dark gray, green, red, white, or nearly black. Some are banded, some homogeneous. In only a portion of them can fossils be found.

FAUMA

On Stag Mesa some thin, discontinuous limestone beds rich in fossils were found intercalated in red and highly ferruginous sands of the Molas and only a few feet below the characteristic limestone at the base of the Hermosa. At no other point have the fossils of the Molas yet been discovered.

The fossils mentioned have been studied by George H. Girty, who has made the following summary statement concerning them:

"The fauna of the Molas formation, though at present imperfectly known, comprises representatives of the echinoids in *Archoeocidaris triplex*?, of the bryozoa in *Rhombopora lepidodendroides*, of the brachiopods in *Rhipidomella pecosi*, *Spirifer boonensis?*, and *Seminula subtilita*, and of the pelecypods in *Myalina perniformis*?. The *Rhombopora*, *Spirifer*, and *Seminula* occur also in the Hermosa formation, and in the case of the latter with the same varietal modifications and with equal abundance. Thus the Molas fauna is seen to be related to that of the Hermosa formation, but contains no species in common with the Ouray limestone. Some points of individuality distinguish the Molas fauna from that of the Hermosa, but it can not be conjectured how far this distinction would be borne out by full collections."

Section across the Molas formation in the northeastern part of the Ignacio quadrangle, about 1 mile northeast of the fish hatchery in Vallecito Valley

	Thickness (feet)
Hermosa formation.	
Molas formation:	
Shale, soft, red, poorly exposed	10
Chert with some limestone, yellow, dark-red, resinous	1½
Shale, red, and nodular limestone	3
Covered. Probably shale like above	15
Limestone and red clay, irregularly mixed. Nodules of limestone as large as a foot across are imbedded in about an equal amount of clay	20±
Like breccia. Yellow or pink limestone penetrated by red mud	6
Limestone, irregular bodies several yards across, irregularly mixed with red clay	30
Total	85
Leadville limestone.	

DISTRIBUTION

The Molas formation is everywhere present between the Leadville limestone and the Hermosa formation. Because it is thin and wastes away rapidly on exposure, it gives few good outcrops but can often be recognized from the red mud and soil above the Leadville. The many benches and mesas underlain by limestone commonly represent remnants of the Molas. Solution cavities in the limestone, some of them several feet deep, are filled with the red mud of the Molas.

HERMOSA FORMATION

NAME AND DISTRIBUTION

The Hermosa formation is a series of alternating limestones, shales, sandstones, and some conglomerate of Pennsylvanian age, having a maximum thickness of 2,000 feet and lying between the Molas and Rico formations. As it is a thick formation and has many hard beds, it is the most widespread of the Paleozoic formations (fig. 5).

DESCRIPTION

The following description is taken from the Needle Mountains folio (Cross and Howe, 1905a, p. 5):

The Hermosa presents a variable development of limestone, sandstone, and shale in different districts. Thus at Rico there is a fairly well-defined division into three sections, the lower consisting chiefly of sandstones and shales with but little limestone, the middle portion being rich in massive limestone beds, the upper containing mainly black and gray shales alternating with green grits and sandstones and with a few limestone layers.

In the Animas Valley, near the mouth of Hermosa Creek, the lower third of the complex is made up of green sandstones and shales with some gypsiferous shales, while the rest of the formation shows limestone layers distributed throughout. Along the great scarp facing the Animas for 10 miles in the Engineer Mountain quadrangle the limestones become more and more prominent and certain bands are very thick.

In the southern part of the Needle Mountains quadrangle the formation has essentially the same characteristics as on the western side of the Animas Valley above Rockwood. In the northwest corner of the quadrangle the limestone members are thinner, but distributed with great regularity in the section.

The limestones are usually massive, bluish gray in color, and commonly contain bituminous matter, causing a distinct odor when struck by the hammer. Many layers are rich in fossils, while others appear to be destitute of them.

The sandstones are generally fine-grained, gray or greenish, consisting largely of quartz but in many cases rich in feldspar. They are massive or thin-bedded with shale partings. The cement is calcareous as a rule and the green color is due to an amorphous substance, the character of which has not been determined.

The shales vary from those which are greenish and sandy in character to dark, calcareous, bituminous varieties.

With all this variety in constitution the basal stratum of the Hermosa over the entire area examined [except in the Ouray quadrangle], is constant. It is a highly fossiliferous limestone somewhat less than 15 feet in thickness. The uppermost strata are not so well known, but in the Rico Mountains they consist of fine-grained micaceous, greenish, sandy shales beneath which is a thin but persistent dark limestone filled with the minute shells of *Triticites secalicus*, formerly called *Fusulina cylindrica*.

Few members of the Hermosa complex reach a thickness of 100 feet. Some limestones and shales attain that figure, but thicknesses ranging from 10 to 50 feet are much more common. Individual strata change laterally, both in character and in thickness. Under these conditions it has been found impracticable to subdivide the complex into smaller lithologic units for purposes of mapping. As will appear from the statements concerning the fauna, no division lines on that basis can be suggested.

Within and near the Silverton quadrangle the formation is characterized by relatively thin limestone layers distributed with comparative regularity from base to top.

In the Ouray quadrangle the fossiliferous limestone is absent from the base of the formation and the lower 300 feet consist of relatively thin alternating beds of sandstone, shale, and a few gnarly fossiliferous limestones. The prevailing colors are dark green, gray, or buff, and here and there reddish or pinkish gray. The upper and great part consists of pink massive grits and sandstones, red sandy shales, and thin gnarly fossiliferous limestone. Heavy limestones are lacking.

FAUNA AND CORRELATION

Cross and Howe (1905a, p. 5) say:

Dr. Girty has summarized his views as to the fauna and correlation of the formation as follows:

"The fauna of the Hermosa formation is distinctly Upper Carboniferous, or Pennsylvanian, in age. * * *"

If the formation be divided into three portions, especially as the division was carried out in the Rico region, the fauna of each is to a certain extent characteristic. That of the lower division consists almost altogether of brachiopods. In the middle division a number of gastropods are introduced, while in the upper, in addition to brachiopods and gastropods surviving from the middle division, a considerable force of pelecypods appears. The brachiopods remain nearly constant in number, but form a diminishing proportion of the entire fauna. The brachiopodous representation remains fairly uniform, though some changes occur in species and abundance. The lower bed especially is often characterized by *Productus gallatinensis*, *Productus inflatus*, and a large variety of *Spirifer* of the *rockymontanus* type.

The fauna of the Hermosa formation also occurs in the Weber limestone and lower Maroon formation of the Crested Butte district, and in the Weber formation of the Tenmile and Leadville districts. From this fact and the similarity in stratigraphic occurrence a correlation of these formations appears to be justified. The Hermosan fauna represents early Pennsylvanian sedimentation, and it is probably older than the upper Coal Measure faunas of the Kansas and Nebraska sections.

Roth (1934) has described a type section of the Hermosa formation from the canyon between Durango and Silverton. He concluded that the formation is equivalent in age to the McCoy formation of Roth.

KERBER FORMATION

The Kerber formation of Pennsylvanian age has been found only in the Kerber Creek area. It has been described by Burbank (1932a, p. 13).

CARBONIFEROUS AND PERMIAN SYSTEMS

MAROON FORMATION

The Maroon formation is found only in the Kerber Creek area where fossils determine its age as Pennsylvanian and Permian. It has been described by Burbank (1932, p. 13–15).

PERMIAN(?) SYSTEM

RICO FORMATION

NAME AND DISTRIBUTION

The Rico formation is a thin series of fossiliferous red beds of Permian (?) age that conformably overlies the Hermosa and is in turn overlain conformably by the Cutler formation. It is believed to be present in the section everywhere on the south and west flanks of the Needle Mountains and in the Rico area but was not found to the north in the Ouray quadrangle.

The following description is taken from the Engineer Mountain folio (Cross and Howe, 1905, p. 6).

DEFINITION

The Rico formation was first discriminated as such during the survey of the mountains from which it derives its name and was originally described in a report on the geology of the Rico Mountains by Cross and Spencer.[a] The name is applied to the lower

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 59.

portion, 250 to 325 feet thick, of the "Red Beds" section of the southwest side of the San Juan Mountains. The beds contain a marine fauna and are thus notably distinguished from the overlying unfossiliferous red strata, to which they bear a striking resemblance in lithologic character. The Rico strata are considered as transitional between marine and fresh-water deposits.

The stratum at the upper limit of the Rico formation as it has been mapped is, except at one locality, mentioned below, the uppermost fossiliferous limestone, or its equivalent where that can be recognized. Discontinuity of exposures and lateral variation in the character of the formation prevent the identification of the equivalent of the highest known fossil-bearing stratum in widely separated sections where fossils cannot be found at that apparent level. The discovery of a fossil-bearing limestone of Rico character in the midst of a section of typical red beds of the Cutler formation on the south face of Engineer Mountain makes it seem probable that the Rico fauna may locally appear considerably above the horizon hitherto supposed to be the top of the formation at its maximum thickness. Although the Rico is thus not a consistently founded formation as to its upper limit, it seems highly desirable to distinguish it as closely as possible from the overlying red beds of the Cutler.

CHARACTER

The formation consists of sandstone and conglomerates with intercalated shales and usually sandy fossiliferous limestones. Lithologically the formation resembles the overlying red beds of the Cutler more than the grayish Hermosa strata below. The basal stratum in and near the Rico Mountains is commonly a sandy limestone or calcareous sandstone of pink color, strongly marked by the abundant shells it contains. These fossils are preserved in white calcite, which contrasts strongly with the pinkish matrix. The manner of occurrence of the Rico fossils is almost diagnostic of the formation near the Rico Mountains, for similar beds do not there appear in the Hermosa. It is much less characteristic in the Animas Valley. Although fossils also occur in thin dark-gray limestones, like those of the Hermosa, at several horizons within the Rico, the features of the lowest stratum are repeated at higher levels in many sections.

The greater part of the formation is made up of sandstones and sandy shales, most of which are highly feldspathic. Many of the massive sandstone or grit beds are conglomeratic, containing pebbles of schist and quartzite. Cross-bedding is common. Some of the shaly beds are chocolate or purplish in color; the grits and sandstones are of lighter shades. The color of the formation as a whole is a much darker red than that of the overlying Cutler formation and where the exposures are good the Rico can be distinguished in a general way by this difference in color at a distance of several miles. The color line is not a sharp one, however, nor does it terminate persistently at a definite horizon.

FOSSILS AND CORRELATION

The fossils of the Rico formation are almost all marine invertebrates. The known fauna embraces approximately 25 genera and 40 species. This material has been studied by G. H. Girty, whose judgments concerning the age and correlation of the formation are given in the succeeding paragraph.

The fauna was originally thought to suggest both Permian and Pennsylvanian affinities. It was therefore called Permo-Carboniferous and was correlated with the Neosho and Chase of the Kansas section. After more detailed and extended comparisons had been made it was referred to the Pennsylvanian without qualification and correlated with distinctly older formations in Kansas—the Deer Creek, Hartford, and Howard limestones.[a] One of the species which was regarded as especially important in the correlation of the Rico is *Chonetes mesolobus*. In Kansas *C. mesolobus* is confined to the lower formations of the Pennsylvanian. In the Rico quadrangle its known occurrence is restricted to a single locality on Dolores River, which has been referred somewhat questionably to the Rico formation. Three other species were found associated with it there, not one of the four being known elsewhere in the Rico. On the other hand, only one of them has been found in the Hermosa formation. The lithologic and stratigraphic evidence is therefore not conclusive in determining the horizon of these fossils as Rico and it is possible that this significant species may have to be left out of the evidence used in correlating the Rico fauna.

A nearly full list of fossils from the Rico formation may be found in the cited report by Cross and Spencer [U. S. Geol. Survey 21st Ann. Rept., pt. 2], and in Professional Paper 16 of the Geological Survey.

CUTLER FORMATION

The following description is taken from the Engineer Mountain folio (Cross and Hole, 1910, p. 7):

LIMITS AND CHARACTER

The Cutler formation was first distinguished as such in the Silverton folio (1905), the name being derived, however, from Cutler Creek, in the Ouray quadrangle, where a characteristic section is exposed. The formation includes a succession of red shales, sandstones, grits, and conglomerates, aggregating 2000 feet as a maximum observed thickness. These strata constitute the greater part of the "Red Beds" of southwestern Colorado. The formation normally overlies the Rico conformably, as may be seen on the south side of the San Juan Mountains, but in the Ouray quadrangle no beds containing the Rico fauna were detected and the Cutler was therefore mapped and described as resting without any visible break on the Hermosa. The base of the Cutler formation is in practice determined by the uppermost fossiliferous stratum assigned to the Rico, or its equivalent, but, as has already been noted, this results in much uncertainty as to the line between the formations in many localities.

The upper limit of the Cutler formation is a stratigraphic break which was first observed in the Ouray quadrangle and which, it seems reasonable to assume, is present in all known sections, since above this break comes the clearly recognizable Dolores formation, of Upper Triassic age.

Except in the Ouray quadrangle, no stratigraphic break between the Cutler and Dolores has been found,

* * * but the field work of 1904 in the Ouray quadrangle on the northern side of the mountains has revealed a notable angular unconformity occurring immediately below the most commonly fossiliferous bed of the Dolores formation. Through this unconformity the Dolores strata may be seen to transgress more than 1000 feet of older 'Red Beds' and several hundred feet of the Hermosa formation, the full extent of the unconformity being obscured by erosion. (Cross, Howe, and Ransome, 1905, p. 5).

Quoting again from the Engineer Mountain folio:

The Cutler formation is composed principally of shallow-water or fluviatile deposits. They are mainly arenaceous but as a rule include a calcareous cement, and thin earthy or sandy limestones are distributed at intervals throughout. Many of these lime-

[a] Girty, G. H., The Carboniferous formations and faunas of Colorado: Prof. Paper U. S. Geol. Survey No. 16, 1903, p. 267.

stones are nodular and some of them form conglomerates of apparently intraformational character.

The fluviatile or continental character of the Cutler formation is suggested by its very abrupt and irregular changes in thickness and by the constitution of its sandstones, conglomerates, and shales. Ripple-marked surfaces and rain-drop impressions are seen on many of its shale layers, cross-bedding is a feature of its sandstones and grits, many of the grits are highly feldspathic, and its conglomerates contain chiefly pebbles of pre-Cambrian rocks.

The strong and bright-red color of the Cutler formation as a whole is very pronounced. The finer-grained beds have the stongest color; the grit and conglomerate strata are generally pinkish but include portions that are gray, white, or dark red.

AGE AND RELATIONS

The Cutler formation was assumed to be Triassic until the discovery of a pronounced break, with local angular unconformity, by which it is now known to be separated from the Triassic beds above.

The absence of recognizable Rico strata below the Cutler on the northern side of the San Juan, already referred to, may be interpreted as indicating either a break or that beds which are fossiliferous in one district are barren in another. The latter explanation is thought to be correct because the Rico fauna occurs in red beds of lithologically pronounced Cutler facies on the south face of Engineer Mountain about 225 feet above the horizon which would otherwise be taken as the upper limit of the Rico. The intervening 225 feet of unfossiliferous beds are lithologically typical of the Cutler. This ocurrence serves to confirm the view already expressed—that the Rico and Cutler formations constitute a series of transitional beds which range from marine to apparrently continental deposits. The Rico formation contains the uppermost marine sediments, but it would seem that the change to continental deposition did not take place at absolutely the same horizon in all parts of the San Juan region.

From its broader stratigraphic relations the Cutler formation is now believed to be equivalent to the beds from which a Permian fauna has been reported in the Grand Canyon district of Utah and Arizona and western New Mexico. It is therefore provisionally referred to the Permian period, but owing to its close relationship with the Rico it may prove to bělong in the Pennsylvanian.

DISTRIBUTION

The Cutler is a thick formation and shows conspicuous bright-red, cliff outcrops. It underlies large areas on the southern and western slopes of the mountains and, in the Engineer Mountain quadrangle, underlies a larger area than any other formation. It also crops out in the Ouray quadrangle. It is well exposed in the Dolores Valley below Rico, in the Animas Canyon above Durango, and in the drainage area of the Florida and Pine rivers in the Ignacio quadrangle.

The Cutler formation was included in the Dolores formation in the Telluride and La Plata folios, but in the map of the San Juan Mountains of this report (pl. 1) the Cutler has been separated as well as possible without further field work from the Dolores and included with the other Carboniferous and Permian formations.

MESOZOIC ROCKS

GENERAL STATEMENT

The Mesozoic sediments are much more widely distributed in the mapped area than are the Paleozoic or Tertiary sediments. They underlie most of the mesa and canyon country that lies to the south and west of the main mountain mass. They also crop out near the northern boundary of the region in the drainage basin of the Gunnison River. They occupy nearly a fifth of the area included on the map. In the southwestern part of the region, the Mesozoic rocks overlie the Paleozoic rocks with apparent regularity and there is no angular unconformity within the Paleozoic or Mesozoic. However, in the Ouray quadrangle there is an angular unconformity at the base of the Mesozoic. In the northern area and in the Canyon of the Piedra River, in the northwestern part of the Pagosa Springs quadrangle, and in the northern part of the mountains, there is striking angular unconformity wthin the Mesozoic at the base of the Jurassic.

The following generalized section (table 7) of the Mesozoic rocks shows their general character and the subdivisions that have been recognized:

The lower part of the section up to and including the Mancos shale is adopted in modified form from Cross's publications, chiefly the Rico folio; the upper part, including most of the Cretaceous, is taken from Reeside's (1924) paper. The published folios include only the formations as high as the Lewis shale. The subdivisions shown in the table have been followed in the published folios, except that the Mesaverde group has not been subdivided. On the map of the San Juan Mountains (pl. 1) the Mesozoic has been divided into the Triassic, Jurassic, and Cretaceous.

For more detailed descriptions of the Mesozoic formations with lists of fossils and discussions of the distribution of the formations to the west and their relations to Mesozoic formation in areas nearby see the published folios by Cross and his associates and the papers on the sediments by Cross (1907, Cross and Howe, 1905, and Reeside, 1924) cited in the references.

An excellent place to study the complete Mesozoic section is near Durango, in the southwestern part of the area. Good sections are also present farther east in the Ignacio quadrangle.

TRIASSIC AND JURASSIC (?) SYSTEMS

DOLORES FORMATION

The Dolores is the upper formation of the red beds. It is of Late Triassic and possibly of Jurassic age. In the southwestern part of the region it appears to be conformable with the Cutler formation of Permian (?) age, but northeast of Ouray it overlies the upturned edges of the Cutler and Hermosa formations. It is

TABLE 7.—*Mesozoic formations of the San Juan region, southwestern Colorado* [1]

Age	Formation	Character	*Thickness (feet)*
Upper Cretaceous	Unconformity.		
	McDermott formation.	In the north, andesitic tuff and tuffaceous sandstone and shale, mostly purple, with a small amount of conglomerate of pebbles of siliceous rocks. The proportion of purely volcanic material decreases southward. Heretofore included in Animas formation.	0–400
	Local unconformity.		
	Kirtland shale.	Light-gray to blue-gray shale, with some black carbonaceous and brown shale and soft white sandstone. Fluviatile.	0–475
		Farmington sandstone member; gray to brown indurated sandstone lenses separated by gray shales. Fluviatile.	0–500
		Shale and soft sandstone like those of upper member. Fluviatile.	0–400
	Fruitland formation.	Gray sandy shale, gray-white cross-bedded soft sandstone, brown indurated sandstone, carbonaceous shale, and coal. Of fresh and brackish water origin.	75–450
	Pictured Cliffs sandstone.	Buff to light-yellow and gray sandstone, interbedded in the lower part with thin gray shale. Marine.	100–400
	Lewis shale.	Greenish-gray and dark-gray sandy shale with a few lenses of brown sandy limestone and buff concretions. Marine.	1, 600–2, 300
	Mesaverde group. Cliff House sandstone.	Yellow to red-brown sandstone with some sandy shale. Some beds massive. Cliff-forming. Marine.	90–400
	Mesaverde group. Menefee formation.	Gray shale, with some sandstone and coal. Coal beds grouped near top and base of formation; barren interval between. Rocks of fresh and brackish water origin, with only a few marine beds.	270–340
	Mesaverde group. Point Lookout sandstone.	Massive buff or cream-colored to red-brown sandstone. Marine.	60–300
	Mancos shale.	Dark-gray and drab sandy shales with a sandstone lentil 35 feet thick 735 feet above base. Contains thin discontinuous fossiliferous limestone layers. Marine.	1, 200–2, 000
Upper and Lower Cretaceous	Dakota (?) sandstone.	Gray or rusty-brown quartzose sandstone with shale lenses and coal. Variable conglomerate of small chert pebbles at base. Forms cliffs and mesas.	100–250
Jurassic	Morrison formation.	Includes the upper sandstone bed of the † La Plata of Cross, the underlying limestone, and all of the † McElmo in San Juan Mountains. The base is commonly a thin layer of thin-bedded limestone, in part brecciated. Over that is a bed of nearly white, cross-bedded, but well-bedded sugary sandstone. The main part is alternating thin friable fine-grained yellowish or gray sandstones and variegated shales and some thin limestones. The shales are mostly green, but some are pink, dark red, or chocolate brown. Nonmarine.	150–1, 000
	Entrada sandstone.	A massive friable cross-bedded pinkish to white quartzose sandstone. Forms cliffs. Probably terrestrial. The basal sandstone of the † La Plata of Cross.	0–200
Upper Triassic and Jurassic (?)	Unconformity in eastern part.		
	Dolores formation.	The upper part is very fine even-grained, poorly bedded bright-red sandstone and shale. The lower part consists of reddish sandstone, more or less shaly, with thin beds and lenses of fossiliferous conglomerate, made up chiefly of small limestone pellets and fragments. Terrestrial.	0–300
	Unconformity in western part.		

[1] Modified from Reeside (1924, p. 4–5), from folios of the Geologic Atlas, and from Cross and Larsen (1935).
† Indicates name no longer in use by the Geological Survey.

present between the Cutler formation and the Entrada sandstone from the extreme western part of the Pagosa Springs quadrangle westward and northwestward as far as the Ouray quadrangle. In the rest of the Pagosa Springs quadrangle and in the adjoining San Cristobal quadrangle it was removed by erosion before the Entrada sandstone was laid down. It was similarly removed by erosion in the northern part of the region, from the northern part of the Ouray quadrangle to the north and east as far as the sediments extend. Its thickness is variable, owing to the removal of the upper part by erosion. In the Rico quadrangle it is 800 feet thick, but it becomes rapidly thinner to the northeast and southeast.

The formation is made up of two parts. The lower part is several hundred feet thick and consists chiefly of reddish more or less shaly sandstone, with several beds of nearly white conglomerate that is made up chiefly of small limestone pebbles. These conglomerates carry fossil bones and teeth of crocodiles and dinosaurs. They are the most characteristic beds of the formation. The upper part is mostly a very even, fine-grained, poorly bedded, reddish sandstone with some sandy shales. It is made up chiefly of quartz and has a calcareous cement.

In the Ignacio quadrangle the Dolores formation can be divided into the same two members as in the northwest. A section from south of Miller Creek is:

	Thickness (feet)
Dolores formation (top not exposed):	
Sandstone and shale, red	150±
Poorly exposed. Thin-bedded	150±
Conglomerate, gray, and shaly sandstone	8
Shale, greenish-gray to reddish, micaceous, with some sandstone and lenses of conglomerate. The conglomerate fragments are as large as 5 inches across and are shale	15
Conglomerate, red	8
Sandstone, red, thin-bedded, especially near top	14
Conglomerate and sandstone, saurian-bearing	16

In this area the lower saurian-bearing conglomerate is fairly persistent and uniform in thickness. The overlying green shale varies in thickness and in the amount of sandstone and conglomerate it contains. The upper sandstone is persistent but variable in thickness.

JURASSIC SYSTEM

The rocks between the Dolores formation and the Lower Cretaceous were first called Gunnison formation. Later they were divided by Cross into La Plata sandstone and McElmo formation and were assigned to the Jurassic. The names proposed by Cross were used by most later authors. However, these names have been abandoned, and are now replaced by Entrada sandstone, Summerville formation, and Morrison formation. There is no doubt that the lower sandstone member of the La Plata sandstone of Cross is the Entrada sandstone, of Late Jurassic age, whereas the shale and limestone member above that sandstone, the upper part of the La Plata sandstone, and the whole of the McElmo formation in the San Juan Mountains are of Morrison age. At the type locality of the McElmo formation in McElmo Canyon the basal part of the formation is interpreted to represent the Summerville formation, but this does not extend eastward into the region described in this paper.

RELATION TO UNDERLYING AND OVERLYING FORMATIONS

The Jurassic rocks overlie one of the greatest unconformities that have been found in the San Juan Mountains. On the western and southwestern parts of the mapped area they rest with apparent conformity on the Triassic and Jurassic(?) Dolores formation, and the only indication of erosion between these two continental deposits is the variable thickness of the Dolores, especially of the upper part of the Dolores.

However, in the northwestern part of the area the unconformity is well shown. In the Uncompahgre Valley near Ouray the Jurassic beds rest on the Dolores formation as they do to the south, but only a few miles to the northeast in the Cow Creek drainage area the Dolores is missing and the Jurassic rests directly on the Cutler formation. The base of these beds is not exposed between Uncompahgre valley and Cow Creek, but to the northeast for about 25 miles in the Gunnison River canyon, the Morrison formation rests directly on the pre-Cambrian. In this distance the whole section of Paleozoic rocks, nearly 4,000 feet thick, must have been upturned and removed before the deposition of the Morrison beds. Farther east for about 60 miles, in the Uncompahgre and Cochetopa quadrangles, the Morrison beds rest on the pre-Cambrian. Not far to the north in the Elk Mountains they rest unconformably on Paleozoic rocks (Emmons, Cross, and Eldridge, 1894, p. 6).

Again, in the Ignacio quadrangle in the southern part of the mountains, the Jurassic rests with apparent conformity on the Dolores formation, but only a few miles to the east in the southwestern part of the San Cristobal quadrangle and adjoining parts of the Pagosa Springs quadrangle it rests directly on the pre-Cambrian. In the northeastern part of the Ignacio quadrangle, southwest of Vallecito, the contact of the Entrada sandstone and Dolores is well exposed in cliffs. The Entrada rests on a surface that has erosional channels cut in the Dolores and the contact cuts across the beds of the Dolores. However, there is no apparent discordance of dips.

In the Piedra Canyon in the northwestern part of the Pagosa Springs quadrangle, an angular unconformity is especially well shown. Three great anticlines in the pre-Entrada rocks were eroded and the Entrada sandstone rests on the bevelled, upturned edges of the older sediments and, in the centers of the eastern anticlines, on the pre-Cambrian (Cross and Larsen, 1914, p. 40–42). To the northeast the Entrada sandstone rests on the pre-Cambrian but it is not exposed east of the Piedra. Only a few miles west of this trangression and for many miles beyond to the west and northwest, the section appears conformable.

It seems clear that this great pre-Entrada uplifted mass was only a little to the east and north of the present Needle Mountains and that it may have occupied an area comparable to that of the San Juan Mountains. West of the uplift the surface was not appreciably warped and remained low enough to undergo no great amount of erosion.

The base of the Jurassic beds is everywhere a remarkably smooth surface, and this is especially well shown where the formation overlies the upturned edges of Paleozoic sediments or pre-Cambrian rocks. Preceding the deposition of the Jurassic there must have been a long interval of erosion sufficient to wear down the mountains to a peneplain with very little relief.

The Morrison formation is overlain conformably by the Dakota sandstone of Early Cretaceous age.

AGE

No fossils satisfactory for determining the age of the Jurassic formation have been found in the San Juan area. A few fish scales have been found in the limestones and shales between the two sandstone beds of the so-called La Plata (base of Morrison) and fish impressions were found in the northwestern part of the Pagosa Springs quadrangle, in the Piedra Canyon below the mouth of Weminuche Creek.

Eldridge found fresh-water shells in the limestones of the Morrison formation in the Elk Mountains some miles north of the area. Vertebrate remains have been found in the Morrison beds west and northwest of the San Juan area and] have demonstrated the Jurassic age of the beds.

DISTRIBUTION]

The Jurassic formations are widely distributed over the Dolores formation in the southwestern and western parts of the area. In the extreme southwestern part of the San Cristobal quadrangle and adjoining part of the Pagosa Springs quadrangle, they directly overlie pre-Cambrian or Paleozoic rocks. To the east they are covered by younger rocks. Northeast of Ouray they directly overlie the pre-Cambrian in the Gunnison basin and are known to crop out as far east as the western boundary of the Saguache quadrangle. Here they end against the Crookton fault. Just north of Saguache Creek in the western part of the Saguache quadrangle in a small gulch just east of Antelope Creek, a small outcrop of pre-Cambrian rock overlain by the Morrison formation and the Dakota sandstone is exposed and surrounded by Conejos quartz latite.

ENTRADA SANDSTONE

The lower, massive sandstone of the La Plata of Cross represents the Entrada sandstone. It is white to cream, rarely pink, of sugary texture, crossbedded, friable, and made up mostly of quartz grains. It crops out as prominent, nearly white, rounded cliffs which are in marked contrast to the red outcrops of the underlying Dolores formation but are in gross aspect much like the overlying sandstone of the Morrison formation (the upper sandstone of the La Plata of Cross). The Entrada sandstone is about 200 feet thick in the La Plata quadrangle but becomes thinner to the north and is absent in the valley of the Gunnison River. To the southeast it also becomes thinner, and it is only 15 to 25 feet thick in the eastern part of the Ignacio quadrangle and is less than 100 feet thick to the southeast in the northwestern part of the Pagosa Springs quadrangle.

MORRISON FORMATION

The Morrison formation includes (1) the discontinuous limestone, in places massive, in places platy or brecciated, that separates the two sandstones of the La Plata of Cross, (2) the upper sandstones of the La Plata, and (3) all of the McElmo. The sandstone above the basal limestone of the Morrison is somewhat like the Entrada sandstone, although it is usually thinner-bedded and differs in its slightly greenish to chalky-white color and its fineness of grain. The overlying and main part of the Morrison (the McElmo of Cross) is a variable complex of limestones, shales, and sandstones. The sandstones are commonly nearly white and resemble the Entrada sandstone; the shales are generally green; but some layers are pink, deep red, or yellow. The beds weather readily and give poor exposures. The Morrison beds reach a thickness of 1,000 feet in the western part of the mapped area, but they are usually thinner, particularly to the east. In the Cochetopa quadrangle they are less than 200 feet thick.

A typical section of the formation in the northern part of the Uncompahgre quadrangle is shown below.

Section of Morrison formation in Uncompahgre quadrangle on the east side of Willow Creek, northwest of Iola, measured by Larsen and Hunter

	Thickness (feet)
Dakota sandstone.	
Morrison formation:	
Poorly exposed soft material, mostly shale, drab to greenish, locally red patches	40
Shale, hard, thin-bedded in middle and coarse above and below, drab to greenish	3
Shale, soft, poorly exposed, similar to top unit	20
Sandstone, shaly, thin-bedded, hard, becoming argillaceous toward bottom, drab	3
Shale, drab	2
Shale, with harder sandy layers near top and bottom, drab to gray	10
Shale, soft, poorly exposed	15
Shale, arenaceous, light-drab, with layers of harder material at top, middle, and bottom	15
Shale, soft, with arenaceous layers, poorly exposed	25
Grit, medium fine-grained, yellow to brown	8
Shale, drab, poorly exposed	20
Shale, arenaceous	2
Shale, soft	10
Sandstone, argillaceous, brown	2
Covered, probably soft shale	40
Sandstone, white; several beds. Some are yellow or iron-stained	90+
Total	305

The Morrison formation reaches a thickness of 1,000 feet in the western part of the mapped area but it is only about 350 feet thick in the eastern part of the Ignacio quadrangle. In the Ouray quadrangle in the northwestern part of the area the formation is about 200 feet thick; in the eastern part of the Uncompahgre quadrangle it is about 300 feet thick, and farther east it is thinner.

Few fossils have been found in the Morrison formation of this region. Fish scales and a few well-preserved fish skeletons have been found in the platy limestones at the base of the Morrison between the lower and upper sandstones of the so-called La Plata. The best fish skeletons were found in Weminuche Creek and Piedra Canyon in the San Cristobal and Pagosa Springs quadrangles. The formation is considered by some geologists to be of Late Jurassic age and by others to be of Early Cretaceous age. The United States Geological Survey has classified it as Jurassic.

CRETACEOUS SYSTEM

DISTRIBUTION

Rocks of Early and Late Cretaceous age are widely distributed in the area and they border the mountains of pre-Cambrian and Paleozoic rock from the southwestern part of the Conejos quadrangle on the southeast to the west and northwest into the northeastern part of the Uncompahgre quadrangle. Farther east, in the Gunnison River drainage area, remnants of these rocks crop out as far as the western border of the Saguache quadrangle. They are thus the most widespread of any of the formations in the area and they probably underlie the largest area of any mapped unit in the San Juan Mountains (pl. 1).

The two lower formations, the Dakota sandstone and the Mancos shale, are the most widespread and are present in all the great area to the south, west, and north of the mountains. The overlying Mesaverde group is present in the southern and locally in the northwestern parts of the area.

The overlying formations are exposed only in the southern part of the area, under the Eocene sediments.

SUBDIVISIONS

The subdivisions of the Cretaceous are shown in table 7, page 49. They are largely taken from Reeside (1924, p. 4–5), as are most of the descriptions of the formations.

In the published folios of the San Juan area the Cretaceous was described only as far up in the section as the Lewis shale and the subdivisions as shown by Reeside were followed except that the Mesaverde group was not subdivided. On the small-scale map of the whole San Juan area (pl. 1) the Cretaceous is mapped as a unit.

In the following pages the subdvisions of the Cretaceous will be briefly described. For more detailed descriptions the reader is referred to the published folios for the lower formations and to Reeside's paper for upper formations.

DAKOTA SANDSTONE

The Dakota sandstone is the most widely distributed of the Cretaceous formations and, as it caps great mesas, it also underlies a very large area.

The following description by Cross is taken from the Engineer Mountain folio (Cross and Hole, 1910, p. 5):

> [The Dakota sandstone] is composed of variable gray or brownish quartzose sandstones, much cross-bedded, with a peculiar conglomerate at or near the base and several shaly layers at different horizons. Its thickness in the Engineer Mountain quadrangle ranges from 100 to 150 feet. The basal conglomerate, carrying small chert pebbles of white, dark-gray, or reddish colors, which is so persistent over large areas adjacent to the Rocky Mountains, is here rather variable in development. Conglomerate of this character is not, moreover, strictly confined to the base of the section.
>
> The thin-bedded sandstones occur in zones 30 to 40 feet thick. These zones are separated by variable sandy shales which as a rule are carbonaceous and carry thin seams of coal. The shale members are strongly developed near the middle and again near the top of the formation. They contain abundant indistinct plant remains.

The coal has been mined locally but is of poor quality.

A section of the Dakota sandstone in the Telluride quadrangle is given in the Telluride folio. The following section was measured in the Uncompahgre quadrangle, on the north side of Gunnison Canyon, about a half mile east of Cebolla.

	Thickness (feet)
Mancos shale.	
Dakota sandstone:	
Sandstone, white, heavy-bedded, with many small pebbles of chert, sandstone, etc. Somewhat cross-bedded. Weathers yellow and makes cliffs with angular to subangular projections. Cavernous	40
Sandstone, thin-bedded, with soft, shaly partings	8
Sandstone, gray to pink. Massive beds 1–5 feet thick, with partings of softer sandstone. Coarse-bedded in part; a cliff maker	32
Sandstone, with conglomeratic lenses, cross-bedded	15
Total	95

The section in the Uncompahgre quadrangle is thinner and has less shale and carbonaceous matter than that in the Telluride quadrangle but they are otherwise similar.

The Dakota sandstone is one of the most resistant formations in the area and it is underlain by much softer beds. It therefore forms prominent cliffs and great plateaus and mesas where the dips are gentle, and prominent hogbacks where the dips are steep.

MANCOS SHALE

The following description of the Mancos shale which overlies the Dakota sandstone, is taken from the Engineer Mountain folio (Cross and Hole, 1910, p. 8):

> In its typical development the formation is a series of dark clay-shale beds nearly 2,000 feet thick, presenting no persistent lithologic or paleontologic horizon which can be used as a guide to subdivision. The shales are characteristically of a dark-gray or lead color and are nearly everywhere somewhat sandy. Near the base two calcareous layers become limestones in places and are locally rich in fossils. Thin sandstones also appear here and there in the basal part of the formation, but neither the limestone nor the sandstone layer is developed with sufficient uniformity to be traced for considerable distances. The invertebrate fossils occur chiefly at horizons about 125 and 225 feet above the Dakota sandstone.

According to Reeside (1924, p. 9), there are a few thin layers of sandstone near the top of the Mancos south of Durango and ferruginous, yellow-brown concretions at many places.

The Mancos shale is easily eroded and it forms broad valleys or rounded hills with very few exposures. Where it underlies the thick formations of volcanic breccia it gives way under the load and large areas of relatively steep slopes are covered by landslide. Such areas are well shown under the San Juan tuff in the Montrose, Telluride, and Uncompahgre quadrangles, and also under the Conejos andesite on the southern slopes of the mountains.

Invertebrate fossils are common in the Mancos shale. For a list of fauna, see Reeside (1924, p. 11–13). The lower part of the shale is of Colorado age and the upper few hundred feet is of Montana age.

The Mancos shale on the east bank of the Late Fork of the Gunnison River, about 300 feet south of Gateway, in the Uncompahgre quadrangle, is well exposed for about 100 feet along the river and for a thickness of about 10 feet. It contains a few shells which have been identified by T. W. Stanton as *Inoceramus barabina*.

MESAVERDE GROUP

The Mesaverde group is present in the southwestern part of the area from the Summitville to the La Plata quadrangles. It is absent to the north except in the eastern part of the Montrose and extreme western part of the Uncompahgre quadrangles, where remnants of this formation remain.

The Mesaverde group has been divided by Collier (1919), into three formations: The Cliff House sandstone at the top, the Menefee formation in the middle, and the Point Lookout sandstone at the base. The following descriptions of these members are taken from Reeside (1924, p. 13–14):

> At the type locality the Point Lookout sandstone is a massive cliff-forming gray to brown marine sandstone; the Menefee formation is a variable assemblage of sandstone and shale with three groups of coal beds, and is of both marine and fresh-water origin; and the Cliff House sandstone is variable in character though essentially a massive marine sandstone. This general description of the three lithologic units may be applied around the entire western side of the San Juan Basin, though the exposures on Animas and Florida Rivers show the three-fold division less clearly than those to the west.

The Menefee formation of the Mesaverde group contains the most important coal beds in southwestern Colorado.

The Mesaverde group is separated from both the Mancos shale below and the Lewis shale above by a zone of transition beds.

As shown by table 8, compiled from Reeside, the Mesaverde group seems to be thinner east of the type locality and thicker to the south.

TABLE 8.—*Thicknesses of the Mesaverde group*

Formation	1	2	3	4	5	6
Cliff House sandstone	400	90	410	200+	750	20
Menefee formation	400	272	340	700	1,076	600
Point Lookout sandstone	250-300	60	270	225	300	400
Total	1,100	422	1,020	1,200-1,300	2,126	1,020

1. Mesa Verde, Montezuma County, Colo. Type locality.
2. Florida River, Colorado.
3. Red Mesa quadrangle.
4. Near Colorado-New Mexico boundary in T. 32 N., R. 14 W., New Mexico.
5. San Juan River, below Farmington, N. Mex.
6. La Plata quadrangle, Colo.

Invertebrate fossils are abundant in the formation and have been described by Reeside (1924, p. 15). Plant remains are also found. The age is Montana.

LEWIS SHALE

The Lewis shale is exposed only in the southern part of the area. It is much like the Mancos shale. The following description is quoted from Reeside (1924, p. 16–17):

It is a fairly homogeneous mass of dark-gray to greenish-gray shale with some sandy layers; some limestone, and numerous calcareous concretions; some yellow and splintery, others blue-gray, dense, and tough. In New Mexico the Lewis is sandier than in Colorado, though containing layers of impure limestone and yellow limestone concretions.

The thickness of the Lewis shale is 1,700 feet at the type locality near Fort Lewis, La Plata County, Colo., 1,600 feet near Durango, and 2,290 feet near Pine River. It is thinner to the south in New Mexico, and about 50 miles south of the State boundary it is less than 100 feet thick.

The Lewis shale grades into both the Cliff House sandstone below and the Pictured Cliffs sandstone above.

For a description of the fossils from the shale the reader is referred to Reeside's report (1924, p. 17–18).

The Lewis shale is of Montana age and the thick part on the north side of the San Juan basin is probably of the same age as the upper part of the Mesaverde group on the south side.

PICTURED CLIFFS SANDSTONE

According to Reeside (1924, p. 18–19), the pictured Cliffs sandstone in the Ignacio quadrangle east of Durango, Colo., "* * * is at most places composed of two heavy beds of sandstone separated locally by shale and coal. The formation is the highest marine deposit of the region."

Its thickness is variable. On the Florida River it is 394 feet thick and it seems to become thinner eastward and southward. On the divide between the Pine and Piedra Rivers it is 125 feet thick, in the Red Mesa quadrangle it is 240 feet thick, and on Cat Creek near Pagosa Junction it is 150 feet thick.

Fossils are described by Reeside. It is of Montana age.

FRUITLAND FORMATION

The Fruitland formation (Reeside, 1924, p. 20) "* * * is of brackish and freshwater origin and is composed of gray to brown, hard sandstone, gray-white soft sandstone, gray, brown, and black shale, and coal."

Bauer and Reeside (1920, p. 167) say:

The formation consists of sandstone, shale, and coal, very irregularly bedded. In constitution the various beds range from shale to sandstone with every conceivable intermediate phase of sandy shale and shaly sandstone. The marked variation both laterally and vertically is shown at many places by the unequal resistance to weathering and consequent production of fantastic assemblages of pillars, knobs, "mushroom" rocks, and other forms. This irregularity is most marked in the gray-white sandstone and gray sandy shale, but it affects to some degree, the coal beds also. The coal beds are distributed throughout the formation, but are more abundant and generally thicker in its lower portion. The Fruitland formation is further characterized by the presence of large concretions of iron carbonate which weathers dark brown or black. Many of these concretions have been converted by veins of crystallized barite into large septaria.

The Fruitland formation is from 350 to 400 feet thick between the Piedra and Pine Rivers. On the Florida River it is 438 feet thick and in the Red Mesa quadrangle it is 430 feet thick.

The Fruitland formation grades into the underlying marine sediments of the Pictured Cliffs sandstone and also into the overlying Kirtland shale.

The formation contains both vertebrate and invertebrate fossils and also plant remains. Reeside (1924, p. 21) lists the known forms, and considers that the formation is of Montana age.

KIRTLAND SHALE

The following description is quoted from Reeside (1924, p. 21–22):

At the type locality the Kirtland shale may be divided into three groups of beds forming distinct members, all of fresh-water origin. The lower member consists mainly of gray shale with some brown and black carbonaceous layers and a minor amount of bluish, greenish, and yellow sandy shale and of soft, easily weathered gray-white sandstones, all irregularly bedded. The middle member contains many irregular lenses of sandstone, soft, gray, and unresistant below but hard, brown, and resistant above. This member was named the Farmington sandstone member by Bauer. The upper member, like the lower member, consists of shale and soft sandstone.

The shaly parts of the Kirtland contain considerable barite in the form of small concretions and veins. Gypsum also is present as sheets in joint planes and as crystals, aragonite in rounded brown fibrous concretions, and siderite in concretions. Silicified wood is common. The shales weather into rounded billowy forms, and where erosion is rapid and the dip of the beds low they have formed extensive badlands. Where the dip is high the shale members form marked valleys.

The sandstones of the Farmington sandstone member are irregular, cross-bedded, and composed almost invariably of two parts—a lower, soft, easily eroded yellow to white sandstone containing clay pellets and locally sandstone balls of material like the matrix and reaching 4 inches in diameter, and an upper, hard sandstone which is fine-grained, dark gray on a fresh surface and dark ferruginous brown on weathered surfaces. These lenses are of small lateral extent, not reaching more than several hundred yards as a rule, and few of them exceed 20 feet in thickness. The writer has not anywhere found pebbles in the Farmington sandstone. The sandstones of the Farmigton member make marked benches where the dip of the beds is low and a ridge where the dip is high.

Except in Bridge Timber Mountain southwest of Durango where younger rocks overlap the formation, all three divisions of the Kirtland formation are mapped by Reeside (1924, pl. 1), from the southern part of the Red Mesa quadrangle northeast, to the eastern boundary of the Ignacio quadrangle. Just beyond, the upper member was removed by erosion preceding the deposition of the Animas formation and still farther southeast, more and more of the formation was removed.

The thickness of the Kirtland shale is shown in table 9.

The Kirtland shale shows a gradational contact with the underlying Fruitland formation. In most places it seems also to have a conformable and gradational contact with the overlying McDermott formation, although locally there was erosion between the two.

The formation has yielded fossils in the New Mexico area that determine its age to be Montana.

TABLE 9.—*Thicknesses of the Kirtland shale*

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Upper shale	0	0	0	135	150	200	190	475
Farmington sandstone	0	0	250	480	162	270	370	350
Lower shale	Present	140	195	215	320	300	370	240
Total	--------	140	445	830	632	770	930	1,065

1. Cat Creek, near Pagosa Junction, Colo.
2. Piedra River, Archuleta County, Colo.
3. Pine River, Piedra River divide, Colo.
4. Los Finos River, La Plata County, Colo.
5. Florida River.
6. Animas River.
7. Southern part of Red Mesa quadrangle, Colo.
8. Colorado-New Mexico State boundary.

McDERMOTT FORMATION

The name McDermott formation was proposed by Reeside (1924, p. 24) "* * * for a series of lenticular sandstones, shales, and conglomerates containing much andesitic debris, and usually of purple color. * * * The formation appears to be conformable on the Kirtland shale and at the type locality is overlain unconformably by the Torrejon formation." Locally it appears to overlie the Kirtland unconformably.

It is of especial interest because it is the first of the formations to carry volcanic debris and marks the beginning of the long period of volcanism.

The formation is present in the Red Mesa quadrangle and extends northeastward to the divide between Florida and Pine Rivers except in Bridge Timber Mountain, southwest of Durango, where it is covered by overlap of younger rocks. Farther east it was removed by erosion before the deposition of the Animas formation.

The "Ruby" formation of the Anthracite quadrangle, about 20 miles north of the Uncompahgre quadrangle, resembles the McDermott and Animas formations and it occupies about the same position in the geologic column—conformably over the youngest Cretaceous beds of the area and unconformably below the Wasatch formation (Emmons, Cross, and Eldridge, 1894, p. 7).

> At the type locality the McDermott formation consists of an irregular assemblage of brown to yellow soft sandstone; gray-white coarse tuffaceous sandstone; purple, yellow and bluish-gray tuffaceous shale; green to drab coarse conglomerate with matrix almost entirely of andesitic debris and pebbles and cobbles nearly all of weathered andesite; in the upper part of the formation conglomerate with rusty brown matrix and pebbles nearly all of siliceous, resistant rocks, such as quartz, quartzite, and chert. Nearly all the finer-grained parts of the formation contain some volcanic debris, the purple shale particularly. Northward from the type locality the proportion of andesitic material in the formation increases. On Animas River it is composed of fairly pure and little-weathered andesitic debris, predominantly purple. Some beds of it are very coarse indeed, masses several feet in diameter being common. East of Animas River notable beds of siliceous pebbles are present in the lower part of the formation, associated with yellow sandstone. Southward from the type locality the proportion of volcanic matter decreases.* * *
>
> Over most of the exposure in the Ignacio quadrangle—that is, from Bridge Timber Mountain to the divide between Florida and Pine Rivers—the McDermott formation is overlain by the Animas formation. On Animas River the contact is marked by an angular discordance and a sharp color contrast between the purple McDermott formation and the greenish to brown Animas formation. At most other localities the sharp change in color is evident though a discordance in dip or local evidence of erosion has not been detected. The lower beds of the Animas formation are usually coarse and composed largely of andesitic debris, but they differ from the McDermott formation in containing much more weathered detritus and more non-volcanic material. Eastward from the divide between Pine River and Piedra River the Animas formation is in contact with successively lower beds of the McDermott formation, the Kirtland shale, and part of the Fruitland formation, and the evidence of the pre-Animas erosion is very clear. It is the writer's belief that the Animas formation is everywhere unconformable upon the McDermott formation and that there is, in fact, a notable gap at this contact. (Reeside 1924, p. 25–26).

The thickness of the McDermott formation is highly variable. In Colorado it usually ranges from 200 to 400 feet, but to the south it becomes much thinner.

AGE

Locally the McDermott formation carries bones and plant remains which indicate a Cretaceous age for the beds, but this is not conclusive.

PEBBLES FROM THE McDERMOTT AND ANIMAS FORMATIONS

Reeside kindly furnished the authors several hundred pebbles collected from several localities in the San Juan basin and at several horizons in the sediments. The pebbles are chiefly of volcanic rocks but some are quartzite, chert, argillite, and other metamorphic rocks.

The volcanic rocks show a surprisingly small range in character and fall into two groups, the one andesitic, the other rhyolitic. At most localities the volcanic pebbles from a bed are all of one type of rock—either rhyolites or andesites, but at some both types are abundant. The rocks do not resemble the Miocene and younger volcanic rocks of the San Juan Mountains. All of the rocks are more or less altered to secondary carbonate, sericite, chloritic minerals, and others. The plagioclase is partly replaced by sericite, a clay mineral, and carbonate, and some of it is albitized. The orthoclase, probably originally sanidine, has unmixed and is now microperthite. The mafic minerals are largely decomposed.

RHYOLITES

The rhyolites are all dense and range in color from white to red-brown to nearly black. Many of them contain as much as 10 percent of phenocrysts of quartz, sodic plagioclase, and microperthite from 1 to 3 millimeters long. Some lack one or all of these minerals as phenocrysts. The groundmasses are, in general, more coarsely crystalline than those of most rhyolite. Some are spherulitic, some granophyric, and some fluidal. For the most part they are of the type commonly called quartz porphyry. Such rocks are rare in the younger volcanic rocks of the San Juan Mountains and are present chiefly in the Sunshine Peak rhyolite.

ANDESITES

The darker rocks contain from 20 to 35 percent of labradorite as phenocrysts about 1 or 2 mm long. They also contain augite, brownish hornblende, and traces of biotite. The plagioclase is zoned, and the hornblende more or less resorbed. The groundmass in more than half the specimens is a felted mass of feldspar tablets, containing both sodic plagioclase and orthoclase but no quartz. The rocks are andesites and latites with little or no quartz and are not like the quartz latites found in younger volcanic rocks of the San Juan Mountains. In some of the rocks the groundmass is very fine textured to glassy.

An analysis of a specimen (SJ 171–1) of a typical andesite fresher than most is given in table 10.

The analyzed rock was collected by Reeside (1924, p. 51) from the bank of the Animas River 4 miles south of Durango, Colo., from a conglomerate 15 feet thick in the McDermott formation and 173 feet above its base. The rock is dense, dull gray, and has abundant phenocrysts, chiefly less than 2 millimeters long, of plagioclase tablets and pyroxene. The plagioclase has the color of the groundmass, because of inclusions. It is albitized along cracks and has some secondary calcite and clay. The fresh feldspar is labradorite (An_{65}). The pyroxene is augite and is fresh. There is much black opaque material in large irregular grains. Some of it is probably secondary. The groundmass is distinctly crystalline and is made up chiefly of sodic plagioclase in stout crystals or irregular grains. There may be a little orthoclase. The whole rock has been somewhat albitized and the large amount of soda may have been partly introduced. However, the rock has the appearance of an andesite, with very sodic feldspar in the groundmass.

TABLE 10.—*Analysis, norm, and mode of pebble of andesite from the conglomerate of the McDermott formation*

[Analysis by F. A. Gonyer, 1940]

Analysis		*Norm*	
SiO_2	53.61	or	8.90
Al_2O_3	18.48	ab	47.16
Fe_2O_3	5.89	an	20.57
FeO	1.72	di	11.23
MgO	2.72	ol	.98
CaO	7.54	il	2.28
Na_2O	5.58	mt	2.32
K_2O	1.53	hm	4.32
H_2O-	.22	ap	1.39
H_2O+	.78	*Symbol:*	
TiO_2	1.25	II.5.″3.4(5)	
P_5O	.41	Beerbachose-andose.	
CO_2	None	*Mode*	
SO_3	.06	Plagioclase An_{65}	50
MnO	.07	Pyroxene	11
BaO	.07	Groundmass	39
SrO	None		
Total	99.93		

MISCELLANEOUS ROCKS

A single specimen of micromonzonite was found and one of a quartz latite.

DISTRIBUTION OF ROCK TYPES

In the collections from the Animas formation, andesites are about three times as abundant as rhyolites. There seems to be no systematic distribution of the types in the section. At the type locality 4 miles south of Durango all the volcanic pebbles from three separate collections from near the base are andesites, and those from two collections from 135 feet above the base are equally divided between andesites and rhyolites. However, a collection from 2 miles southeast of Durango is nearly all rhyolites. Two collections from the upper part of the formation—one from 500 feet above the base in sec. 24, T. 35, R. 1 W., and the other from the highest layer exposed near Carbon Junction—are nearly all andesites.

Volcanic pebbles collected from eight localities from the McDermott formation are all andesites. However, the volcanic pebbles of a collection from the top of the McDermott formation, 4 miles south of Durango, are all rhyolites. The Animas of Coal Creek, northeast of Durango, contains pebbles of both andesite and rhyolite.

TABLE 11.—*Analyses, norms, and modes of Late Cretaceous or early Eocene granodiorite porphyry*

[After Burbank, 1936, p. 237-238]

Analyses	1	2	3	*Norms*	1	2	3
SiO_2	65.38	65.02	65.35	Q	20.16	20.46	20.64
Al_2O_3	15.41	15.83	16.09	or	20.02	20.02	19.46
Fe_2O_3	1.97	2.13	2.69	ab	35.11	34.06	37.20
FeO	2.19	1.56	1.40	an	12.79	14.46	10.56
MgO	1.43	1.14	1.33	C	.20	.20	1.40
CaO	2.87	3.32	2.52	hy	4.66	3.43	3.30
Na_2O	4.13	4.03	4.44	mt	3.02	3.25	3.48
K_2O	3.42	3.42	3.34	il	1.67	.80	.80
H_2O-	.09	.44	.14	hm	------	------	.32
H_2O+	1.29	1.24	1.26	ap	.67	.67	.67
TiO_2	.88	.40	.39	*Symbol:*			
CO_2	.23	1.23	.58	No. 1	I(II) .4. 2.(3) 4		
P_2O_5	.27	.15	.19	No. 2	I'' .4. 2''.(3) 4		
MnO	.09	.12	.06	No. 3	I'' .4. 2''.4		
BaO	.09	.03	n. d.				
Cr_2O_3	n. d.	n. d.	.03				
SO_3	n. d.	n. d.	.04				
Total	99.74	100.06	99.85				

Modes

	1	2
Phenocrysts:		
Quartz	0.5	2.50
Orthoclase	.5	.60
Plagioclase	15.00 (An_{25-55})[1]	40.00 (An_{25-30})
Ferromagnesians [2]	10.00	8.00
Groundmass:		
Quartz	22.00	19.00
Orthoclase	14.60	16.50
Plagioclase	31.00 (An_{20})	7.00 (An_{25})
Accessories [3]	6.40	6.40

[1] Including some albite.

[2] In the sill (column 1) as described by Burbank, some of the original hornblende and biotite have been resorbed; in the laccolith (column 2) they have completely reacted with the liquid to form sodic plagioclase, magnetite, hydromica, orthoclase, epidote, chlorite, rutile, calcite, quartz, and other minor reaction products.

[3] Accessories include magnetite, hematite, chlorite, epidote, rutile, titanite, apatite, calcite, and other minerals.

NOTES

1. Sodic granodiorite porphyry, sill above American Nettie mine, altitude 9,700 ft, SW¼ sec. 19, T. 44 N., R. 7 W., Ouray County, Colo. Analyst, Charles Milton.

2. Sodic granodiorite porphyry, Dexter Creek laccolith, altitude 9,100 ft, NE¼ sec. 20, T. 44 N., R. 7 W., Ouray County, Colo. Analyst, J. G. Fairchild.

3. Sodic granodiorite porphyry, Dexter Creek laccolith, altitude 10,125 ft, NW¼ sec. 20, T. 44 N., R. 7 W., Ouray County, Colo. Analyst, J. J. Fahey.

INTRUSIVE ROCKS OF LATE CRETACEOUS OR EARLY PALEOCENE AGE

Burbank (1936, p. 236) has shown that the intrusive bodies near Ouray and that in Cow Creek, about 6 miles northeast of Ouray, are older than the Telluride conglomerate. They are therefore probably of about the same age as the extrusions of the volcanic rocks that furnished pebbles to the McDermott and Animas formations which are exposed about 50 miles to the south of Ouray. The intrusive rocks of the La Plata and Rico Mountains and some in other places cut rock no younger than Cretaceous and it is possible that some of these may also be Late Cretaceous or early Paleocene in age.

Burbank (1936, p. 236), who first recognized the age of the intrusive rocks near Ouray, states:

The granodiorite porphyry bodies of the Ouray District are chiefly laccoliths and sills which cover a roughly eliptical area at least five miles in longest diameter. The intrusions are of late Cretaceous or early Eocene [Paleocene] age. The largest injections of magma occurred at the base of the Mancos shale of Upper Cretaceous age, but thin sills and dikes intrude the underlying Mesozoic and Paleozoic sedimentary rocks. The larger laccolithic bodies originally exceeded 1500 feet (457 m) in thickness, but were somewhat reduced in thickness by early Tertiary erosion. At the time of the igneous intrusions the overlying cover of Upper Cretaceous formations, including possibly the older Eocene beds, had a thickness estimated to be from 2 to 3.5 km. Most of the exposed mineralized rock, however, lies in the underlying sedimentary beds, from a few meters to 500 meters below the base of the laccoliths. The principal channel through which the concordant injections were fed is believed to be exposed near the town of Ouray, and is somewhat eccentric with respect to the area covered by the laccolithic bodies.

Burbank (1936) made a detailed study of the crystallization of the granodiorite porphyry, and showed that in the slowly crystallized rocks of the laccoliths the iron is largely in the ferric state. He presented three analyses of rocks from different parts of the laccolith and two modal analyses as shown in table 11.

CENOZOIC ROCKS

GENERAL FEATURES

The sediments mapped as Tertiary in the San Juan Mountains are all of Late Cretaceous and Paleocene to Oligocene (?) age. They are found in three distinct areas and kinds of association and no correlations can be made among the three. Glacial till has been found in the Eocene in these widely separated localities:

1. The greatest and by far the thickest body of Tertiary sediments lies in the San Juan basin in the southwestern part of the region. It includes the Torrejon and Wasatch formations.

2. Much smaller and thinner bodies immediately underlie the Miocene volcanic rocks about 20 miles east and northeast of the Paleocene and Eocene of the San Juan basin. These are for the most part Oligocene (?) in age.

3. A third area of Oligocene (?) sediments lies northwest in the Engineer Mountain, Telluride, Silverton, and Montrose quadrangles. These beds were called the San Miguel formation in the Telluride folio, but the name was later changed to Telluride conglomerate, because of the use of San Miguel for a formation in Texas.

4. Eocene till, called the Ridgway till, underlies the Telluride conglomerate near Ridgway, in the central part of the Montrose quadrangle. Similar till has been found by Atwood near Gunnison and east of Pagosa Springs.

EOCENE AND EARLIER DEPOSITS

Sediments of Late Cretaceous and Paleocene and of unquestioned Eocene age in the San Juan basin underlie the southern parts of the Pagosa Springs, Ignacio, and Red Mesa quadrangles and extend for many miles southward into New Mexico. The Animas formation, which is of Late Cretaceous and Paleocene age, is unconformable upon the McDermott formation (Cretaceous). On the Animas River there is angular discordance and to the east in the region between Florida River and Pagosa Junction the Animas formation successively overlaps the McDermott formation, the Kirtland shale, and the Fruitland formation.

The sediments included with the Paleocene in this report have been described in detail by Reeside (1924, p. 32–34). The succession of the formations is shown in table 12. They are all of terrestrial origin and attain a thickness of more than 4,500 feet.

TABLE 12.—*Tertiary formations of the San Juan basin, in the southern part of the San Juan region, Colorado* [1]

Age	Formation	Character	Thickness (feet)
Eocene	Wasatch formation.	Massive persistent gray to brown resistant conglomeratic sandstone interbedded with variegated shale; red shale abundant. In the extreme northern rim of the basin variegated shale chiefly, with beds of coarse arkose that contain an abundance of pink feldspar. Fluviatile. The Tiffany beds of Granger are the basal part of the formation but are not differentiated in lithology.[2]	0–1,400
Paleocene	Torrejon formation.	Lenticular gray to brown conglomeratic resistant sandstone interbedded with red and gray shale underlain by gray and greenish-gray shale and soft white to yellow conglomeratic sandstone. Fluviatile.	0–1,450
	Ridgway till.	A lower till containing fragments of pre-Cambrian, Paleozoic, and volcanic rocks. An upper member of clay, with some pebbles.	0–200
	Unconformity		
Late Cretaceous and Paleocene	Animas formation.	At base coarse beds with weathered and waterworn andesitic debris and pebbles and siliceous rocks. Remainder of formation shale and sandstone with much andesitic debris and occasional beds of fine conglomerate. Whole formation pistachio-green to tan, with very rare reddish layers. Fluviatile.	0–2,700

[1] Modified from Reeside (1924, p. 4) and Cross and Larsen (1935, p. 44).
[2] The Wasatch and Torrejon are conformable in Colorado but unconformable to the south.

ANIMAS FORMATION

Reeside (1924, p. 32) restricted:

* * * the name Animas to the greenish-gray and tan beds with much andesitic debris that on Animas River in the Ignacio quadrangle, Colorado, lie unconformably upon the purple beds assigned to the McDermott formation and unconformably below the Torrejon formation.

The Animas River beds of Cross (Emmons, Cross, and Eldridge, 1896, p. 217–219) include the McDermott formation and part of the Animas formation as restricted by Reeside. Reeside has traced the Animas formation from Pagosa Junction westward to a point some miles southwest of Durango and a few miles north of the Colorado-New Mexico boundary, where the formation pinches out. It is not known to the south. Thus, it is at the base of the Tertiary section nearly everywhere in the southern part of the San Juan area. It is locally absent on Bridge Timber Mountain where it is overlapped by the Wasatch beds.

The Animas formation is unconformable upon the McDermott formation. On Animas River there is angular discordance and a sharp color change. Elsewhere the color change is prominent, but no discordance has been noted. The Animas formation furthermore overlaps successively the McDermott formation, the Kirtland shale, and parts of the Fruitland formation in the region between the Florida River-Pine River divide and Cat Creek, north of Pagosa Junction. * * * The top of the Animas formation as now preserved is an extremely variable surface. Near Animas River the overlapping Torrejon formation covers up a large part of the formation, and the Wasatch beds ("Tiffany" zone) cover the rest. (Reeside, 1924, p. 32.)

The formation is, therefore, variable in thickness. It is about 1,100 feet thick on the Animas River but gradually thins out to the southwest. To the east it is 1,800 feet thick on the Florida River, 2,670 feet thick between Pine and Piedra Rivers, and 1,840 feet thick on Cat Creek near Pagosa Junction.

The lower 300 feet of the Animas formation contains coarse conglomerates separated by shale and sandstone. All these beds are greenish-gray to tan and contain much weathered andesitic material. The conglomerates contain many pebbles of quartz, quartzite, and chert and a few of nonandesitic igneous rocks, but consist predominantly of andesite. Above this 300-foot zone greenish-gray to tan shale and sandstone are the predominant rocks, though layers of fine conglomerate are also fairly common. All this upper part of the formation contains much andesitic detritus. Reddish bands occur locally, but are not a common feature. The Animas formation contains throughout some vegetable debris, locally enough to form thin coal beds. This feature becomes more pronounced eastward from the type locality. On Cat Creek near Pagosa Junction a number of lenticular coal beds are present and fossil plants occur abundantly at many horizons.

A considerable thickness of beds believed to be of Animas age are exposed in the northwestern part of the Summitville quadrangle, chiefly in the drainage area of Coal Creek and to the north. These beds dip at considerable angles and are broken by faulting. They are probably faulted down into their present position. They consist of sandstones and conglomerates and contain three beds of lignite, one of which is being worked for local use. Some of the sandstones are quartzose or arkosic but some of the conglomerates are made up chiefly of andesitic rocks. The mapping of these beds is very much generalized because of poor exposures, and the rapid reconnaissance nature of the writers' study of them. They were not recognized west of the San Juan River but they may be present, for much of this area is covered by landslide.

These beds resemble the Animas formation in Cat Creek about 20 miles to the southwest and are believed to belong to the Animas.

Partial section of beds of Animas (?) age near coal mine in Coal Creek about 5 miles northeast of Pagosa Springs

	Thickness (feet)
Landslide.	
Arkose	10
Sandstone, muddy, and shale	20
Sandstone, with plant remains	10
Sandstone, pebbly, with some muddy sandstones. Pebbles are abundant in some lenses and layers and are scattered through the sandstone. All pebbles are well rounded, less than 1 inch across, and consist of volcanic rocks	64
Sandstone beds, thick, arkosic, with some iron carbonate nodules	25
Sandstone, coarse, arkosic, with some shale layers. Some pebbles as much as an inch across of granite, quartzite, etc. Some lenses and layers with clay pebbles as much as 4 inches across	29
Sandstone, fine, muddy, with some shale	11
Coal, and bony coal, with two layers of red shale each about 2 feet thick	19
Sandstone, heavy-bedded, with sugary texture and abundant dark sand grains. Rather friable. Cross-bedded	100
	288
Base not exposed.	

The pebbles of the conglomerates of the Animas formation are essentially like those of the McDermott formation, and the petrographic descriptions of them are placed at the end of the description of the McDermott formation.

RIDGWAY TILL

Till now considered to be Paleocene has been found by Atwood (1915, 1917, 1926) near Ridgway, not far from the center of the Montrose quadrangle; near Gunnison, in the northern part and north of the Uncompahgre and Cochetopa quadrangles; and on White Creek, near the center of the Summitville quadrangle. In all three districts this till, which is known as Ridgway till, overlies the Mancos shale or older rocks. In the Ridgway area it is overlain by the Telluride conglomerate, of Oligocene (?) age; near Gunnison it is overlain by the San Juan tuff or other volcanic rocks; in the Summitville area its upper contact is not shown. Because of its small area it is mapped with the Telluride conglomerate and Blanco Basin formation.

Near Ridgway the till is made up of two members. The lower member is as much as 100 feet thick and is a typical glacial till. The fragments are derived from the pre-Cambrian and Paleozoic formations and from volcanic tuff and intrusive porphyries. The upper member overlies an erosional surface of the lower and is a clay with some small pebbles. Atwood concluded that the lower boulder till came from the San Juan Mountains, to the southeast, and the upper pebble till from the West Elk Mountains, to the northeast.

The till of the Gunnison area and the Summitville quadrangle is a typical till.

The presence of abundant fragments of volcanic rocks in the till wherever it has been found shows that the glaciation took place before the Cretaceous and Paleocene volcanic pile had been completely removed by erosion. The fact that the post-Animas beds of the San Juan basin lack volcanic material indicates that the volcanic pile had been largely or completely removed before the Torrejon formation was laid down. However, before the glaciers occupied the area, doming and folding of the older rocks raised them several thousand feet at least, and the new mountains had been deeply eroded to expose the pre-Cambrian rocks over considerable areas in the Gunnison River drainage basin and had probably been reduced to a surface of low relief. The presence of volcanic rocks in the glacial deposits indicates an early Paleocene age, but the amount of uplift and erosion preceding the glaciation was much greater than any recorded below the Torrejon formation in the area of sediments south of Durango. It seems probable that the uplift and consequent erosion were greater in the northern and central part of the San Juan Mountains than to the south and that the glaciation was of early Paleocene age.

TORREJON FORMATION

At the base of the Torrejon formation there is an unconformity, and in the Red Mesa quadrangle the Torrejon overlaps the Animas and the McDermott formations. The formation is widespread in New Mexico where it overlies the Puerco formation in places, but in Colorado the Puerco is absent and the Torrejon directly overlies the Animas beds and is confined to an inlier surrounded for the most part by the Wasatch formation. One of these extends for many miles up the Animas valley, another up Cox Canyon to the west and still another in McDermott Arroyo. In Colorado the Torrejon formation consists of brown lenticular sandstones and variegated shales. In New Mexico the formation contains good vertebrate fossils and some plant remains. Reeside assigned it to the Eocene; it is now considered to be Paleocene.

WASATCH FORMATION

The Wasatch formation underlies the southern part of the area of Tertiary rocks and is the most widespread of the Tertiary sediments. In Colorado it conformably overlies the Torrejon formation and sedimentation was probably continuous from Torrejon time to Wasatch time. To the south in New Mexico it seems to overlie the Torrejon unconformably.

A phase of the Wasatch formation consisting of brown indurated sandstones and variegated shales is widespread in New Mexico but it persists for only a few miles north into Colorado.

> It passes then into soft, fine conglomerate, soft sandstone, usually arkosic, and variegated shale. The mass viewed from a distance is of a rather even dove-gray color, but closer inspection shows red, greenish, and gray tones in about equal amount. This material weathers into slopes as if it were all shale. This softer phase of the Wasatch formation has been traced eastward across the Ignacio quadrangle to the H–D Hills, which extend from R. 6 W. to Piedra River. Here the lower 400 feet of the Wasatch formation, containing near the base the "Tiffany" fauna, consists chiefly of variegated green, red, and gray shale, with a minor amount of fairly well indurated arkose. The arkose contains pebbles of pink feldspar, as much as three-fourths of an inch in diameter in a matrix of fine-grained greenish material. The higher beds consist of gray shale with some red bands, soft sandstone and arkosic conglomerate. (Reeside, 1924, p. 45)

In Colorado the "Tiffany zone" at the base of the Wasatch formation carries vertebrate fossils and plant remains. The formation is of Eocene age.

OLIGOCENE (?) FORMATIONS

TELLURIDE CONGLOMERATE

The Telluride conglomerate is present, with interruptions, below the San Juan tuff or later volcanic rocks, from the Engineer Mountain quadrangle northward and westward and has been mapped in the Engineer Mountain, Telluride, Silverton, and Montrose quadrangles. In the Telluride folio it was called the San Miguel formation but in the later folios it was called the Telluride conglomerate. Typical exposures of the Telluride are shown in figures 6, 8, and 10.

The following description is taken from the published folios. In the Ouray folio Cross, Howe, and Irving (1907, p. 6) state:

> The Telluride formation varies greatly in texture and thickness from a thin, coarse conglomerate in the Silverton and Ouray quadrangles to a complex of fine-grained conglomerates, sandstones, and shales about 1,000 feet in thickness as developed in Mt. Wilson on the western border of the Telluride area. It is made up of detritus of schist, granite, quartzite, and slate, and lesser amounts of the harder sediments of the Paleozoic formations—in particular of limestone.

In the Ouray quadrangle a granite porphyry that megascopically resembles a coarse andesite is abundant, greenstones are common, and fragments of tuff like that in the underlying Ridgway till are rare. Fragments of the sediments are more abundant in the lower part of the formation than in that higher up. Fragments of the adjacent underlying rocks are abundant near the base.

On Cow Creek in the Ouray quadrangle "an impure red limestone occurs within a few feet of the base of the formation. It is about 10 feet thick and grades upward into a coarse pink and brown grit which in many places becomes coarsely conglomeratic." (Cross, Howe, and Irving, 1907, p. 6.)

The Telluride conglomerate overlies unconformably the Cretaceous and older rocks and, locally, the glacial till. It is overlain, after some erosion by the San Juan tuff. It carries no determinable fossils and its age is judged from its relation to the other formation. It is believed to be of nearly the same age as the Blanco Basin formation which is tentatively placed in the Oligocene.

BLANCO BASIN FORMATION

In many places on the southern slopes of the San Juan Mountains, in the San Cristobal, Pagosa Springs, Summitville, and Conejos quadrangles, a series of arkosic sandstones, conglomerates, and other sediments, lacking in volcanic material, unconformably overlie the Cretaceous formations and the Animas formation, and are overlain with apparent conformity by the Conejos quartz latite. The name Blanco Basin formation is proposed for these beds, from their development about Blanco Basin, in the central part of the Summitville quadrangle.

The Blanco Basin formation is nearly everywhere poorly exposed, as it is in general a thin, soft formation, overlying in many places the Mancos shale and overlain by a great thickness of volcanic breccia. Landslide and talus cover it in most places. Moreover, it was examined only incidentally to the study of the overlying volcanic rocks. It is therefore imperfectly known and only approximately mapped.

The Blanco Basin formation has been found beneath the Conejos quartz latite from Weminuche Creek, in the south-central part of the San Cristobal quadrangle, southeastward as far as the southwest corner of the Conejos quadrangle. It makes up nearly all the mapped Tertiary of this area, except that on the east slopes of the San Juan River along Coal Creek and that in the Summitville quadrangle. It is not everywhere present, as it was probably locally removed by erosion before the volcanic materials were laid down. The mapping is much generalized, and the formation is probably not as continuous and regular as shown on the map. It is fairly well exposed where the automobile road from Pagosa Springs to Wolf Creek Pass starts up the grade. It is also well exposed in several places in the drainage basin of the Chama River in the southeastern part of the Summitville quadrangle, and near the railroad in the canyon of Wolf Creek near the southwest corner of the Conejos quadrangle, where it is nearly flat and bevels the edges of Cretaceous rocks which dip 12° westerly.

In much of the area in the Summitville quadrangle there are three members in the formation—an upper cliff-forming white sandstone with some horizontal fluting; a middle member that crops out as broken cliffs and is made up of alternating beds of white sandstone and red shale, giving a general pinkish outcrop; and a lower bright-red member of muddy sandstone and shale that is soft and gives poor exposures.

Two sections of the formation follow:

Section of Blanco Basin formation north of the trail between Weminuche and Huerta Creeks, in the southern part of the San Cristobal quadrangle

Conejos quartz latite. Near the base it contains a few pebbles of pre-Cambrian rocks and beds of arkose.

Blanco Basin formation:	*Thickness (feet)*
Grit, red, gray, or pale-green, and sandy shale. Soft and crumbly and very poorly exposed. Some red clay. Grows less sandy and coherent upwards	350
Grit-conglomerate. Predominantly grit with boulders and pebbles irregularly scattered throughout it; soft clay matrix	20
Grit nearly free from pebbles. Predominantly dark red but some is gray. Color is very irregular. Mostly arkosic	13
Conglomerate-grit. Half pebbles and half arkosic grit. Pebbles very irregularly distributed and pebble layers not continuous. The pebbles are lenticular and are partly quartzites derived from the Uncompahgre or Ignacio quartzites, partly coarse red granite of the Pine River type, fine-grained gray granite, gneiss, and schist. No chert	15±
Total	398±

Unconformity.
Mancos shale.

Section of Blanco Basin formation east of Chama River near southern boundary of Summitville quadrangle

Conejos quartz latite: Soft muddy tuffs and gravelly sands made up of volcanic rocks, several hundred feet thick.

Blanco Basin formation:	*Thickness (feet)*
Sandstone, white, arkosic, containing some small pebbles	140
Sandstone, grit, and conglomerate, with thin layers of red shale. Beds as much as 6 feet thick near base and 20 feet or more higher up. Some lenses of fine conglomerate. Pebbles of quartzite, coarse red granite, schist, and other rocks; none of volcanic rocks	300
Shale, brick-red, muddy; partly pale green when fresh	35
Grit and fine conglomerate. Beds as much as 1 foot thick. Pebbles 4 inches or less in diameter are mostly quartz. Some large feldspar grains	20

Section of Blanco Basin formation east of Chama River near southern boundry of Summitville quadrangle—Continued

Blanco Basin formation—Continued	*Thickness (feet)*
Sandstone, fine-textured, muddy, shaly in part. Pale ocher-yellow on fresh exposures but weathers brick-red	40
Sandstone and pebbly grit, nearly white; red near top. Base fine shaly sandstone. Higher up arkose grit and pebbly sandstone. Beds thin near base and as much as 6 inches thick near top	60
Total	575

Angular unconformity.
Mancos shale.

The folding that preceded the deposition of the Blanco Basin formation appears to have been much more intense than any other since that preceding the deposition of the Jurassic formations, and the succeeding erosion removed the whole sedimentary section from parts of the region and exposed the pre-Cambrian rocks. The pre-Cambrian rocks under the volcanic rocks in the San Cristobal quadrangle and elsewhere were probably exposed at this time. Many of the fragments in the Blanco Basin formation are of the types common in the pre-Cambrian of the San Cristobal quadrangle and the Needle Mountains area.

The Blanco Basin formation is overlain with apparent conformity by the Conejos quartz latite of Miocene age (probably middle Miocene).

These considerations would seem to place the age of the Blanco Basin formation as late Eocene, Oligocene, or early Miocene. It is most plausibly placed in the Oligocene. In its position on a peneplaned surface of Cretaceous and older rocks and in apparent conformity under the volcanic rocks and in its general petrographic character and lack of volcanic fragments, it resembles the Telluride conglomerate, which underlies the volcanic rocks on the northwestern flanks of the San Juan Mountains. However, the Telluride is overlain by the San Juan tuff, a much older volcanic formation than the Conejos quartz latite. The Blanco Basin formation and the Telluride conglomerate are probably closely related in age and origin, and they are here tentatively classified as Oligocene (?).

VOLCANIC AND ASSOCIATED INTRUSIVE ROCKS

OUTLINE OF VOLCANIC HISTORY

Igneous activity took place repeatedly during the pre-Cambrian. The oldest rocks of the area, the highly metamorphosed schists and gneisses, were in part derived from granitic rocks, ranging from granite to gabbro. They include some rocks derived from sediments and probably some derived from volcanic rocks. Several younger intrusive bodies show less metamorphism. The youngest pre-Cambrian rocks of the area are a group of unmetamorphosed granitic rocks ranging from granite to diorite. The Irving greenstone is a group of mildly metamorphosed volcanic rocks.

No igneous rocks are represented in the Paleozoic and the Mesozoic until Late Cretaceous time, although there may be some fine-grained tuff beds in some of the sediments. The Iron Hill complex may be an exception to this.

Near the end of the Cretaceous, at the beginning of McDermott time, volcanism occurred in the area north and northeast of Durango and probably continued into early Paleocene time. A considerable pile of andesites, latites, and rhyolites accumulated but it seems to have been entirely removed by erosion in early Paleocene time. The only relics of this period of volcanism are a few intrusive rocks near Ouray and possibly some of the intrusive rocks to the southwest. This period of volcanism is shown chiefly by the volcanic pebbles in the conglomerates of the McDermott (Late Cretaceous) and Animas (Late Cretaceous and Paleocene) formations. Volcanic pebbles make up most of the conglomerates near Durango, at the base of the San Juan Mountains, and become less abundant and more altered to the south, indicating that the volcanic mountains were in the present San Juan Mountains.

The available evidence indicates that no volcanic rocks were erupted from early Paleocene time to about middle Miocene. The Paleocene and Eocene sediments, overlying the Animas formation, and the Oligocene (?) rocks contain no volcanic debris.

Following this long interval without a record of volcanism, eruptions began about middle Miocene time and continued with interruptions into Quaternary time. These eruptions built up a great, low volcanic dome more than 100 miles across, and probably several miles high. This dome has been faulted, tilted gently to the east and north, domed or gently folded, and deeply incised by erosion to form the present San Juan Mountains.

The earliest known of these eruptive formations, at least in the western part of the area, is the Lake Fork quartz latite (probably of early Miocene age), which built up a volcanic mountain about 15 miles across at its base and at least 4,000 feet high. Its center was east of the Lake Fork of the Gunnison River, a few miles southeast of the center of the Uncompahgre quadrangle. It is made up of flows and irregular to chaotic breccia, chiefly of quartz latite in considerable variety, with some basalt.

Before the Lake Fork volcano had been greatly modified by erosion it was, in large part, buried by the much more widespread quartz latite tuff-breccia, the San Juan tuff. This tuff is made up almost entirely of bedded clastic material deposited by water and probably derived from explosive vents situated to the west and possibly also to the northwest of the Lake Fork volcano. The San Juan tuff must have covered a large area, for it is now preserved in an area nearly 100 miles across from southwest to northeast. It is commonly more than 1,000 feet in thickness.

After being somewhat eroded, the San Juan tuff was partly covered by a thick complex of volcanic rocks, the Silverton volcanic series, whose geographic center was near the center of the Silverton quadrangle. At the beginning of Silverton time lava flows and explosive eruptions built up a dome in the eastern part of the mass, the Picayune quartz latite. During this period some rhyolites were erupted, probably from a separate vent nearby. These rhyolite eruptions continued after those of quartz latite had ceased, and they spread over a larger area than the underlying quartz latite. The rocks are called the Eureka rhyolite. The rhyolite was overlain by the Burns quartz latite, a series of flows with some well-bedded tuffs. The tuffs carry well-preserved plant remains, which determine their age as Miocene. The quartz latite was covered by widespread and extensive eruptions of dark pyroxene quartz latite, chiefly in lava flows but with some explosive eruptions. These in turn were followed by local pyroclastic beds that were mostly sorted and distributed by water and are called the Henson tuff. At the end of the Silverton eruptions a great irregular dome of volcanic rocks had been built up that was at least 40 miles across and more than 3,000 feet high.

About the time these early volcanic rocks were erupted in the northwestern part of the San Juan Mountains, other eruptions were taking place in the eastern part of the area near Saguache, and in the San Luis Hills east of the Conejos quadrangle. In most of the area near Saguache these rocks were studied only by rapid reconnaissance methods. They are chiefly quartz latites. Near Beidel the Beidell quartz latite is overlain irregularly by the Tracy Creek quartz latite. In the San Luis Hills a lower group of quartz latites is intruded by stocks of monzonite and syenite. After extensive erosion these rocks were covered by flows of dark latite that carries little free silica.

While the Lake Fork, San Juan, and Silverton volcanic rocks were being erupted in the northwestern part of the area, the volcanic rocks rose as high mountains above the general level. After the Silverton eruptions these new mountains were depressed several thousand feet and were reduced by erosion to a mature landscape before the eruption of the Potosi rocks.

In the eastern part of the area the pre-Potosi rocks formed a mountain topography at the time the Potosi eruptions began.

During Potosi time a long series of great eruptions built up a low broad dome that makes up the main part of the volcanic rocks of the region. It was about 150 miles across and over a very large area was more than a mile thick. Its slopes were so gentle that it was almost a plane.

During Potosi time eruptions alternated between dark quartz latite and rhyolitic materials. The following list gives the main succession of eruptions, beginning with the oldest:

Conejos quartz latite (volcanic agglomerate with flows and stream-laid gravel and boulders)
Erosion to deep canyons
Treasure Mountain rhyolite
Sheep Mountain quartz latite
Erosion to deep canyons
Alboroto rhyolite
Huerto quartz latite
Erosion to deep canyons
Piedra rhyolite

The three periods of erosion following the quartz latite eruptions were long enough to allow the development of canyons comparable in depth to the present canyons.

The three quartz latite formations were each piled up about local centers by relatively small outpourings of lava and explosions of breccia. Many of the flows came out over rather steep slopes. They are rarely well layered and are mostly chaotic, with little regularity or uniformity in the sections. The lavas varied greatly in composition. During Conejos time a large amount of material was erupted, and the materials from the different centers merged and formed a great mass of quartz latite. The other two quartz latite eruptions were small and yielded local piles.

The rhyolitic eruptions, however, came from few centers and spread over large areas as widespread flat flows and widespread tuff beds. Some of these flows are less than 100 feet thick, but some are more than 1,000 feet thick, and locally where a flow filled in the depressions in an irregular topography, they are several thousand feet thick. Tremendous outpourings of rhyolitic lava and great explosive ash showers occurred. Locally steep volcanic cones piled up around local vents, but these form only a small part of the rhyolitic material. The largest of these were made in the early part of Alboroto time in the Creede and Cochetopa quadrangles. During the periods of rhyolitic eruptions local centers poured out small amounts of dark quartz latites.

The Potosi eruptions were followed by a period of erosion during which canyons were cut at least as deep as the present canyons. In one of these canyons, now occupied by the Rio Grande near Creede, a lake was formed in some unknown way, and a thick deposit of fine rhyolitic tuff with very subordinate flows partly filled the canyon. These deposits made the Creede formation. Vegetation was abundant, as indicated by the fossil leaves of Miocene age found in the beds.

Erosion cut deeply into these tuff beds before the next eruptions of the Fisher quartz latite took place. These eruptions came from several vents, and no vent spread material over a very large area or erupted an amount of material comparable to that of the rhyolite formation of the Potosi volcanic series. The lava flows and explosive breccia were irregular and chaotic and commonly filled the old canyons.

A local volcanic cone of quartz latite, probably of Fisher age, was built up near Chiquito Peak, north of the center of the Conejos quadrangle. Pyroclastic rocks and debris from this volcano furnished the material for the tuff beds, sands, and gravels of the Los Pinos quartz latite which overlie the Potosi rocks in the Conejos quadrangle. To the south in New Mexico these beds thicken and they gradually change to sands and gravels made up chiefly of material derived from pre-Cambrian rocks.

During Potosi and Fisher time the great dome of newly extruded volcanic rocks stood several thousand feet above the general level of the surrounding area except near the borders of the dome and especially in the southern and southeastern part of the mountains where the land appears to have subsided at about the same rate as the volcanic rocks accumulated. After the eruption of the Fisher rocks the main part of the mountains subsided several thousand feet except near the borders of the mountains where there was little movement.

A long period of erosion followed and the San Juan peneplain was developed over the whole area. The Hinsdale formation was spread over this peneplain.

In the northeastern part of the San Cristobal quadrangle and adjoining part of the Uncompahgre quadrangle rhyolite lavas and welded tuff beds spread as a thin local accumulation on the San Juan peneplain, and in the northern part of the Summitville quadrangle and adjoining parts of the Creede quadrangle small local cones of rhyolite lava and breccia were built up. The total amount of rhyolite erupted at this time was small.

There followed great floods of basaltic magma with subordinate pyroclastic eruptions. These formed low domes in most of the San Juan region, but in New Mexico and the southeastern part of the San Juan region they produced a great lava plain at least 100 miles across. The lavas of this plain were only a few hundred feet thick. These eruptions resembled on a small scale the great plateau eruptions. At Rio Grande Pyramid, near the center of the San Cristobal quadrangle, a cone at least 1,200 feet high was built up of pyroclastic basaltic material. These basaltic lavas covered most of the eastern part of the San Juan Mountains and extended for 70 miles south into New Mexico and are the most widespread lavas of the region.

Near the end of the Pliocene the basalt plateau was tilted to the east, faulted, and folded, and canyons were eroded in it. During Pleistocene time a few small eruptions of basalt flowed into these canyons. One such eruption took place near the head of La Jara Creek in the Conejos quadrangle. Others are present southward in New Mexico. One basaltic lava plunged over the cliffs into the Rio Brazos Canyon, flowed down the canyon for 6 miles and at the mouth of the canyon spread out like an alluvial fan. This rapidly eroding stream has cut about 50 feet below the base of the lava and removed most of the basalt from the canyon. This is about the amount of erosion that would be expected since the last glaciation. No later volcanic eruptions are known in the region. The period since the last extensive volcanic eruption is probably short compared with some of the periods of quiet that separated some of the other volcanic series.

LAKE FORK QUARTZ LATITE

NAME AND DEFINITION

In the San Cristobal quadrangle and in the areas to the west and northwest where the San Juan tuff is best developed, no volcanic pile that might have served as a source for the fragments of the San Juan tuff was found. In the central part of the Uncompahgre quadrangle, however, a great volcanic pile of flows and breccia of quartz latite both underlies and projects through the San Juan beds. No similar mass of pre-San Juan volcanic rocks has been found in the area included in this report, although some rocks in the eastern part of the mountains are known to be older than the Potosi and may possibly be of about the same age as the pre-San Juan volcanics of the Uncompahgre quadrangle.

Because these pre-San Juan volcanic rocks are found chiefly in the drainage basin of the Lake Fork of the Gunnison River, the name Lake Fork quartz latite has been proposed for them. The accumulation of the San Juan tuff must have followed immediately after the Lake Fork volcano was built up. The name Lake Fork quartz latite should therefore be defined as a group of dark quartz latites, in part flows, in part clastic beds, that immediately preceded the deposition of the San Juan tuff. Only one volcanic cone or dome of such rocks is known and, with the possible exception of the rocks in the eastern part of the mountain, no other bodies of such rocks are believed to be exposed in the San Juan Mountains.

AGE

The fact that the Lake Fork quartz latite is older than the San Juan tuff is clearly shown by the following facts:

The typical San Juan tuff overlies rocks of Lake Fork type in the drainage of Little Blue Creek. The San Juan of this area is identical in character with that of the main mass to the west and is connected with it by almost continuous exposures for many miles. The exposures of rock of Lake Fork type are separated from the main mass of the Lake Fork by several miles in which the two formations are not exposed. The Lake Fork quartz latite directly overlies the pre-Cambrian and Paleozoic rocks in both the Lake Fork drainage and in the Little Blue Creek area. This fact, together with the similarity of the rocks, makes the correlation of these two masses reasonably certain.

Again, both east and west of Lake Fork of the Gunnison River the rocks that are typical San Juan tuff overlie a great thickness of the main mass of the Lake Fork quartz latite.

In the Uncompahgre quadrangle the greater part of the fragments in the San Juan tuff are not like any of the rocks found in the Lake Fork quartz latite, but some of the fragments in the San Juan are identical with the Lake Fork rocks and nearly all of the important rock types found in the Lake Fork have been found in fragments in San Juan tuff.

GENERAL CHARACTER

Exposures of the Lake Fork quartz latite are confined to an area in the central part of the Uncompahgre quadrangle about 20 miles across. The thickest part—about 4,000 feet—is east of the Lake Fork of the Gunnison River near the heads of Indian and Trout Creeks. From this area it thins out rapidly in all directions and 5 or 6 miles from the central area this quartz latite is only a few hundred feet thick. The thickest part of the mass is therefore only about 10 miles across and the outer apron is thin.

The central part of the mass is not overlain by younger rocks and has been much modified by postvolcanic erosion; the flanks are overlain by San Juan or Potosi rocks. Where overlain by the San Juan tuff there was little erosion, but where overlain by the Potosi volcanic series the Lake Fork was much eroded before it was covered by the later rocks. An intrusive stock of granodiorite porphyry is exposed between the forks of Trout Creek and probably represents the throat of the volcano. The general form of the body as it is at present indicates that it has been deeply dissected both in pre-Potosi and Recent times, but that its general form is still preserved and that it never had a much greater thickness or a much wider distribution than it has at present. It was probably a dome a little more than 4,000 feet high and about 10 or 12 miles across, with a thin apron surrounding the main dome and extending about 4 or 5 miles beyond it. The main dome covered an area of about 100 square miles and the whole mass covered an area of about 300 square miles. The total volume was about 40 cubic miles.

The Lake Fork quartz latite is made up of a rather chaotic aggregate of flows, flow breccias, and pyroclastic breccias. Breccias greatly predominate in the lower part but flows predominate in the upper half. On the flanks of the mass, breccia predominates. For the whole mass breccia probably makes up more than half the material. The rocks vary considerably in texture and composition, but are mostly hornblende-quartz-latites or hornblende-biotite-quartz latites, although some are pyroxene rocks, a few are almost rhyolites, and a few are basalts. The flows and associated breccias are made up of about the same kinds of rocks and the fragments of any one of the breccia beds are mainly of a single kind of rock. No regular succession in the beds was found although a textural variety of quartz latite, mostly hornblendic, makes up much of the upper massive part of the body.

PYROCLASTIC BRECCIA

A large number of rocks from the lower part of the Lake Fork quartz latite exhibit a kind of brecciation which is more extensively developed here than in any other part of the San Juan complex. In many places a rock which was originally massive, either a homogeneous lava or a flow breccia, has been shattered in place so that at the present time the body appears as a typical breccia; that is, it is made up of angular fragments with very little if any finer grained matrix.

In some places one can see that there has been little displacement of adjoining fragments for they fit well together. In other places the dislocation of fragments is sufficient to destroy this evidence of shattering in place. The greatest amount of dislocation has commonly occurred on certain zones or directions of extensive brecciation but masses between such zones have been less broken up. In these chief shatter zones the amount of fine matrix is larger than elsewhere.

In addition to this gradation in amount of fracturing there is a further gradation from rock with no foreign material to breccia containing more and more fragments of differing character. There is thus developed a resemblance to breccias which must be considered as accumulations of transported material and in some places it is difficult to tell which is which.

The fragments of these rocks, which are termed protoclastic breccia because they were apparently shattered in place, vary from the extreme where the average diameter is only 1 or 2 inches to that in which the fragments are several feet or yards in size and the breccia character is easily passed by unnoticed. The area in which this breccia is most distinct is on the east side of the Lake Fork, from Stony Cut to Indian Creek. In all this area there are many knolls and short ridges which are due to dikes or to the presence of these brecciated flows that do not break down under ordinary weathering conditions so readily as the associated tuffs, and breccias.

DETAILED PETROGRAPHY

The rocks of the Lake Fork quartz latite are predominantly light-colored hornblendic quartz latites; some carry more or less biotite, others carry pyroxene. Most of the rocks carry little dark mineral, a sodic plagioclase, and considerable orthoclase and quartz. A few are rhyolites. Dark pyroxene rocks are somewhat less common than hornblende rocks. They are much richer in dark minerals, have a more calcic feldspar, and carry less orthoclase and quartz. They grade into olivine basalts.

LIGHT-COLORED ROCKS

Group 1.—One of the commonest kinds of rock and one that makes up many of the larger flows, is a pale- to medium-brown or bluish-gray, dense rock that is made up of about one-third white feldspar phenocrysts from 0.5 to 3 mm long, considerable black hornblende, and some biotite in an aphanitic groundmass. The abundance and small size of the phenocrysts give these rocks a granular appearance in the hand specimen. Many of the specimens have abundant spherulites of christobalite perched on the walls of the gas cavities. The microscope shows that the rocks are seriate porphyritic, the plagioclase is strongly zoned andesine, the hornblende is green in some specimens, brown in others. Both it and the biotite are more or less resorbed and where the resorption has progressed far, pyroxene comes in. Magnetite is abundant. The groundmass is dusted with hematite and is made up largely of oligoclase laths with interstitial quartz and orthoclase. The rocks are hornblende-biotite-quartz latites. A related, less common rock has brown hornblende, much resorbed, and augite and hypersthene in small crystals. The plagioclase phenocrysts have cores and borders more sodic than an intermediate zone and average andesine-labradorite. These rocks differ from the hornblende-biotite rocks chiefly in the greater resorption of the biotite and hornblende, but are also probably a little more mafic. A few of the rocks have pyroxene as the only mafic mineral.

Group 2.—A second kind of rock is about as abundant as the one described in the preceding paragraph and is common in flows, breccia beds, and small dikes. It differs from the latter chiefly in texture, especially in the hand specimen, but has a little less dark mineral and fewer and larger phenocrysts of the calcic feldspar. In the hand specimens the rocks look much like felsitic rhyolites, for they are dense to fluidal, have few large plagioclase phenocrysts, a little biotite, and some have hornblende in a felsitic groundmass that makes up most of the rock. The rocks carry from 10 to 25 percent of phenocrysts, most of which are white andesine in crystals as long as 10 mm; biotite and green hornblende are in small amount. The groundmass is similar to that of the rocks described in the preceding paragraph. It is made up of minute oligoclase laths in a glass or a fine granophyric intergrowth of quartz and orthoclase. In some, biotite exceeds the hornblende in amount, in which case neither shows much resorption; in others, hornblende exceeds the biotite and both, especially the hornblende, are much resorbed. As the resorption goes farther, biotite completely disappears and hypersthene comes in in small prisms. The variation in the proportion of the dark minerals to light is not entirely due to resorption, because some hornblende rocks without biotite show no evidence of resorption. These rocks are hornblende-quartz latites with more or less biotite and rare hypersthene and are low in dark minerals. An analysis of one of these rocks is shown in table 13, column 1.

A variety of the type described in the preceding paragraph has the appearance of a rhyolite: very few feldspar phenocrysts and a little resorbed biotite in a fluidal felsitic groundmass. The microscope shows that it has a groundmass much like that of the other rocks, with laths of oligoclase-andesine in a granophyric matrix. It may have had some hornblende, now completely resorbed. It is a quartz latite, almost a rhyolite. An analysis of such a rock is shown in table 13, column 2.

Group 3.—Hornblende quartz latites much like those previously described but having little or no biotite, more hornblende, and a darker groundmass, constitute a third group that is less common. They have from 15 to 20 percent of phenocrysts, mostly about 1 mm long. Andesine-labradorite is most common, green hornblende is abundant, and magnetite and apatite are in small amount. The hornblende shows little resorption. The groundmass is dusted with iron oxide and is made up mostly of felted laths of oligoclase or oligoclase-andesine, with a little interstitial quartz and orthoclase.

Group 4.—A fourth group of rocks is similar to that described in the preceding paragraph and is about as abundant, but it has more and a little larger phenocrysts, a brown hornblende, and has some pyroxene in the groundmass. It contains from 20 to 40 percent of phenocrysts mostly from 1 to 2 mm long. As the hornblende is more resorbed, pyroxene becomes more abundant. The pyroxene is chiefly hypersthene and is partly altered to bastite.

Group 5.—A fifth group of quartz latites was found chiefly in the drainage area of Indian Creek below an altitude of 10,000 feet, where it is common. It is a rather dense, dark red-brown rock, with a rough fracture and carries from 25 to 35 percent of small inconspicuous phenocrysts. Microscopically it is much like the fourth group but has a few phenocrysts of augite and hypersthene, and the groundmass is clouded and very fine and carries a few visible feldspar laths but is mostly submicroscopic or glassy. Cristobalite is rather common in the gas cavities. An analysis of one of these rocks is shown in table 13, column 3. The analyzed rock lacks pyroxene phenocrysts.

Group 6.—A sixth group, found chiefly in the upper part of the formation in the drainage areas of Skunk and Big Birch Creeks and in the western part of the drainage area of Indian Creek, is a brownish-gray, rather vesicular rock that carries about 35 percent phenocrysts as long as 2 mm. The phenocrysts are chiefly white calcic labradorite but there is considerable pyroxene and a little hornblende, much resorbed. The groundmass is made up of plagioclase laths in an indistinct matrix. The rocks are pyroxene-hornblende-quartz latites and pyroxene-quartz latites, and they are much richer in dark minerals and lime than are the rocks previously described. An analysis of one of these rocks, lacking pyroxene phenocrysts, is given in table 13, column 4.

DARK ROCKS

Dark pyroxene-quartz latites, nearer the basalts than the rocks previously described, are scattered through the formation. They are of two kinds and grade into true basalts.

Group 1.—One kind of dark pyroxene rock is a nearly black basaltic rock, partly dense, partly vesicular, and partly with a few phenocrysts as much as 10 mm long. The rocks are seriate porphyritic, and are made up nearly half of phenocrysts as long as 1 mm. Labradorite is the chief phenocryst; hypersthene is abundant, augite less so, and magnetite occurs in moderate amount. The groundmass is very finely crystalline and is made up of minute plagioclase laths, pyroxene rods, and grains of iron ore in an indistinct matrix. In some the groundmass is glassy. The plagioclase has inclusions of the groundmass. A few of the rocks have a little brown hornblende much resorbed.

One specimen collected from the head of Indian Creek, at an altitude of 10,450 feet, east of the saddle having an altitude of 10,400 feet, and north of the peak having an altitude of 10,710 feet, is similar to the rocks described in the preceding paragraph but the feldspar phenocrysts are labradorite-bytownite. Olivine, altered to iddingsite, is present and the groundmass is rather coarse and is made up of stout andesine-labradorite crystals, olivine, pyroxene, and magnetite with some interstitial orthoclase and albite. The rock is an olivine basalt.

Another variant, believed to belong to the Lake Fork quartz latite, was collected from the saddle having an altitude of 8,500+ feet, which is east of Dry Powderhorn Creek and south of the peak with an altitude of 8,850 feet. This is a dark, vesicular, basaltic-looking rock with a few phenocrysts of quartz as much as 1 centimeter across. The quartz is much resorbed and is bordered by augite grains. There is much green-brown hornblende, also much resorbed and with an extinction angle of only 8½°, a medium large axial angle, and a strong dispersion of the optic axes with $r<v$. The rock has much cristobalite in the cavities.

Group 2.—The second group of dark pyroxene rocks is much like the tabular feldspar pyroxene-quartz latite so common in all the quartz latite subdivisions of the Potosi volcanic series. This group is common in the small dikes but is also found in the flows and, rarely, as fragments in the breccia beds. In hand specimen the rocks show many inconspicuous tabular crystals of plagioclase about 1 millimeter in length. They are made up about 40 percent of phenocrysts of which labradorite-bytownite is most abundant, and hypersthene and augite are in moderate amount. The groundmass is very finely crystalline, is dusted with iron oxide, and is made up of plagioclase laths in an indistinctly crystalline to glassy matrix. This matrix probably contains some quartz and orthoclase. In rare specimens the feldspar crystals are as long as 10 mm. Rare specimens contain considerable olivine altered to serpentine. An analysis of one of these rocks is shown in table 13, column 5.

The tuff beds are light colored and are made up mostly of fine material with some larger fragments. The fragments are angular and the material is chaotic. Most of the fragments are of a light-colored biotite-hornblende-quartz latite that is made up 35 percent of phenocrysts and that has a vitreous groundmass. Some of the fragments, especially the larger ones, are of rocks similar to those described on the preceding pages.

ALTERED ROCKS

There is a large amount of altered rock in the formation. The largest body is associated with the intrusive stock of Trout Creek but much altered rock is present in the Indian Creek drainage basin as well. The altered rocks are mostly nearly white to flesh colored and retain more or less of the texture of the original rock. They are made up chiefly of quartz and alunite with some clay and pyrite. The alunite replaces both the feldspar phenocrysts and the groundmass. Some are granular aggregates of quartz and alunite. Some have much limonite. Locally the rocks carry much secondary chlorite and epidote.

THE OUTLYING PARTS

In the outlying parts of the Lake Fork quartz latite, away from the main volcanic cone, the rocks are chiefly clastic. The commonest fragment is light colored, vesicular, and glassy. It carries inconspicuous phenocrysts which may be 1 mm long and make up about 40 percent of the rock. Andesine-labradorite is the chief phenocrysts, brown hornblende is abundant, and augite, hypersthene, and magnetite are in moderate amount. The groundmass carries feldspar laths and iron oxide in an abundant glassy paste.

In the outlying parts of the Lake Fork quartz latite the group 1 type of rock is rare; the group 2 type is fairly common, both as flow breccia and fragments in the breccia. The group 5 type is also fairly common both in flow breccias and in fragments in the tuff breccias. The two varieties of dark pyroxene-quartz latite described in the preceding paragraph were both found at a number of places in the formation, mostly as flows but also in the breccia beds.

A section across the formation in Little Blue Creek at a distance from the central mass where the formation is thin is:

	Thickness (feet)
San Juan tuff.	
Lake Fork quartz latite:	
Flow-breccia of hornblende-quartz latite	70
Flow of dark tabular feldspar-pyroxene-quartz latite. Abundant amygdules of chalcedony	80
Flow-breccia and angular chaotic breccia of hornblende-quartz latite	50
Conglomerate made up of pebbles of pre-Cambrian and volcanic rocks in an arkosic matrix	50+

INTRUSIVE ROCKS OF LAKE FORK AGE

The center of the volcanic dome of Lake Fork quartz latite, in the central part of the Uncomphagre quadrangle, was near the head of Trout Creek, and the intrusive granodiorite porphyry near the forks of Trout Creek probably represents the neck of the Lake Fork volcano. This body is surrounded by altered rock and is itself so much altered that its exact form and size are uncertain and the mapping of it is only approximate. It is nearly a mile in its longest dimension.

The chief rock is rather even, half-millimeter grained and it shows a fluidal texture. All the crystals tend to be irregular and to include the groundmass near their borders. Laths of andesine-labradorite with irregular borders of oligoclase, make up about 64 percent of the rock, augite and hypersthene about 15, biotite and magnetite each about 3, and interstitial quartz and orthoclase about 15 percent. The biotite partly borders the magnetite and is partly altered to chlorite. Some of the rock is porphyritic, with a variable proportion of phenocrysts of plagioclase and pyroxene. Some of the border phases have only 25 percent of phenocrysts and have some hornblende partly resorbed.

Most of the rocks are much altered; chlorite, epidote, calcite, quartz, and other secondary minerals have developed. Another type of alteration is to a nearly white or pale-pink aggregate of quartz and alunite, with some clay and pyrite. Another is to opal and limonite. The rocks surrounding the stock have undergone the same type of alteration. There has been some prospecting in the area.

In addition to the large intrusive body there are small dikes scattered through the Lake Fork quartz latite, and these are made up of rocks identical with the effusive rocks of the volcanoes.

CHEMICAL COMPOSITION

Five chemical analyses, made by F. A. Gonyer in the Mineralogical Laboratory of Harvard University, are given in table 13, and the analyses and calculated compositions of the groundmasses of the Lake Fork, San Juan, and Silverton rocks are plotted on variation diagrams in figures 42 and 43.

TABLE 13.—*Analyses, norms, and modes of Lake Fork quartz latite*

[Analysis by F. A. Gonyer, 1944]

	1	*2*	*3*	*4*	*5*
Analyses					
SiO_2	70. 86	69. 06	61. 54	60. 22	57. 44
Al_2O_3	14. 92	15. 42	17. 81	16. 30	17. 70
Fe_2O_3	2. 73	2. 08	4. 48	5. 28	3. 84
FeO	. 14	. 43	. 58	. 43	2. 74
MgO	. 49	. 73	1. 70	2. 46	3. 12
CaO	2. 14	1. 76	3. 94	4. 30	5. 72
Na_2O	3. 82	3. 79	3. 81	3. 68	3. 57
K_2O	3. 47	3. 70	3. 70	3. 27	2. 66
H_2O+	. 72	1. 83	. 87	2. 18	. 75
TiO_2	. 29	. 37	. 66	. 65	. 92
P_2O_5	. 19	. 18	. 36	. 82	1. 05
MnO	. 05	. 06	. 06	. 08	. 07
CO_2	None	. 03	None	. 38	None
SO_3	None	. 06	. 06	. 05	. 03
BaO	. 14	. 11	. 12	. 11	. 11
SrO	. 03	. 02	. 03	. 03	. 04
Total	99. 98	99. 63	99. 72	100. 25	99. 79

TABLE 13.—*Analyses, norms, and modes of Lake Fork quartz latite*—Continued

	1	*2*	*3*	*4*	*5*
Norms					
Q	30. 36	28. 50	15. 12	15. 30	12. 30
or	20. 57	21. 68	21. 68	19. 46	16. 12
ab	31. 96	31. 96	31. 96	31. 44	29. 87
an	10. 29	8. 06	18. 35	16. 40	21. 41
C	1. 10	2. 30	. 90	. 60	1. 10
hy	1. 20	1. 80	4. 20	6. 10	8. 33
mt	---	---	---	---	5. 57
hm	2. 72	2. 08	4. 48	5. 28	5. 57
il	. 46	. 76	1. 37	1. 22	1. 67
ti	. 20	---	---	---	---
ap	. 34	. 34	. 66	2. 02	2. 69
Symbol	I."4. 21.3(4)	I."4. 2.(3)4	I(II. 4".(2) 3,3(4)	(I)II. 4".(2) 3.(3)4	"II.4 (5).3."4
Name	Toscanose	Lasenose	Amiatose	Tonalose	Tonalose
Phenocrysts in modes					
Plagioclase	7	4	14	21	20
(An content)	(43)	(49)	(50)	(48)	(48)
Biotite	2	2	1	---	---
Hornblende	1	---	1	8	1. 5
Augite	---	---	---	---	4
Hypersthene	---	---	---	---	3
Magnetite	---	. 03	---	2	---
Groundmass	90	94	84	69	72

1. Lake Fork quartz latite (U 1625). West slope of hill 9,000 ft southeast of lower fork of Little Blue Creek at 8,900 ft altitude. Deep brownish-drab, dense felsite with few phenocrysts, 2 mm in maximum length, of white feldspar and biotite. Some small, rough gas cavities. Under the microscope a welded tuff with fragments, all alike, as large as 8 mm across. The fragments contain a few phenocrysts of plagioclase, biotite, brown hornblende, and zircon in a groundmass that contains some tablets of calcic andesine 0.3 mm long in a submicroscopic matrix that is stained red with iron oxide dust. There is some tridymite in the pores.

2. Lake Fork quartz latite (U 2538). Between west and middle forks of Trout Creek, east side of saddle at 10,500+ ft altitude. Brownish drab. Plagioclase phenocrysts are about 2 mm long. The groundmass is made up of oligoclase-andesine tablets imbedded in a spongelike intergrowth of quartz and orthoclase.

3. Lake Fork quartz latite (U 2348). Northeast slope of Trout Creek on shoulder 1 mile south of point 10710 at 9,900 ft altitude. Deep brownish drab. Plagioclase phenocrysts as much as 5 mm long. The hornblende is deep brown and the largest prisms are 7 mm long. Most of the phenocrysts are about 1 mm long. The groundmass is made up of small oligoclase-andesine laths in an indistinct sponge of quartz and alkalic feldspar.

4. Lake Fork quartz latite (U 2352). East slope of most easterly fork of Trout Creek and 1 mile south of point 10710. Top of knoll at 10,100+ ft altitude. Benzo brown. This rock looks much like the common quartz latites of the Beidell or San Luis Hills areas. Plagioclase chiefly from 1 to 10 mm long. The rock has few vesicules. The groundmass is very finely crystalline and has oligoclase tablets in a submicroscopic matrix. Cristobalite is abundant in the porous parts of the rock.

5. Lake Fork quartz latite (U 2433). Ridge between branches of east fork of Trout Creek and 1 mile south of point 10710, at an altitude of 10.100+ ft. Dense, dark olive-gray. In the hand specimen it looks much like the tabular feldspar quartz latite of the Potosi but has less conspicuous phenocrysts. The phenocrysts are variable in size and most are less than 2 mm long. The plagioclase is only slightly zoned and carries scattered inclusions of the groundmass. The groundmass is made up of stout oligoclase-andesine tablets, magnetite, and pyroxene grains in a submicroscopic matrix that has a low index of refraction.

SAN JUAN TUFF

NAME AND DEFINITION

The name San Juan formation was proposed (Cross, 1898, p. 226; Cross and Purington, 1899, p. 5) in the study of the Telluride quadrangle for the thick and widespread andesitic tuff that overlies the Telluride conglomerate (San Miguel formation) and underlies the flows and tuffs of the Silverton volcanic series (Intermediate series). This formation is everywhere made up of clastic volcanic material in which fine fragments predominate and the name San Juan tuff is appropriate and has been used to designate the formation in the Silverton and Ouray folios.

The West Elk breccia of the Anthracite and Crested Butte folio (Emmons, Cross, and Eldridge, 1894, p. 5) as it is exposed on the south flank of the West Elk Mountains, proves to be equivalent to the San Juan tuff. It has the same position in the geologic column, the two are connected except for short breaks, and they have an identical and unique petrographic character.

In the Telluride quadrangle the San Juan tuff overlies the Telluride conglomerate without apparent unconformity but to the east only remnants of the Telluride conglomerate remain and the San Juan tuff directly overlies the older, pre-Tertiary rocks ranging from the pre-Cambrian to Cretaceous in age, and in many places the contact shows marked irregularity. This irregularity is particularly striking in Whitehead Gulch in the Silverton quadrangle where the tuff filled in many depressions in the old land surface. It is also well shown in the upper drainage area of the Rio Grande in the west-central part of the San Cristobal quadrangle, in the drainage area of the Lake Fork of the Gunnison, in the northwestern part of the San Cristobal quadrangle, and in the northern half of the Uncompahgre quadrangle.

The San Juan tuff overlies older volcanic rocks only in the central part of the Uncompahgre quadrangle where it laps up on the older volcano of the Lake Fork quartz latite. This volcano had probably undergone some erosion before the San Juan tuffs were deposited but it retained most of its original form.

The upper surface of the San Juan tuff is also a surface of erosion and must have had considerable relief at the time the Silverton volcanic series was erupted, as is well shown in the northwestern part of the San Cristobal quadrangle.

DISTRIBUTION AND THICKNESS

The San Juan tuff is confined to the northwestern part of the San Juan Mountains, chiefly to an area about 50 miles across. It extends west of the Telluride quadrangle, is widely distributed in the Telluride, Silverton, and Montrose quadrangles, and is confined mostly to the northwestern quarter of the San Cristobal quadrangle. It is widely distributed in the Uncompahgre quadrangle, except in the southeast part, and extends to the north of the Montrose and Uncompahgre quadrangles into the West Elk Mountains.

Its thickness differs greatly, for both its upper and lower surfaces are irregular surfaces of erosion. It has a thickness of about 3,000 feet in the southern part of the Ouray quadrangle, but in most places it is much thinner and in many places it is only a few hundred feet thick. In general, the formation is thickest near the southern boundary of the Ouray quadrangle and seems to become thinner to the north, south, and east, and probably to the west.

The original top and the original horizontal extent of the San Juan tuff is uncertain, because its upper surface has been eroded. On the west and northwest its boundary is a cliff of erosion and the formation has a great thickness in these cliff exposures, indicating that it originally extended for a considerable distance beyond its present limits. On the east and southeast the formation pinches out below younger formations which overlie an eroded surface of the San Juan. In the Gunnison River drainage basin, as the formation becomes thinner to the east, it shows better bedding and sorting and the fragments become smaller and better rounded in much the way that other great clastic formations, such as the Conejos quartz latite, change on approaching their outer limit.

Because no good estimate of the amount of the San Juan tuff that has been removed by erosion can be made, no reliable estimate of the original areal extent and volume of the tuff can be made. As a minimum estimate it is probable that the pile of breccia was more than 100 miles across and must have had a volume of at least 1,000 cubic miles.

GENERAL CHARACTER

Although composed almost exclusively of fragments of dark rocks, the San Juan tuff presents much variety in aspect because of differences in texture, the distinctness or obscurity of its bedding, the variation in composition, and its many colors that resulted from different degrees of alteration. It has a distinct parallel bedding that is plain in all large exposures but may be obscure within some of the coarser and more massive beds. The bedding is brought out by the alternation of layers of different textures or colors and is more distinct in some places than in others.

The textural varieties range from fine sandy tuffs to coarse breccias, agglomerates, or conglomerates, but the intermediate phase in which angular, subangular, or, less commonly, well-rounded fragments are enclosed in a tuffaceous matrix, are most abundant. The term "tuff-agglomerate" best expresses its average mechanical character. Most of the formation consists of a tuff whose particles range from microscopic size to about a centimeter across, holding larger subangular fragments that are commonly less than a foot across but in a few places as much as 10 feet across. There is much variation in the relative amounts of fine- and coarse-grained material, but there seems to be no regular progressive change from top to bottom.

The prevailing color of the tuff is gray or purplish gray with grayish-blue, robin's egg blue, and greenish tints locally developed. Commonly the fragments are pale dull green from alteration and the matrix is reddish or purplish. The rocks are uniformly gray in the Uncompahgre quadrangle and adjoining areas where the prevailing fragments are quartz latite and there is less alteration. In the Uncompahgre quadrangle much of the formation is well bedded and some crossbedding is present. Sandy beds are common and the fragments of the coarser beds may be more or less rounded.

Most of the San Juan tuff is not highly indurated and, in consequence, the formation in many places underlies rounded slopes. However, in common with most of the soft tuff-breccia formations of the San Juan Mountains, in many places it weathers into a badland topography with countless fantastic, or hoodoo, forms, many rising as nearly vertical pinnacles or columns to more than 200 feet, protected at the summit by a remnant of a more resistant layer or by a single large boulder. Great broken cliffs of bare rock and deep, steep-walled canyons are common.

The formation is favorable for landslides, especially where it overlies soft beds like the Mancos shale, as it does in the Montrose quadrangle and the western part of the Uncompahgre quadrangle. In this area great landslides cover much of the slopes for many hundreds of feet vertically below the tuffs and the base of the formation, and the underlying rocks are rarely exposed in such areas. Typical exposures of the San Juan tuff are shown in figures 6–10.

A few small lava flows have been described in the San Juan tuff under Potosi Peak by Burbank (1930, p. 151–232).

PETROGRAPHIC CHARACTER

Except for abundant fragments of granite and other pre-Cambrian rocks in the lower beds in the Telluride quadrangle and elsewhere, the San Juan tuff is made up almost entirely of quartz latite. Basalts and rhyolites are rare and the rocks as a whole can properly be called dark quartz latites.

In the Telluride, Silverton, and San Cristobal quadrangles the formation is much altered and dark pyroxene rocks make up most of the fragments. A common type of pebble contains abundant phenocrysts of labradorite and pyroxene. The pyroxene is invariably altered to chloritic minerals and carbonates; the plagioclase in some fragments is fresh, in others it is completely decomposed. Biotite and hornblende are present in some of the pebbles; both are commonly greatly altered. Light-colored rocks are less common. They carry many millimeter-sized phenocrysts of plagioclase, augite, hornblende, and biotite in a micrographic groundmass of quartz and alkalic feldspar. On the whole they are less altered than are the dark pyroxene rocks. A few of the rocks lack phenocrysts.

A study of a large collection of pebbles collected from the ravine west of Pole Creek on the north side of Deep Creek in the western part of the San Cristobal quadrangle shows the character of the materials in these exposures. The predominant pebbles are dark quartz latites. The feldspars of these rocks, both the phenocrysts and the groundmass microlites, are often fresh or nearly so, even where the mafic phenocrysts are entirely altered. The groundmass contains abundant plagioclase microlites. In some rocks the difference in the alteration products indicates that both augite and hypersthene were originally present but no unaltered remnant of either of these minerals has been seen in the sections. Some hornblende and biotite are occasionally present with the pyroxene. The groundmasses are generally well crystalized but they are sometimes obscured by ferritic grains or, rarely, trichites. The alteration products—calcite, chlorite, quartz, and sometimes sericite—may obscure the original character of the groundmass. One thin section shows a fragment of microcline granite and one other a dense limestone.

The exposures in West Lost Trail Creek and southward, on the north slopes of the Rio Grande Valley, west of the center of the San Cristobal quadrangle, are outwardly very much like those of the formation to the west. However, the rocks of the fragments are much fresher than the rocks to the west and many have a glassy groundmass.

To the northeast, in the Ouray quadrangle, light-colored quartz latites become more abundant and to the north and in the Uncompahgre quadrangle the fragments are predominantly of this type. Throughout this area the San Juan tuff is uniform in a general way. The predominant pebbles, and by far the greater part of the fine material, consist of a light greenish-gray, vesicular hornblende-pyroxene-quartz latite, which is made up of about a third of phenocrysts mostly less than 3 mm in cross section, but as much as 5 mm in some, of which andesine or labradorite is the chief constituent, brown hornblende next, and with augite and hypersthene nearly always present. Biotite and iron ore are present in some specimens and quartz is rare. The groundmass is mostly a rhyolitic glass with

FIGURE 7.—Vermillion Peak, looking south from knob at the head of Groundhog Gulch, in the southeastern part of the Telluride quadrangle. Characteristic cliffs of San Juan tuff are capped by a flow of Treasure Mountain rhyolite.

FIGURE 8.—View northwest from Molar Lake in the Silverton quadrangle showing the mountains southwest of Grand Turk. The upper cliffs are San Juan tuff underlain by a thin layer of Telluride conglomerate; the lower steep slopes are of the Cutler formation and below that is the Hermosa formation.

some laths of plagioclase and grains of iron oxide. The analysis of this rock is shown in table 14. A less common rock has fewer and smaller phenocrysts and more plagioclase laths in the groundmass, but is otherwise similar. Rocks like these quartz latites were not found in the Lake Fork volcano.

The rock next in abundance in the fragments of the San Juan tuff of the Uncompahgre quadrangle, and about one-tenth as numerous as the rock described above, is a dark bluish- to greenish-gray, nearly black pyroxene rock, approaching a basalt in composition and appearance. It is like the pyroxene-quartz latite described as the Lake Fork quartz latite but has a more glassy groundmass and more hornblende. The rocks commonly carry abundant small vesicles. They are made up of about one-third phenocrysts, inconspicuous in the hand specimen and mostly less than 1.5 mm across. They are chiefly labradorite with augite, hypersthene, and brown hornblende in variable proportions, some apatite and magnetite, and in some specimens a little altered olivine. The groundmass is mostly dark glass filled with laths of plagioclase and grains of pyroxene.

Fragments of a dense red-brown hornblende-pyroxene rock, like the rocks described as the fifth group of andesites of the Lake Fork quartz latite on page 65, are widely distributed in the San Juan but are less abundant than the rocks previously described.

Fragments of felsitic quartz latite like that of the Lake Fork quartz latite are rare in the San Juan tuff and other types of Lake Fork rocks are almost entirely lacking.

In the Uncompahgre quadrangle, the tuff in the drainage basin of Cimarron Creek and that north of Gunnison River on the south flank of the West Elk Mountains have the same relations to the underlying and overlying rocks, and are identical in petrographic character. They are, without doubt, of the same age. There are commonly some fragments of pre-Cambrian rocks in the lower part of the formation, and north of Cebolla 50 feet of conglomerate, made up of fragments of the harder pre-Cambrian rocks with a sandy or clayey matrix, is at the base of the formation. It might be correlated with the Telluride conglomerate.

SOURCE OF MATERIAL AND CONDITIONS OF ACCUMULATION

The marked similarity in the Uncompahgre quadrangle and adjoining area between nearly all but the commonest type of fragments of the San Juan tuff and some of the common rocks of the Lake Fork volcano leaves no doubt that some of the San Juan tuff was derived from the Lake Fork volcano. However, even in the area near the Lake Fork volcano, the prevailing rock of the tuff is different from any of the rocks found in either the flows or breccia beds of the Lake Fork volcano, and over a wide area is a uniform quartz latite with a vitreous groundmass and of a type common in pyroclastic rocks but rare in widespread lava flows. Moreover, the San Juan tuff shows no tendency to become thicker or more chaotic, or to carry larger fragments near the Lake Fork volcano but is thinner and probably less chaotic, and with smaller fragments than usual in that area. Indeed, the Lake Fork volcano is on the eastern margin of the San Juan tuff. The conclusion seems inevitable that the Lake Fork volcano furnished some material for the San Juan tuff, but that the major part of the San Juan of this area came from another source and probably from an explosive volcano that was active during the San Juan time.

The thickest part of the San Juan tuff is in the southern part of the Ouray quadrangle, and in the

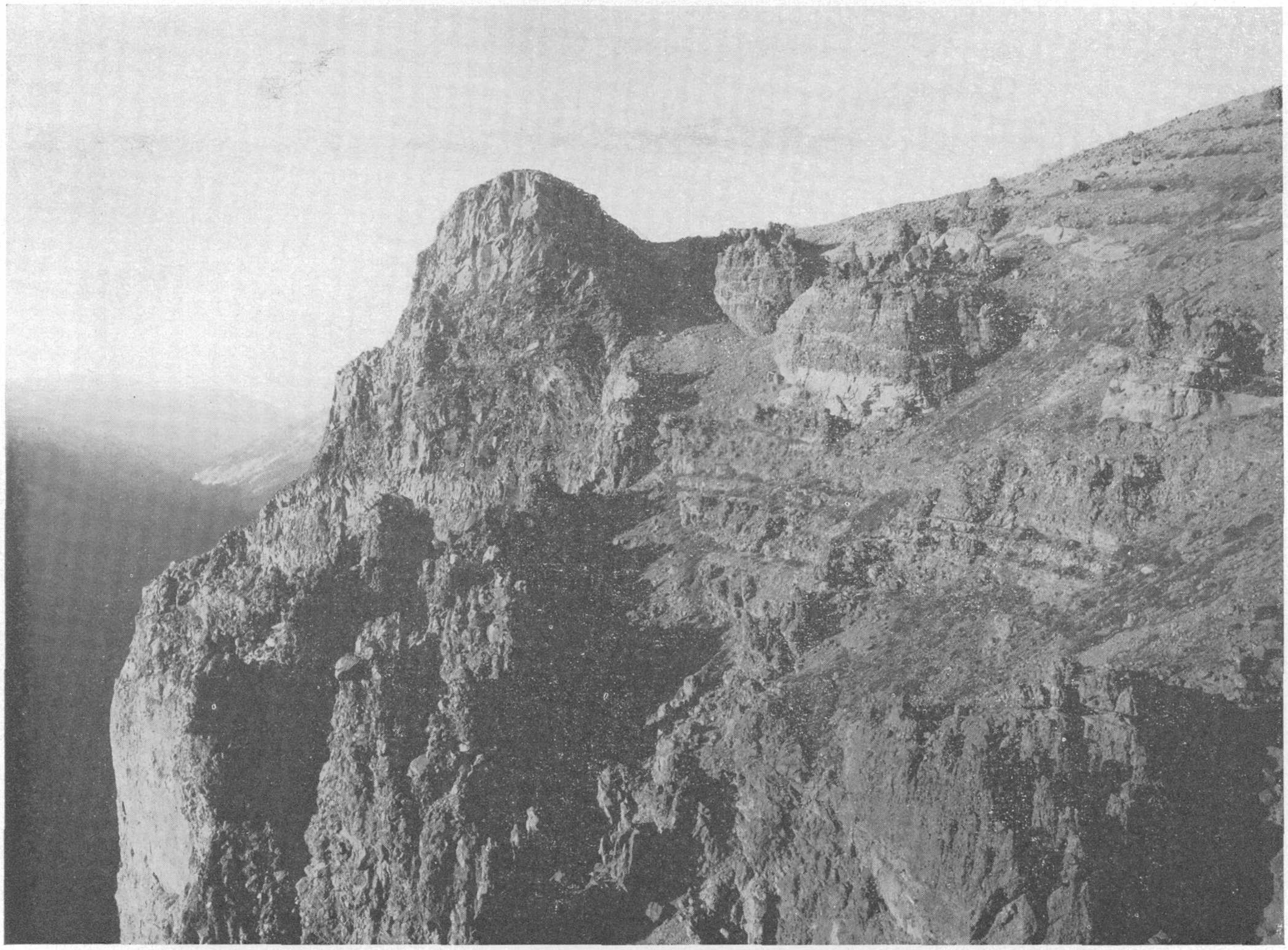

FIGURE 9.—Details of San Juan tuff near the head of Little Cimmarron Creek, Lake City quadrangle. The point left of the center is capped by a massive instrusive body.

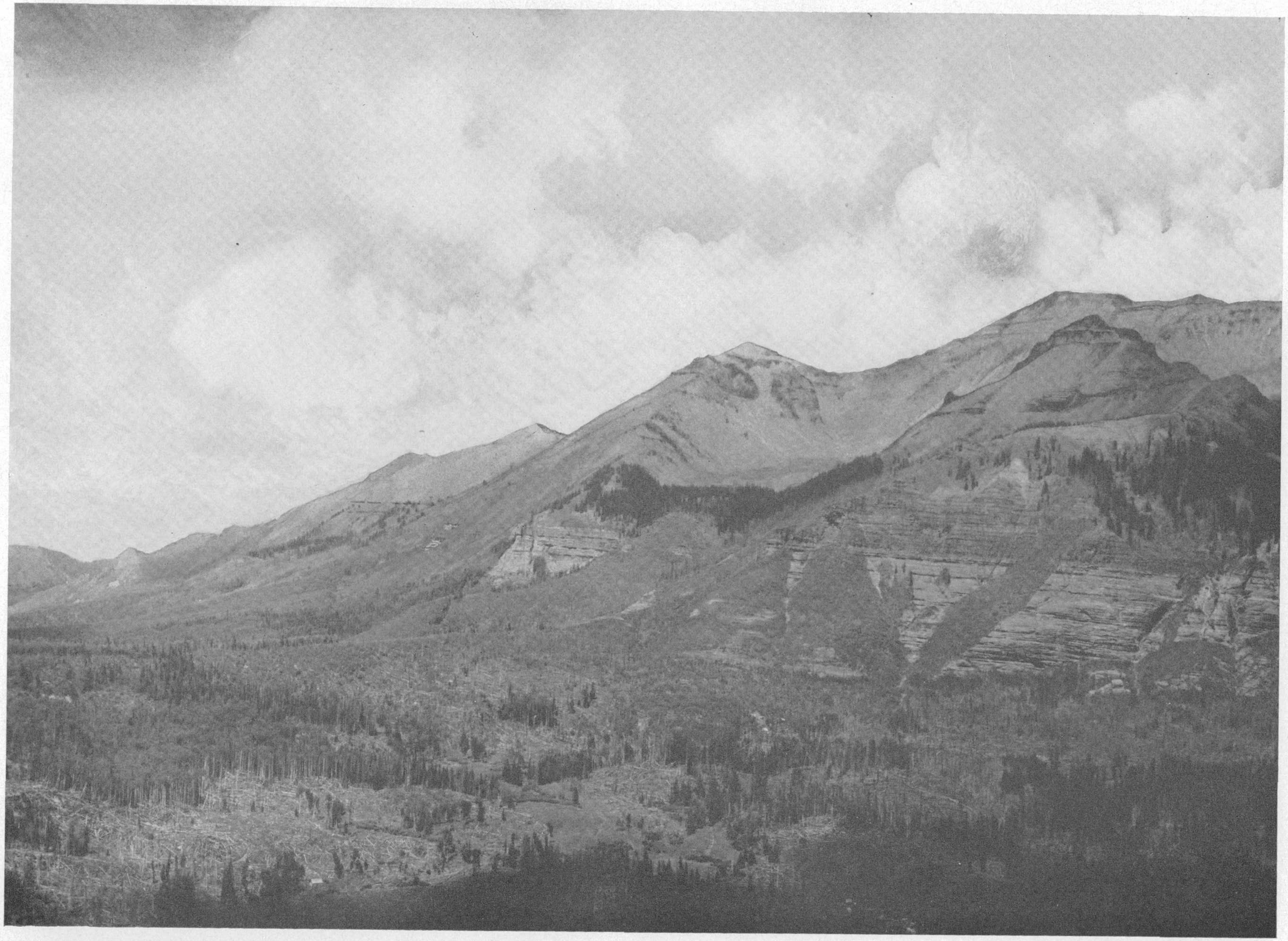

FIGURE 10.—San Juan tuff and Telluride conglomerate in the mountains north of the San Miguel River, as seen from east of Mill Creek, Telluride quadrangle. Campbell Peak is near the center, Iron Mountain on the left, and the high ridge that leads to Dallas Peak on the right. The light-colored cliffs are outcrops of the Telluride conglomerate, above them are the closely bedded San Juan tuffs, and the tops of the mountains are underlain by well-bedded Treasure Mountain rhyolite.

western and southern area dark quartz latites are the dominant rock of the San Juan. No source or sources for the main part of the San Juan material have been found but as likely a place as any would be near the thickest part of the formation and near the southwestern corner of the Ouray quadrangle. If this is true, the actual center of eruption is probably covered.

The bedding, the sorting, and the rounding in the San Juan material show that it was deposited by water. It was mostly deposited by rivers or smaller streams but in part may have been deposited in lakes. Part of the material was probably derived from older volcanic rocks, but perhaps a major part was derived from pyroclastic eruptions that took place during the accumulation of the San Juan tuff.

TABLE 14.—*Analyses, norms, and modes of fragments from the San Juan tuff*

Analyses

	1	*2*	*3*
SiO_2	59.91	58.94	63.03
Al_2O_3	19.02	16.68	15.86
Fe_2O_3	4.44	4.78	3.31
FeO	.74	1.44	1.74
MgO	.30	2.53	1.69
CaO	5.41	5.62	4.40
Na_2O	4.10	2.83	3.17
K_2O	2.93	2.84	3.75
H_2O+	1.84	2.98	1.73
H_2O-	------	------	.43
TiO_2	.92	.75	.64
P_2O_5	.41	.32	.24
MnO	.07	.04	.10
CO_2	------	None	------
SO_3	.04	.03	------
BaO	.09	.11	.08
SrO	None	.02	.03
Total	100.22	99.91	100.20

Norms

	1	*2*	*3*
Q	13.80	17.24	19.32
or	17.24	16.68	22.24
ab	34.58	23.58	27.25
an	24.74	24.74	17.51
di	------	1.51	1.94
hy	.80	5.60	3.30
mt	------	2.78	3.94
hm	4.44	2.88	.64
il	1.76	1.44	1.22
ap	1.01	.67	.67

Symbols.

No. 1 I''.4(5).3.''4 Yellowstonose
No. 2 (I) II.4.3.3 (4) Toxalose
No. 3 I(II).4.(2)3.3'' Amiatose

Modes

	1	*2*	*3*
Plagioclase	25	22	33
(An content)	(62)	(53)	(58)
Biotite	----------	tr	2
Hornblende	1	9	5
Augite	----------	----------	5
Hypersthene	----------	.5	1
Magnetite	1	----------	2

1. Type of fragment that makes up most of the San Juan tuff of a large area (*U3024*). Typical pebble from tuff 150 yd west of road from Iola to Powderhorn and 0.5 mile south of Iola. Gull gray. Very abundant small vesicles. Few, inconspicuous phenocrysts which are commonly less than 0.5 mm long and grade into the feldspar of the groundmass. The plagioclase phenocrysts have abundant inclusions of the groundmass. The hornblende is brown and partly resorbed. The groundmass is dusted with opaque particles and contains abundant tiny, stout plagioclase crystals in a glassy or indistinctly crystalline groundmass. Analysis by F. A. Gonyer, 1944.

2. Commonest pebble in the San Jaun tuff (*Mt. 122*) west of Cimarron Creek, 0.5 mile above the head gate of the big ditch. Eastern part of Montrose quadrangle. Pale olive-gray, porous. Resembles the rock represented by analysis 1 but has abundant sharp crystals of hornblende as much as a 1 mm long. Seriate porphyritic with phenocrysts ranging in size from 2 to 0.1 mm long. The large plagioclase have rounded, corroded cores that are a little more sodic than the main part of the plagioclase. The hornblende is brown. The groundmass is grassy or submicroscopic, and has an index of refraction of about 1.493. Analysis by F. A. Gonyer, 1944.

3. Quartz latite obsidian (*L. C. 347*), Lake City quadrangle, head of Fall Creek on west side of stream entering at an altitude of 11,750 ft, at an altitude of 12,500 ft. A dense black rock with a subvitreous luster. It is seriate porphyritic with phenocrysts from 3 mm long to very small. The hornblende is pale green; it and the biotite are much resorbed, with development of pyroxene and iron oxide. The pyroxene is chiefly in very small grains. The large plagioclase crystals are strongly zoned. The glass is light brown in section and has an index of refraction of about 1.502. Analysis by G. Steiger.

CHEMICAL COMPOSITION

In the southern part of the San Juan tuff the rocks are much decomposed and no analyses were made of rocks here. In this area there is some variety in the fragments of the breccia, and on the average the rocks are richer in mafic minerals than are the rocks to the north, and pyroxene rocks are common. In the Uncompahgre and Montrose quadrangles the San Juan is not much altered and the fragments are commonly little altered. The fragments of the San Juan in this northern area are in very large part of hornblende rocks with glassy or submicroscopic groundmasses that have little range in character. Three analyses of fragments from this area have been made and are listed in table 14. The first analysis was made of a rock whose content of mafic minerals is low. The other two represent the more widespread type of fragment.

SILVERTON VOLCANIC SERIES

DISTRIBUTION

After extensive erosion the San Juan tuff was succeeded in the western San Juan region by a complex of lavas, tuffs, and agglomerates, named after the Silverton quadrangle in which they have their greatest development. Because the Silverton rocks seem to have been in large degree erupted within an erosional valley or basin, and because their outlying parts were eroded away before the eruption of the overlying Potosi volcanic series, they now occupy comparatively small areas. They are the most important among the rocks of the Silverton quadrangle, reaching an observed maximum thickness of about 3,000 feet. To the west they thin out and disappear in the Telluride quadrangle. In the Telluride folio they were called the Intermediate series. They do not extend south of the Telluride quadrangle. To the north, they extend for only a short distance into the Montrose, Ouray, and Lake City quadrangles. To the east they extend for only a few miles into the San Cristobal quadrangle, except in the drainage area of Lake Fork of the Gunnison River in the extreme northern part where they extend nearly to the middle of the quadrangle.

The present extent of the formation is about 40 miles east and west and 25 miles north and south. It reaches a thickness of about 3,000 feet in the Silverton quadrangle and it is nearly as thick in the Lake City and San Cristobal quadrangles. Its eastern limit seems to be largely the result of erosion preceding the Potosi eruptions. To the north it seems to have been deposited against a steep slope of San Juan tuff. To the west it seems to wedge out slowly and to the south it seems to wedge out more rapidly. It probably never occupied a very much larger area than its present distribution indicates. Other centers of eruption may have existed during Silverton time. The size of the area of the main part of the Silverton pile is about 1,000 square miles, and that of the volume was about 250 cubic miles. It is, therefore, much smaller than the Potosi volcanic series or Hinsdale formation and is smaller than the San Juan tuff and the Fisher quartz latite.

SUBDIVISIONS

In the Silverton and Ouray folios the formation was divided into five members and on the geological map of this report (pl. 1) these members have been mapped except in the western part where the formation is not subdivided but is mapped as undifferentiated Silverton volcanic series. The members are:

1. Picayune quartz latite (called andesite in the older reports) is the earliest member of the series, and is made up of flows and tuffs of quartz latite, with some rhyolite of the Eureka type. This member is extensively developed in the San Cristobal and Uncompahgre quadrangles and is of very local development in the Silverton quadrangle.
2. Eureka rhyolite, flow, welded tuffs, flow breccia, and tuffs. This is one of the most widespread members of the Silverton series.
3. Burns quartz latite, a siliceous hornblende-quartz latite with tuff at the top and bottom, but made up mostly of flows in the central part. The tuffs contain scanty plant remains which have yielded evidence of the age of the rocks. It is a widespread formation in the Silverton quadrangle and is found in the Ouray, San Cristobal, and Uncompahgre quadrangles. In the last quadrangle it is interbedded with the pyroxene-quartz latite (called pyroxene andesite in the older reports).
4. Pyroxene-quartz latite flows with some breccia of dark pyroxene rocks. It is one of the most important and widespread members of the series.
5. Henson tuff, mostly sandy tuff of quartz latitic composition. It is a thin and local member.

PICAYUNE QUARTZ LATITE

The name Picayune andesite was proposed in the Silverton folio for the lowest formation of the Silverton series. However, because further study of this member in the Lake City and San Cristobal quadrangles has shown that the member is predominantly a quartz latite with some rhyolite, the name Picayune quartz latite is more appropriate.

GENERAL CHARACTER, DISTRIBUTION, AND THICKNESS

The Picayune quartz latite is made up of interlayered flows and tuffs. The rocks of the group are prevailingly dark in tone and crop out in somber cliffs in which a stratified arrangement of successive flows or beds can be recognized in many places. Commonly the beds dip irregularly and can seldom be followed far. The rocks are chiefly dark-purple or greenish quartz latites grading into rhyolites on the one hand and into darker quartz latites on the other. The rocks near Animas Forks in the Silverton quadrangle are dark porphyritic quartz latites, with pyroxene, hornblende, and biotite. Lighter colored quartz latites are also present. Rhyolites of the Eureka type are interbedded with the tuffs and have been in part separated and mapped as Eureka rhyolite except in the San Cristobal quadrangle where they are included with the Picayune. This interlayering of the dark quartz latite with rhyolites of the Eureka type is well shown west of Lake San Cristobal where many horizons of rhyolite were found in a section of 1,800 feet of Picayune. No regular succession of rocks of different types was found.

Intrusive masses of different size and shape and made up of rocks similar to those of the flows and breccia fragments are present and are distinguished from the flows with great difficulty and only in favorable places.

The largest mass of Picayune quart latite lies in the drainage basin of Henson Creek in the southern part of the Lake City Quadrangle and in the drainage basin of Lake Fork of the Gunnison in the adjoining part of the San Cristobal Quadrangle. This mass is about 12 miles east-west and 10 miles north-south. In much of this body the formation is nearly 2,000 feet thick, with the base not exposed and the upper surface either a surface of erosion or of intrusion. This body represents a volcanic dome somewhat modified by erosion. A much smaller body of Picayune rocks is exposed a few miles northeast of the center of the Silverton quadrangle, in the drainage of Animas River, around the mouth of Picayune Gulch. This outcrop is only a few miles in extent and is bounded partly by faults and partly by overlying formations. This mass is only about 3 miles southwest from the outcrop in the Lake Fork of the Gunnison River.

PETROGRAPHY

The most common rock in the Picayune quartz latite, especially in the massive rock, is a dense red or green quartz latite that carries abundant stout white plagioclase tables about 2 millimeters long, some resorbed bleached biotite, and some hornblende in an aphanitic groundmass. Phenocrysts make up about one-fourth of the rock. Andesine or andesine-labradorite predominates and orthoclase is rare. Biotite, much resorbed and bleached, is the chief dark mineral; hornblende, also resorbed, is common; and altered pyroxene is present in varying amounts. The chief accessories are magnetite, apatite, and zircon. The groundmass is mostly a fine-grained granophyric intergrowth of quartz and alkalic feldspar, but some is microfelsitic. The rocks are everywhere much altered and carry secondary quartz in veinlets and filling cavities, and much secondary calcite, chlorite, sericite, epidote, and rarely piedmontite. In places the plagioclase is albitized. Pyrite is locally abundant.

In some specimens the plagioclase, hornblende, and pyroxene crystals become more abundant and minute flakes of plagioclase are abundant in the groundmass.

Quartz latites that are nearer the rhyolites in composition are also abundant. They are commonly red and show a fluidal structure and platy parting. They contain a lesser amount of phenocrysts, especially hornblende, and have a microfelsitic or granophyric groundmass that contains many trichites of hematite.

The quartz latites grade into nearly white to red fluidal rhyolites that carry few phenocrysts. They differ from the quartz latites in their lighter color, smaller biotite and plagioclase content, and lack of hornblende. Other rhyolites are like the Eureka rhyolite, and less common rhyolites have embayed quartz phenocrysts.

A flow breccia or welded tuff of quartz latite is fairly abundant. Commonly it is red with mottled greenish spots, rarely white. It has phenocrysts of andesine, orthoclase, and biotite in the residual groundmass. In the Animas River in the Silverton quadrangle

> The Picayune type of andesite [quartz latite] is a rock of pronounced porphyritic texture through its abundant tablets of labradorite, which lie in a groundmass usually much stained by chlorite, giving the rock a dark-green color. Altered prisms of a pyroxene now completely replaced by chlorite are also prominent, but less so than the feldspar tablets, which often exceed half a centimeter in diameter. The groundmass originally contained microlites of plagioclase and augite (?) with a dust of magnetite, but is now greatly obscured by alteration products. A good deal of the rock is highly amygdaloidal, the vesicles being filled with chlorite and calcite.
>
> Some of the Picayune rock in the Animas area is breccia or tuff, many of the fragments being finer-grained than the type above described. Fragments of rhyolite flow-breccia are also common in the tuffs. (Cross, Howe, and Ransome, 1901, p. 7.)

No analyses of Picayune rocks have been made, because no rocks fresh enough for analyses were found. The microscopic study gives a fair idea of the range in composition. They must range from rhyolites high in silica, potash, and soda content and low in iron, magnesia, and lime, to dark quartz latites with moderate amounts of silica, iron, magnesia, lime, and potash.

EUREKA RHYOLITE

DESCRIPTION

The Eureka rhyolite is mainly in flows or welded tuffs. In the Silverton quadrangle it is largely a huge surface flow, reaching a thickness of 2,000 feet on the east side of the Animas just above Eureka, and thinning out westward. To the east the flows are not so thick, but even there some of the flows are several hundred feet thick and their areal extent is measured by square miles. A small amount of tuff separates some of the flows but more commonly the flows are in direct contact and are so similar that the boundaries are not easily detected. In the Lake City quadrangle

> Intrusive bodies occur in the area extending from Deer Park around the western slopes of Kendall Mountain to Arastra Gulch, the rock cutting the San Juan tuffs. The map representation of this crosscutting relationship on the western slopes of Kendall Mountain is hardly more than a diagrammatic generalization, the best that could be done in view of the complex network of dikes and the poor exposures. In Cunningham Gulch the lower contact of the rhyolite cuts through schists and San Juan tuffs. In the area of the Picayune andesite small dikes interlace in complex fashion in several places.
>
> The number of these crosscutting channels makes it appear possible that they represent some of the main conduits through which this magma came to the surface. (Cross, Howe, and Ransome, 1901, p. 8.)

The greatest and most typical exposure of this rock is in the steep walls of Animas Valley at and above Eureka Gulch. The main, lower part of the flows has a distinct fluidal structure but the upper 200 or 300 feet lacks it. In other places the fluidal structure is found chiefly in the lower parts of the flows or near the contacts of the intrusives.

> [The Eureka rhyolite] is so characterized by small included fragments of andesites, of rocks very similar to the rhyolite itself, or occasionally of granite, schist, etc., and has so commonly a distinct flow structure, that much of the rock may be called a flow-breccia. * * * [It] has not been found in fresh condition * * * and it assumes various aspects according to the number, size, and character of its included fragments and the degree and kind of alteration it may have undergone. Normally it is a grayish rock exhibiting many small angular inclusions, averaging much less than half an inch in diameter, of dark, fine-grained andesites or of reddish or grayish rhyolite, and has a prominent fluidal texture in the dense felsitic groundmass which holds the fragments. (Cross, Howe, and Ransome, 1901, p. 7.)

The microscope shows that the matrix in which the fragments are imbedded usually contains from 20 to 40 percent of millimeter-sized phenocrysts. Orthoclase is commonly most abundant, oligoclase less so, resorbed quartz still less common, and biotite, bleached and resorbed, is in small amount. The groundmass has a fluidal texture, expressed by the curving of trains of trichites or ferritic grains around the crystals and included fragments of rock. It is a cryptocrystalline mass, locally spherulitic or microgranophyric, and is clearly rhyolitic in composition.

The rocks are always much altered. Commonly the orthoclase is fairly fresh, the plagioclase somewhat altered, and the biotite almost completely altered. More or less secondary calcite, epidote, and chlorite are common. At the head of the Rio Grande the Eureka rhyolite has fewer inclusions and the feldspars are kaolinized. In places the color is red.

The Eureka rhyolite is not very different from some of the rhyolites of the Potosi volcanic series. The Eureka carries more inclusions than the Potosi and is more commonly white or gray or dark red. The Eureka rocks carry more phenocrysts, especially those of orthoclase and quartz. They are also more uniformly altered than are the rhyolites of the Potosi.

The rocks are so decomposed that no material suitable for chemical analysis was found, but microscopic study shows with reasonable assurance that the composition ranges from that of a rhyolite to that of a quartz latite near the rhyolites.

DISTRIBUTION AND THICKNESS

The Eureka rhyolite is widely distributed in the Silverton quadrangle and it extends eastward down Henson Creek as far as Lake City and for a few miles into the San Cristobal Quadrangle. It has a maximum observed thickness near Eureka Gulch of 2,000 feet, but it thins out to the west, north, and east. To the notheast, in the drainage of Henson Creek, it is commonly more than 1,000 feet thick and may be as much as 2,000 feet. The total area covered and the total volume are small compared with those of the formations of the Potosi volcanic series and Hinsdale formation.

BURNS QUARTZ LATITE

GENERAL CHARACTER AND DISTRIBUTION

Cross, Howe, and Ransome (1901, p. 8) say:

> The division of the Silverton series succeeding the Eureka rhyolite contains several somewhat different kinds of lava, most of which are characterized by hornblende, in contrast to the succeeding pyroxenic member of the series. These rocks are often much decomposed, and the original ferro-magnesian silicates can not always be recognized. * * * These latites belong to one general epoch of eruption within the Silverton period. The greater part of the complex consists of more or less overlapping massive lava flows, but fine- and coarse-grained tuffs and breccias occur in variable development below, above, and between the flows. At two horizons, thin-bedded tuffs are associated with calcareous layers, the uppermost beds of the section containing scanty fossil remains. The position of this complex within the Silverton series is very distincly shown east of the Animas River, in the vicinity of Burns and Niagara gulches, where its most widely distributed and easily recognizable facies occurs between the Eureka rhyolite and the pyroxene-andesites [here called quartz latites].

The Burns quartz latite is widely distributed and best developed in the Silverton quadrangle and the descriptions are taken largely from the text of the Silverton folio. It makes up part of the rocks mapped as undifferentiated Silverton volcanic series in the western part of the Silverton and Telluride quadrangles. The latite extends for only a few miles east of the Silverton quadrangle into the San Cristobal quadrangle, and for a few miles north in the Ouray quadrangle, but to the northeast in the Lake City quadrangle it extends down Henson Creek to and beyond Lake City.

In most places the Burns quartz latite is less than 1,000 feet thick but in the central parts of the Silverton area it is much thicker. As it overlies an irregular surface of the Eureka rhyolite and older rocks and is, in turn, overlain irregularly by the pyroxene-quartz latite, its thickness changes rapidly from place to place.

DESCRIPTION

The most widely distributed of the massive flows in the Burns quartz latite is a hornblende-quartz latite found in Niagara Gulch, where it occurs in a massive flow between two notable tuff bands. The rock is pale purplish-drab. The larger phenocrysts are about 3 mm long. The plagioclase has a core of labradorite and a broad sodic border. The rock probably originally contained a little hypersthene, now altered to bastite. The hornblende is brown and partly resorbed. The groundmass is dusted with opaque grains and has some oligoclase tablets in a spongelike intergrowth of quartz and alkalic feldspar. An analysis by W. F. Hillebrand and a norm and mode of a fairly fresh specimen of this rock (P. R. C. 1253) from the ridge north of the head of Pole Creek are given in table 15.

TABLE 15.—*Analysis, norm, and mode of Burns quartz latite*

Analysis		*Norm*	
SiO_2	62.09	Q	15.54
Al_2O_3	16.77	or	21.68
Fe_2O_3	3.96	ab	31.96
FeO	.99	an	17.79
MgO	1.63	di	1.08
CaO	4.26	hy	3.80
Na_2O	3.77	mt	1.16
K_2O	3.18	il	1.37
H_2O-	.50	hm	3.20
H_2O+	1.32	ap	.67
TiO_2	.73	*Symbol:*	
ZrO_2	tr	I(II).4''.(2)3.3(4)	
P_2O_5	.25	Amiatose	
MnO	.14		
BaO	.10	*Mode*	
SrO	.05	$Ab_{45}An_{52}$	15
Li_2O	tr	Hornblende	5
S	None	Augite	1
		Biotite	tr
Total	100.24	Groundmass	79

Several flows on Canby Mountain and adjoining summits are made up of rock similar to that just described but with more conspicuous hornblende and augite. The lowest of these flows has a somewhat coarser groundmass. The flows of Kendall Mountain are characterized by some quartz phenocrysts and by irregularly and sparsely disseminated crystals of orthoclase, some of which are as much as 12 millimeters wide.

This rock commonly contains much secondary chlorite, epidote, calcite, and other minerals. The rock which occurs at the mouth of Cunningham Gulch and extends down the Animas to Arastra Gulch is greenish gray, with a subordinate porphyritic texture and micropoikilitic groundmass made up of orthoclase and quartz. A few phenocrysts of quartz are present. The rock of Arastra Gulch is similar to that just described but has a coarser groundmass and a few large crystals of orthoclase.

The tuffs of the Burns eruptions are usually fine-grained but are in places of coarse texture. Some are locally developed between lava flows and are widely distributed at two general horizons, one at the base, the other at the top of the series of rocks referred to the Burns epoch. The coarser tuffs and breccias have much the general character of the San Juan tuff, consisting of more or less distinctly angular fragments of quartz latite in a matrix of fine volcanic sand. Such rocks have commonly a dark-gray or purplish color. Rhyolitic flow breccia and granitic or rarely quartzitic debris are found in places. The fragments seldom exceed a few inches in diameter.

The fine-grained tuffs of the complex are in some places very homogeneous in texture, forming greenish or gray sandstones not commonly much indurated. They are composed of fine angular particles, which may be less than 1 mm in diameter, representing the crystals or the groundmass of latites and other rocks. The ferromagnesian silicates are much decomposed and are usually unrecognizable. Quartz grains are ordinarily accompanied by orthoclase and microcline, testifying to the destruction of granitic masses in the production of the tuff.

The tuffs at the base of the Burns quartz latite are irregular and reach a thickness of 250 feet in Minnie Gulch. They are usually fine grained, well bedded, and of a dull green. Coarse conglomerate or breccia is present locally. These tuffs contain some quartz and microcline derived from granitic rocks. At the top of the lower tuff zone there occurs locally massive limestone a few feet thick, either dark gray and well bedded or showing marble facies.

A variable amount of fine-grained tuffs is usually found at the top of the Burns quartz latite, especially in the region around the head of the Animas and farther eastward, and they locally reach a thickness of several hundred feet. Commonly these tuffs are similar to those of the lower horizon, but in places the upper 50 feet or more is made up of calcareous shales and thin beds of limestone. Plant remains and gastropod shells are present in the uppermost parts of these beds.

In the San Cristobal quadrangle both flows and tuffs are present. Most of the flows are dense, gray to black or red and carry up to one-third andesine or labradorite laths from 0.5 to 1 mm long and some biotite, brown hornblende, and augite in an aphanitic groundmass. The microscope shows the groundmass to carry minute plagioclase tablets and some of the dark minerals in a felsitic micrograsnophyric or submicroscopic paste.

In the Lake City and Ouray quadrangle the Burns quartz latite is represented only by fine-grained sandy tuffs and calcareous beds, probably belonging to the upper tuff member.

PYROXENE-QUARTZ LATITE

DISTRIBUTION

The Burns quartz latite is succeeded by dark pyroxene-quartz latite (called andesite in the older reports) in a complex of flows and tuffs reaching a thickness of more than 3,000 feet in the Silverton quadrangle. It is the most widespread and makes up the greatest volume of any of the subdivisions of the Silverton volcanic series. The pyroxene-quartz latite reached its greatest development near the center of the Silverton quadrangle. It extends westward into the Telluride quadrangle where it has not been separated from the Burns quartz latite, and northward for a short distance into the Ouray quadrangle and to the northeast for a few miles into the Lake City quadrangle where it is exposed in the drainage basin of Henson Creek. To the east in the San Cristobal quadrangle it is present in the drainage of Pole Creek and attains a thickness of more than 2,000 feet south of the Lake Fork of the Gunnison River. To the south of the Silverton quadrangle part of it has been eroded away.

DESCRIPTION

In the northeastern part of the Silverton quadrangle some of the rocks are distinctly porphyritic, with abundant phenocrysts as much as 5 centimeters wide of labradorite, and some smaller crystals of augite and biotite. Some of these flows are dark and rich in pyroxene. The rocks are commonly seriate porphyritic to porphyritic in texture. Many have some granophyric quartz and orthoclase. Hornblende and biotite are present in a few of the rocks. Much of the hypersthene and some of the augite are altered.

In the San Cristobal quadrangle, south of the Lake Fork of the Gunnison River and near the head of Cottonwood Gulch, the pyroxene-quartz latite consists chiefly of massive flows with some thin layers of plant-bearing tuff and some breccia. Many of the flows are fairly thin but the upper flow in Wager Gulch is several hundred feet thick. The rocks are commonly dense, except at the borders of flows. In color they are mostly dark gray or green; rarely they are light gray or green. The flows show little variation. Nearly all show abundant tablets of plagioclase as much as 2 millimeters across, some pyroxene, and rarely either hornblende or biotite or both in an aphanitic groundmass that commonly is latitic in composition. All the rocks are dark quartz latites. Nearly all carry from 20 to 50 percent of phenocrysts, of which calcic andesine is much greater in amount than augite and hypersthene, which are the chief dark minerals. Either biotite or hornblende or both may be present as well as the pyroxene and rarely to the exclusion of pyroxene. Some of the biotite-rich rocks are nearer the average quartz latites in composition. The groundmass is commonly a fine-grained micrographic intergrowth of quartz and alkilic feldspar with some laths of sodic feldspar and some grains of pyroxene and magnetite; in some rocks it is glassy. The proportion of plagioclase laths in the groundmass ranges from nearly zero in the felsic types to nearly 100 percent in the mafic types. In the dark rocks the plagioclase laths are sodic labradorite and the rocks approach basalts. Some of the quartz latites carry a few phenocrysts of orthoclase, as well as the andesine, and have biotite as the only dark mineral. Such rocks commonly have a spherulitic groundmass with or without small plagioclase laths. In all these rock the plagioclase phenocrysts are zoned and the biotite and hornblende resorbed. The rocks are mostly fresh but the hypersthene is in most specimens altered and the augite is sometimes altered.

TABLE 16.—*Analyses, norms, and modes of rocks of pyroxene quartz latite of the Silverton volcanic series*

[Analyses by W. F. Hillebrand]

Analyses	1	2	Norms	1	2
SiO_2	58.88	56.03	Q	17.46	10.86
Al_2O_3	16.10	15.97	or	11.12	19.46
Fe_2O_3	3.12	4.78	ab	27.25	24.10
FeO	2.94	3.00	an	23.35	21.13
MgO	2.30	3.36	di	3.77	6.51
CaO	6.05	6.44	hy	5.98	5.50
Na_2O	3.17	2.85	mt	4.41	6.96
K_2O	1.86	3.29	il	1.37	1.98
H_2O+	2.86	1.08	ap	.67	1.39
H_2O-	1.66	1.31			
TiO_2	.73	1.01			
P_2O_5	.17	.48			
MnO	.16	.16			
ZrO_2	.02	tr.			
S	------	.08			
Li_2O	tr.	-------			
BaO	.13	.08			
SrO	.14	.04			
FeS_2	.07	-------			
Total	99.97	99.88			

Symbols:

1 ''II.4.3.4 Tonalose

2 II.4(5).3.3 Harzose

Modes	1	2
Plagioclase	27 (An 58)	34 (An 52)
Augite	5	4.5
Hypersthene	3	5
Biotite	.5	---------
Hornblende	.5	---------
Magnetite	1	1
Groundmass	63	59

1. Vitrophyric pyroxene-quartz latite (P. R. C. 1355) from Silverton quadrangle, ridge west of Edith Mountain. A dense, nearly black rock with inconspicuous white tablets as long as 5 mm of plagioclase, and some prisms of pyroxene. Seriate porphyritic. The plagioclase has little zoning and has scattered inclusions of the groundmass. The hypersthene is somewhat altered to bastite. The groundmass is a smoky glass, with an index of refraction about 1.522.

2. Pyroxene-quartz latite from Silverton quadrangle, Copper Gulch, on Dolly Varden claim. Dense, nearly black. Abundant black plagioclase tablets as long as 10 mm. The plagioclase has little zoning and has abundant films of chloritic material along the cleavage cracks. About half of the hypersthene is altered to reddish serpentine. The groundmass has an average grain size of about 0.05 mm and is made up of andesine tablets, magnetite, pyroxene, oligoclase, and some quartz and orthoclase.

In the middle fork of Pole Creek near the western border of the San Cristobal quadrangle the rocks are much like the mafic types of the areas described in the preceding paragraphs.

CHEMICAL ANALYSES

Chemical analyses of two of these rocks of the darker, silica-poor variety are given in table 16.

HENSON TUFF

The Henson tuff, the youngest member of the Silverton volcanic series, is a pyroclastic formation consisting chiefly of well-bedded, fine-grained, greenish or brownish-gray, sandy tuff, composed of dark quartz latitic material. It is of local distribution and is confined to the southeastern part of the Ouray quadrangle and the adjoining parts of the Silverton and Lake City quadrangles. It is exposed chiefly in the drainage basin of Henson Creek and the ridges just beyond that drainage. Their maximum extent, east and west, is about 12 miles, and north and south only a few miles. Their maximum observed thickness is about 600 feet on the divide between North Fork of Henson Creek and Cow Creek in the Ouray quadrangle. It may originally have had a much wider disbribution and greater thickness, for it has undergone extensive erosion preceding the eruption of the lavas of the Potosi volcanic series.

The following description is taken from the Ouray folio (Cross, Howe, and Irving, 1907, p. 9):

The Henson tuff is very much like the Burns tuff in texture and composition and hence also in appearance. There are, however, no calcareous shales or limestone layers in the Henson tuff at the points where that formation has been examined. Much of the tuff consists of rather rounded sand grains, evidently derived in large degree from pyroxene andesite (quartz latites). Some grains exhibit parts of crystals of labradorite, augite, or hypersthene embedded in dark ferritic or microlitic groundmass, but many grains are without large crystals and probably represent particles of the [latitic] groundmass. The tuff grains are in general only 2 or 3 mm in diameter, and some beds consist of very fine particles. Bedding is nearly perfect, but is not conspicuous in some exposures owing to the uniform texture and friable condition of the strata.

The colors of the tuffs are either brownish or greenish as a rule, generally of dull hues, but in some places a vivid green, due to abundant chlorite, is strongly developed. The color of some such beds is visible for miles.

The Henson tuff at some localities carries angular or subangular fragments of pyroxene andesite [quartz latite], rhyolite, or quartz latite. The andesite [mafic quartz latites] is similar to the rock of the underlying flows, and the rhyolite and latite are distinctly of the facies of flows of the Potosi series and unlike any known earlier lavas. Such fragments reach a diameter of 1 foot or more and they have been found locally of such abundance as to make a volcanic breccia with subordinate tuff matrix. This phase of the Henson is well exposed on the divide between North Fork of Henson Creek and Cow Creek, on and near the trail. The tuffs on the south slope of Wildhorse Peak also contain many fragments of the rocks named.

PRE-POTOSI ROCKS OF THE EASTERN PART OF THE MOUNTAINS

DISTRIBUTION AND CHARACTER

Several large bodies of volcanic rocks that are definitely older than the Conejos quartz latite, the oldest formation of the Potosi volcanic series, are present in the Saguache quadrangle and the north part of the Del Norte quadrangle. The largest of these is north of Saguache, near the mining town of Bonanza, and underlies a known area of more than 100 square miles. A somewhat smaller body lies south of Saguache near the old mining camp of Beidell, and small bodies are in the drainage areas of La Garita and Carnero Creeks. These rocks formed a mountain mass when the Conejos eruptions began and they were probably never completely covered by later eruptions. These pre-Potosi mountains were near the eastern border of the thick body of Potosi rocks as all of the formations of the Potosi are relatively thin in this eastern area.

Somewhat similar rocks believed to be pre-Potosi, though they were nowhere seen in contact with the Potosi volcanic series, form the San Luis Hills east of Conejos and on both sides of the Colorado-New Mexico State boundary, and similar rocks were found near the Rio Grande as far south as the road from Taos Junction to Taos.

The chief rocks in all these areas are light-colored quartz latites with conspicuous plagioclase phenocrysts. Near Beidell two groups of quartz latites that are separated by a surface of erosion make up the pre-Potosi rocks. In the San Luis Hills a lower member is made up of quartz latites similar to those near Saguache, and is intruded by stocks of syenite and diorite. An upper member overlies a very irregular surface of erosion cut in the latites and associated intrusive rocks and is made up of olivine-quartz latites. The quartz latites of all these areas are much alike and the microscopic study and chemical analyses of all these rocks and the presence of olivine-quartz latites and stocks of syenite indicate that they have a lower silica content than the Potosi rocks. They do not resemble the rocks of the Silverton volcanic series, the San Juan tuff, or the Lake Fork quartz latite and chemically they somewhat resemble the fragments of the McDermott and Animas formations near Durango which are of Late Cretaceous and early Paleocene age.

UNDIFFERENTIATED VOLCANIC ROCKS OF THE NORTHERN PART OF THE SAGUACHE QUADRANGLE

In the northern part of the Saguache quadrangle, in the extreme northeastern part of the area included on the San Juan Mountains map (pl. 1), an area of about 250 square miles is mapped as undifferentiated volcanics. The rocks of this area are chiefly of pre-Conejos age, but near the western and southern border and in the high mountains of the central part, some bodies of the Potosi volcanic series, especially the Conejos and Sheep Mountain divisions of the Potosi, have been included. At the time this area was examined no suitable base map was available and the area was examined only in a very rapid reconnaissance with the hope that a suitable base map would later be available. Patton (1916) had earlier mapped a small area around the mining camp of Bonanza. A good topographic map of a small area near Bonanza has been made by the United States Geological Survey and a detailed geologic map of this small area was prepared by W. S. Burbank (1932a).

In the following description of the rocks of the Bonanza area, the detailed section as worked out by Burbank will be described first, followed by a description of the area to the west. Free use will be made of Burbank's report. The volcanic rocks of the Bonanza area are pre-Potosi. Burbank (1932a, p. 16) states that the approximate thickness is about 4,000 feet and gives the following section of the mapped extrusive rocks of the area:

	Feet
Andesite [quartz latite (?)] (flows, only small part of series within the district)	300
Brewer Creek latite (flows)	500
Porphyry Peak rhyolite (local (?) flows, tuffs, and agglomerates; some intrusives)	1, 000
Squirrel Gulch latite (flows)	300–500
Hayden Peak latite (local flows, tuffs, and breccias; probably some intrusives). Believed to be in part contemporaneous with Bonanza latite and in part younger	1, 000–1, 500
Bonanza latite (mostly flows, some tuff and breccia in upper part)	500–1, 000
Rawley andesite (mostly thin flows, with some latites and breccia)	1, 000–2, 000

The rocks of the northern part of the district are different from those of the southern part. The Rawley andesite is found in both parts, the Bonanza latite, Squirrel Gulch latite, and Porphyry Peak rhyolite are confined to the northern part, and the Hayden Peak and Brewer Creek latites to the southern part. All of the volcanic rocks of the Bonanza area would probably be included in a single unit if described on the scale of the San Juan report.

The most abundant and typical lava of the Rawley andesite is a dark augite-biotite andesite which has phenocrysts of labradorite (An_{55-63}), augite, and some brown hornblende in an andesitic groundmass. Some rocks contain augite as the chief or only mafite. In the southern part of the district the upper part of the Rawley andesite contains dark mica-bearing biotite andesites or latites. These rocks are conspicuously porphyritic with phenocrysts as much as 6 mm long of andesine and biotite in a finely crystalline groundmass that contains plagioclase, orthoclase, and quartz. The first few thin flows at the base of the Rawley andesite on Alder Creek are dark gray, greenish, or reddish brown latites that exhibit a distinct flow structure. They contain phenocrysts of andesine 2 to 4 mm long and some of biotite in a groundmass of devitrified glass. A latite from the middle part of the Rawley andesite in the northern part of the district is coarse grained and contains phenocrysts of sodic labradorite, augite, hornblende, and biotite in a microgranular groundmass of plagioclase, orthoclase, and quartz. These rocks would be called quartz latites and latites in the classification used in this report.

Three analyses of the Rawley andesite are given in table 17, columns 5, 8, and 10, page 87.

The lower part of the Bonanza latite consists of greenish-gray or blackish-gray rocks with a distinct fluidal and platy structure. It is characterized by abundant inclusions of latite and andesite which are especially abundant near the base of the member. It contains phenocrysts of andesine (An_{45-50}), fewer of orthoclase, some biotite, and rare quartz in a groundmass that is partly glassy or sub-microscopic and contains plagioclase, orthoclase, and quartz. An analysis is given in table 17, column 7.

The upper part of the Bonanza latite breaks up readily on weathering and shows few exposures. It contains more phenocrysts of sanidine than of plagioclase, and a few of quartz and biotite in a rhyolitic groundmass.

The Squirrel Gulch latite is characterized by massive flows with a columnar jointing. The rock is blackish and contains conspicuous phenocrysts, as much as 10 mm long, of plagioclase, hornblende, biotite, and augite in a groundmass of glass, with abundant feldspar microlites. An analysis of this quartz latite is shown in table 17, column 6.

The Porphyry Peak rhyolite is a complex of flows and tuffs with possibly some intrusive bodies. The flows consist of a light-colored rock with distinct flow structure. The rock contains phenocrysts, 1 to 2 mm long, of sanidine, quartz, biotite, and some plagioclase, in a groundmass that ranges from microgranular to spherulitic to glassy. Some obsidian is present in this rhyolite. An analysis of the typical rock is shown in table 17, column 1.

The Hayden Peak latite consists of a lower horizon of dark porphyritic latites and an upper horizon of flows and tuff beds of light-colored, fine-textured quartz latites. The rock contains phenocrysts of plagioclase and sanidine in variable proportions in a groundmass consisting of orthoclase and quartz, with some plagioclase.

The Brewer Creek latite is a purplish-gray or brownish-gray rock, with abundant phenocrysts, ranging in size from 2 to 12 mm, of andesine, some of orthoclase, small quartz grains and biotite in a trachytic groundmass consisting of plagioclase, orthoclase, and some quartz.

The younger andesites of Brewer Creek resemble the Brewer Creek andesites.

A body of intrusive rock in Eagle Gulch and to the north underlies an area of nearly 2 square miles. The rock is a gray porphyritic latite that contains somewhat more phenocrysts, from 2 to 8 mm long, of microperthite than of oligoclase, and some phenocrysts of biotite. The groundmass is a granular intergrowth of orthoclase, plagioclase, and quartz. An analysis of this rock is given in table 17, column 3.

A small body of biotite granite porphyry is present about a mile south of Alder Creek near the center of sec. 9, T. 47 N., R. 8 E. Dikes of diorite and monzonite and bodies of intrusive rhyolite and latite are present in the area. A volcanic neck in Greenback Gulch consists of intrusive bodies and ramifying dikes of rhyolite, enormous blocks of andesite country rock, and bodies of altered breccia of indeterminate origin.

The rocks of the Bonanza area extend for some distance in all directions from that area. To the north, the Porphyry Peak rhyolite extends to and across Silver Creek. A somewhat similar porphyry was found in Kerber Creek a mile east of the lake, and as an intrusive body on the shoulder southwest of Antora Peak. On the northern side of Sheep Mountain and in the adjacent parts of Silver Creek there is a large amount of a light-pinkish latite porphyry which is characterized by a rather smooth fracture, by feldspar phenocrysts as long as 10 mm, and by biotite ranging down to groundmass size. It contains a lesser amount of orthoclase phenocrysts than the Porphyry Peak rhyolite, and no augite.

Under the Porphyry Peak rhyolite in Silver Creek and about 2 miles below the point where the Bonanza road reaches that creek, a pyroxene andesite resembling the Rawley andesite is exposed. It is a dark-gray rock, with a slight pinkish tone, and carries abundant phenocrysts of plagioclase, augite, and hypersthene in a dense, microcrystalline groundmass consisting of laths of plagioclase, augite, red iron oxide, and secondary calcite and chlorite.

To the west of the Bonanza area, biotite-quartz latites much like those of the Bonanza area were found just north of the head of Little Kerber Creek and on the ridge south of Phantom Creek. Farther west, much of the basins of Tuttle and Ford Creeks are made up of similar latites. The sequence in this area is not well understood, although in Ford Creek, above the mouth of Tuttle Creek, this kind of biotite latite overlies flows of quartz latite, which contain hornblende, biotite, and some augite.

Rocks similar to the Hayden Peak latite were found in the bed of Starvation Gulch at an altitude of about 10,000 feet many miles to the northwest.

West of the Bonanza area the latites are overlain by a thick augite andesite or dark quartz latite. This rock is one of the most distinctive and widespread rocks of this region and is exposed from the heads of Starvation Gulch and Silver Creek southward beyond Antora Peak. It is believed to be equivalent to the similar rock forming the ridges between Little Kerber and Ford Creeks and north of the head of Findley Gulch. This indicates a known distribution of at least 10 miles north and south and somewhat less east and west. It is especially well exposed in the great cliffs of the amphitheater at the head of Brewer Creek. It is also well exposed along the steep upper slopes of the ridge west of Kerber Creek and in several places forms the top of that divide. Its form is undulatory and its thickness irregular. At the head of Brewer Creek it is several hundred feet thick. At the head of Kerber Creek, above the lake, this dark rock seems to be both above and below the biotite latite porphyry. Farther north in Silver Creek the dark quartz latite contains a thin persistent tuff member, usually about 25 feet thick. Underlying the tuff there are about 100 feet of flows, under which there are 20 feet of rhyolite which in turn is underlain by the biotite rhyolite porphyry of the Porphyry Peak rhyolite. The flows here dip south of west and the sequence is not always clear. The typical augite andesites (or quartz latite) of this horizon are dense, and dark to black where fresh, but are in many places altered to gray or pink rock in which the feldspar is lighter colored and more conspicuous or, if alteration has been more intense, to still lighter colored rocks with less conspicuous feldspar. The rocks are porphyritic and carry abundant feldspar crystals, as long as several millimeters. In the fresher rocks mica also can be seen in the hand specimen. However, the more typical specimens show phenocrysts of plagioclase as much as 3 mm across, augite, biotite, and hornblende, with an abundance of chlorite, calcite, and iron oxides resulting from the alteration of the augite and hornblende. The biotites are commonly more or less leached and are commonly changed to chlorite and iron oxides, containing some epidote. Most of the groundmass is microcrystalline and consists chiefly of plagioclase, chlorite, calcite, hematite, and probably some quartz. Also, orthoclase is commonly present. Apatite, epidote, and garnets were observed in accessory amounts and one or two isotropic and unrecognized minerals were found as products of alteration.

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In Antora Peak and to the southwest this upper dark quartz latite is overlain by a quartz latite that is similar to and probably equivalent to the latites of the middle horizon of the Sheep Mountain andesite. Still farther south, south of the Bonanza-Indian Creek trail, it is overlain by latites that definitely belong to the middle horizon of the Sheep Mountain quartz latite. Still farther west rocks of the Potosi, especially the Conejos quartz latite and the Sheep Mountain quartz latite, underlie more of the area.

In the northern part of this area of undifferentiated volcanic rocks, the lower part consists of a series of irregular thickness of soft gravels, sands, and muds, probably mostly of volcanic origin. The rocks are in part well bedded and in part poorly bedded. They are overlain very irregularly by dark andesitic flows and breccia beds. They are well exposed on both sides of Tomiche Creek and extend eastward nearly to Marshall Pass.

SOUTH OF THE SAGUACHE RIVER

These rocks are made up of a lower group of quartz latites, called the Beidell quartz latite, and an upper group of light-colored latites, called the Tracy Creek quartz latite. The two groups are separated by a surface of erosion.

BEIDELL QUARTZ LATITE

General character and occurrence

The oldest group of rocks recognized in the Del Norte and Creede quadrangles is a complex of flows and associated tuff-breccias of quartz latite, carrying hornblende as the most conspicuous dark constituent, with some local bodies of dark quartz latite and rhyolite. This complex is best developed around the old mining camp of Beidell, in the extreme northern part of the Del Norte quadrangle, and adjoining parts of the Saguache quadrangle, where it occupies a rudely circular area about 7 miles across. It receives its name of Beidell quartz latite from this occurrence. A smaller body occurs in the drainage basin of Carnero Creek just above the main fork, and two small bodies occur in the drainage basin of La Garita Creek, one in the Del Norte quadrangle near the mouth of Little La Garita Creek, and the other in the eastern part of the Creede quadrangle north of Lone Rock.

Because much of the Beidell quartz latite is covered and the base is nowhere exposed, no estimate of the volume of the Beidell eruptions can be made. A minimum estimate for the volume of the Beidell mass is 10 cubic miles and the total volume of the Beidell eruptions may have been many times that amount.

The base of this formation was nowhere seen. In most places it is overlain by the Conejos quartz latite and it formed a mountain topography at the time the Conejos rocks were erupted. This is well shown in all the bodies but especially in the Carnero Creek mass which formed a steep hill of at least 1,000 feet relief at the time of the Conejos eruptions. On the northern borders of the Beidell mass, chiefly in the Saguache quadrangle, this quartz latite is overlain irregularly by by the Tracy Creek quartz latite.

In the Beidell area the rocks dip gently and regularly to the east, as do the other rocks of the area. The succession of rocks is variable, but the flows of fluidal, felsitic, and spherulitic rhyolite in the upper basin of Beidell and Cottonwood Creeks are in the lower part of the section and no great thickness of them is exposed. Over them is a complex of thin, irregular flows and associated chaotic tuff-breccia. The tuff-breccia for the most part is made up of large angular fragments of one type of rock with little interstitial fine material, and it shows little bedding. Local bodies of fine-textured well-bedded tuff are present. These are chiefly hornblende-quartz latites and some pyroxene rocks. Over this is the thickest member, which is a succession of flows, each commonly about 100 feet thick, which are regularly bedded throughout the exposures represented by cliffs several miles long. The flows are of quaker-drab to purple-drab quartz latites and are characterized by abundant phenocrysts, as much as several millimeters across, of white plagioclase, conspicuous hornblende, some biotite, and in some flows pale-green pyroxene. These flows make up most of the drainage area of San Juan and Red Rock Creeks and are nearly 1,000 feet thick.

The body in the Carnero drainage basin is about 3 miles long and nearly 2 miles wide. Between the forks of the creek it forms some hills that rise nearly 1,000 feet above the creek bed. It projects with steep slopes through the Conejos andesites and from a distance was at first thought to be an intrusive stock but was later found to be an old pre-Conejos mountain that was buried by the Conejos eruptions. The rock is massive and from a distance looks like a single great flow or intrusive body. It is made up of a few very thick flows. The rock is a quartz latite like those of the San Juan and Rock Creek areas of the Beidell mass.

The two bodies in La Garita Creek are also hills or mountains of Beidell rocks that were buried by the Conejos eruptions. They are thick, massive flows of quartz latites similar to the other quartz latites of the formation.

Petrography

The rhyolitic rocks forming most of the lower horizon are chiefly light-colored, felsitic rocks, carrying a very few crystals of feldspars and biotite. Some of the rocks have a prominent fluidal banding, others are characterized by layers of spherulites, each an inch or more across, that coalesce parallel to the fluidal banding but normal to that dimension are bordered by broad gas cavities. They weather to flat fragments consisting of many spherulites and thus the fragments have a botryoidal surface. The microscope shows that the felsitic rocks consist chiefly of a fine spongelike intergrowth of quartz and orthoclase, with a few phenocrysts of andesine and biotite. They are commonly somewhat altered and the original gas cavities are filled with secondary quartz and carbonates. The groundmass of the spherulitic rocks is coarsely spherulitic and the larger spherulites are made up of an aggregate of smaller spherulites. The rocks are plagioclase-bearing rhyolites.

The materials of both the flows and the breccia of the middle horizon are much alike and consist largely of vinaceous-drab, quaker-drab, or greenish-gray quartz latites, most of which carry abundant phenocrysts as much as 5 mm across, chiefly of plagioclase, with much hornblende, some biotite, and, commonly, pyroxene. Phenocrysts constitute from one-fourth to one-half the volume of most rocks; the feldspar is andesine-labradorite, the hornblende is deep brown and is commonly more or less resorbed, the pyroxene is usually augite, but in some rocks hypersthene. Apatite and magnetite are the chief accessories. The groundmass is very fine textured and is mostly a felted mass of minute laths of andesine with some interstitial material, probably quartz, orthoclase, and biotite. Some of the specimens carry many minute rods of augite in the groundmass.

Many of the flows have abundant small gas cavities and these are commonly partly filled with spherulites of cristobalite. In some of the rocks pyroxene is the main mafic mineral, and in some, biotite. Quartz and orthoclase are abundant in the groundmass of some of the rocks. A flow in about the middle of the section on the ridge south of Beidell Creek is a purple-drab rock which carries a few phenocrysts of feldspar, altered hornblende, and biotite, in a dense, fluidal, felsitic groundmass and in the hand specimen resembles a felsitic rhyolite. It has a black glass at its base, similar in appearance to those common in rhyolites. The microscope, however, shows that the rock is a biotite-hornblende-quartz latite with very few phenocrysts of andesine-labradorite, biotite, and brown hornblende in a fluidal groundmass consisting of minute oligoclase laths and some indistinctly crystalline material probably quartz and alkalic feldspar. The groundmass is clouded with minute trichites of hematite. The hornblende is largely resorbed and shows a dull reddish-brown aggregate with rare remnants of fresh hornblende; the biotite is resorbed to a lesser extent.

Quartz latite porphyry forms the crest of a rather prominent hill between Lime and Beidell creeks and just south of the road between the two hills. Its relation to the surrounding breccia was nowhere seen but it is probably a local flow, though it may be intrusive. The rock is massive, hard, and resistant, forms conspicuous outcrops, and a prominent hill. It has much the composition of the quartz latite to the southwest but differs greatly in appearance and habit. It is a dense rock, with a deep to pale olive-gray color and a smooth, conchoidal fracture. It carries abundant phenocrysts of white plagioclase about 2 mm long; also biotite, hornblende, and augite in a dense, aphanitic groundmass. Phenocrysts form nearly half the rock and are chiefly andesine with about 10 percent of dark minerals. The dark minerals are biotite, green-brown hornblende, and augite in different amounts. The hornblende and biotite are more or less resorbed and the augite is locally altered to carbonates and chlorite. The plagioclase crystals have a clear core, a broad intermediate zone that is much clouded, and a narrow border that is clear. Apatite, iron ore, and zircon are accessory. The groundmass is fine-textured and consists of micrographic intergrowths of quartz and orthoclase, with some small laths of plagioclase.

The thick flows of the upper horizon are quaker-drab to purple-drab quartz latites which are characterized by abundant phenocrysts, as much as several millimeters across, of white plagioclase with conspicuous hornblende and some biotite, and in some specimens pale-green pyroxene. The rocks are commonly rather porous. They are nearly half phenocrysts, the chief of which is andesine or andesine-labradorite. The lower flow of upper Red Rock Creek carries biotite, green hornblende, and augite in nearly equal amount; the upper flow contains chiefly biotite and deep-brown hornblende. The hornblende and biotite are but slightly resorbed. Hypersthene is present exceptionally; it and, to a less extent, the augite, are partly or entirely altered to chloritic or serpentinous minerals. The groundmass is commonly very fine-textured and in some it is glassy. It always carries some small laths of plagioclase and, in the crystalline types, consists largely of quartz and alkalic feldspar. Small gas cavities are nearly always abundant and are partly filled with spheroids of cristobalite which has the following optical properties: sensibly uniaxial, negative, $\omega=1.488\pm0.003$, birefringence about 0.005. A silica determination of a sample, estimated as made up 90 percent of the spherulites and weighing 100 milligrams, showed 95 percent SiO_2 and confirms the microscopic determination as cristobalite. An analysis of a typical specimen of this quartz latite is shown in table 17, column 4.

The rocks are comparatively fresh, except where locally altered by hydrothermal agents, as near the mineral veins. The sharp ridge just east of BM 8292 in Lime Creek is formed by a white, iron-stained, altered rock which is made up of a coarse-grained aggregate of quartz and alunite.

Structure and source of material

Most of the Beidell quartz latite consists of regular flows and tuff beds that give good evidence as to their structure. They dip regularly toward the east and the San Luis Valley at about the same small angles as do the overlying Potosi and Hinsdale rocks. The structure and regularity of the Beidell rocks indicate a widespread group of regular flows and tuffs, similar to those of the Conejos quartz latite rather than a local, steep-sided volcanic pile.

The evidence is uncertain but the main source of the Beidell quartz latite may have been from the west, although a part of the rocks of the Beidell area probably represent a local accumulation around a volcano whose center is represented by the stock at Beidell.

Intrusive rocks of probable Beidell age

The Beidell quartz latite in the northern part of the Del Norte quadrangle and adjoining parts of the Saguache quadrangle seems to have accumulated around a volcanic vent whose center was near the old mining camp of Beidell. The largest intrusive mass found in this area is an irregular body about half a mile wide, just north of Beidell Creek. The rock of this stock is a dense, deep olive-gray to gray quartz latite porphyry which shows a few phenocrysts of biotite and plagioclase as much as a centimeter across in a groundmass that looks microgranular in the hand specimen. The phenocrysts make up about one-third of the rock and are chiefly plagioclase with a composition ranging from andesine to labradorite. Partly resorbed biotite is the chief dark mineral; hornblende probably crystallized at an early stage but it has been completely resorbed and is now indicated only by skeletons of magnetite grains. The groundmass consists of very small andesine laths with interstitial quartz and orthoclase. There are considerable secondary sericite, carbonates, epidote, and chlorite. Much alteration and mineralization took place in the neighborhood of the stock. The old mining camp of Beidell is situated on the stock.

Many dikes of quartz latite, much like those of the associated flows, are exposed in the Beidell area but are not indicated on the geologic map. They are chiefly dense, gray, olive gray, or quaker drab, and have abundant crystals of andesine or labradorite, hornblende, biotite, and augite. The groundmass is very fine textured and is made up chiefly of minute plagioclase laths, with some interstitial orthoclase and quartz.

TRACY CREEK QUARTZ LATITE

Petrography

A large body of related flows, with subordinate tuff-breccia, called the Tracy Creek quartz latite, occurs chiefly in the extreme southern part of the Saguache quadrangle and extends into the Del Norte quadrangle. It occupies much of the drainage area of Tracy Creek except at its head, and extends locally into the drainage area of Saguache Creek to the north and of Red Rock Creek to the south. The distribution is shown approximately on the map but the character of the base map does not permit the accurate representation of any of the details. The small inliers of the underlying Beidell quartz latite represent areas in which small canyons have been cut through the Tracy Creek rock. There are many more such areas than those represented.

These flows irregularly overlie the Beidell quartz latite and the contact is well shown in many of the sharp gullies to the south of Tracy Creek. They are overlain with great irregularity by the dark quartz latites of Conejos age. This contact is well shown at many places but notably northeast and northwest of the mouth of North Tracy Creek. Here the Tracy Creek rocks extend nearly to the crest of the ridge and at one point a narrow wedge crosses the ridge and extends nearly to the alluvium of Saguache Creek valley, whereas the overlying Conejos quartz latite, which is here largely chaotic breccia, forms the crest and all of the steep cliffs facing Saguache Creek.

In the upper drainage area of Tracy Creek and to the north the base of this formation is a dense, dark-gray, platy rock which carries sparse and irregularly distributed embayed crystals of quartz, several millimeters across. It shows, with a pocket lens, abundant but small and inconspicuous tablets of plagioclase, slender prisms of hornblende, and rarely visible augite or biotite. In thin section the rocks consist of a variable but moderate proportion of small phenocrysts in a fine-textured groundmass. The phenocrysts are andesine or andesine-labradorite in tabular crystals, and deep-brown hornblende with more or less augite. The hornblende in some rocks is completely resorbed, and its former presence is shown by the skeletons of magnetite dust with feldspar and augite. Where the hornblende disappears the large augites, which are commonly clouded, become more abundant. The groundmass is very finely crystalline and consists of andesine and oligoclase-andesine laths and many grains of magnetite and rods of augite. Apatite is abundant and some of the rock may contain a little orthoclase. Mafic minerals make up a considerable part of the rock. Most of the rocks are dense but some show small cavities which are lined with spherulites of cristobalite, and some specimens carry shreds of a pale-brown mica, probably phlogopite. The rocks are commonly fresh but some carry a little secondary carbonate. The rocks are characterized by their dense, fine texture, irregularly distributed quartz phenocrysts, more or less resorbed brown hornblende, abundant augite in the groundmass, and a sodic feldspar. An analysis of a rock of this type is shown in table 17, column 9.

To the north of Tracy Creek this formation consists of several flows, with some breccia, of a nearly white to light-gray or reddish-brown, fluidal, platy tridymite latite, which carries a few visible crystals of biotite and plagioclase in a dense, aphanitic groundmass. Most of these rocks are dense but a few show flat cavities in which abundant tablets of tridymite are easily visible. Some of the rocks have a very fine, indistinct, oolitic appearance. Some of the upper flows to the south of Tracy Creek are also of this type.

This tridymite latite is characterized by a sodic plagioclase as the chief mineral, abundant tridymite, and some biotite and magnetite. It carries a few small phenocrysts of pale-brown biotite and calcic andesine in a fine-textured groundmass, which is submicroscopic in some flows, and in others consists of small laths of sodic oligoclase. There are some magnetite and apatite in all the specimens and probably much tridymite in the groundmass of some. All the rocks carry abundant tridymite, either in irregular streaks associated with gas pores or in rounded bodies as much as a millimeter across. It commonly makes up about a fourth of the rock. No orthoclase or quartz could be found, but the analysis indicates either much orthoclase or a high potash content for the plagioclase. An analysis of this rock is shown in table 17, column 2.

A flow above the normal latite on the northwestern slope of the high peak southwest of the forks of Tracy Creek is intermediate between the two varieties described above. In the hand specimen it closely resembles the latter rock. It is characterized by abundant small phenocrysts of oligoclase-andesine and some of greenish-brown hornblende in a very finely crystalline groundmass which may contain much orthoclase. There is considerable tridymite in the cavities.

Structure and source of the material

The lack of thin, regular flows, and the irregular surfaces of erosion at both the base and top of the Tracy Creek quartz latite make it impossible to work out the details of the structure of this area. However, it is clear that south of Tracy Creek these flows dip to the north. They have also been affected by the more recent tilting of the mountain front toward the San Luis Valley. No direct evidence of the source of the Tracy Creek rocks was found but their local distribution and structure make it seem probable that the source was probably south of Tracy Creek. No estimate of the original body of Tracy Creek rock can be made but the exposed body is only about 8 miles across and probably has a volume, allowing for erosion, of only a few cubic miles.

TABLE 17.—*Analyses, norms, and modes of pre-Potosi volcanic rocks of the eastern part of the San Juan Mountains*

	1	2	3	4 [1]	5	6	7	8	9	10	11	12	13 [2]	14 [3]	15 [4]	16 [5]
	ANALYSES															
SiO_2	71.57	67.23	67.16	67.01	59.66	58.10	58.04	57.62	54.82	54.23	60.68	59.91	56.34	55.48	59.68	58.45
Al_2O_3	16.84	17.63	16.03	17.74	16.09	18.72	17.89	15.84	15.58	18.82	17.14	16.92	16.34	15.04	18.40	16.61
Fe_2O_3	.63	1.05	1.67	2.16	2.57	2.01	2.17	3.05	7.04	1.69	4.63	4.06	3.76	3.68	2.54	2.74
FeO	.07	.59	1.38	.36	3.53	2.64	2.41	3.90	1.65	4.06	.58	.98	3.68	4.77	1.05	3.44
MgO	.29	.14	.77	.54	2.29	1.12	1.55	2.14	3.51	2.25	1.82	1.83	3.81	5.92	1.14	2.58
CaO	.31	2.86	1.62	2.26	4.48	5.37	4.54	4.81	7.03	6.62	4.00	4.02	5.96	6.72	4.24	4.66
Na_2O	3.05	4.71	4.23	4.21	3.08	3.09	3.37	3.07	4.15	3.91	4.27	4.26	3.70	3.62	6.40	4.16
K_2O	5.56	4.16	5.78	3.94	4.92	3.88	4.17	4.95	3.21	3.08	4.37	4.66	3.56	2.14	4.42	4.66
H_2O+	1.06	.40	.64	1.17	1.84	1.99	1.70	1.39	.60	1.51	.85	.73	.75	.65	.36	.46
H_2O-	.28	.44	.11	----	.25	.92	.09	.24	.21	.08	----	----	----	----	tr	.14
TiO_2	.34	.36	.56	.38	1.00	.90	.49	1.30	1.28	1.43	.93	1.54	1.08	1.58	1.28	1.38
P_2O_5	none	.15	.05	.14	.35	.06	.43	.44	.36	.16	.41	.33	.51	.52	.45	.51
MnO	tr	.06	.12	.04	----	.10	.12	.15	----	.17	.04	.07	.06	.07	tr	.08
CO_2	tr	----	.06	none	.10	.81	3.35	1.06	----	2.13	none	.17	none	tr	----	----
ZrO_2	.05	----	none	----	----	tr	.12	----	----	tr	----	----	----	----	----	----
SO_3	none	----	.03	----	----	.03	none	.05	----	----	----	----	----	----	----	----
S	none	----	none	.05	----	none	none	n.d.	----	tr	.05	.13	.12	.07	----	----
Cl	tr	----	none	----	----	----	.02	n.d.	----	tr	----	----	----	----	----	----
BaO	----	.13	----	.14	----	----	----	.04	----	----	.11	.16	.09	.04	----	----
SrO	----	----	----	.04	----	----	----	----	.17	----	.04	.03	.02	none	----	----
Total	100.05	99.91	100.21	100.18	100.16	99.74	100.46	100.05	99.61	100.14	99.92	99.80	99.78	100.30	99.96	99.87
	NORMS															
Q	31.50	17.64	15.12	22.14	10.38	11.52	10.26	8.64	2.94	2.40	9.24	8.28	5.82	5.82	----	4.80
or	33.56	25.02	34.47	22.80	28.91	22.80	25.02	29.47	18.90	18.35	26.13	27.80	21.13	12.23	26.13	27.80
ab	25.68	39.82	35.63	35.63	26.20	26.20	28.82	25.68	35.11	33.01	36.15	36.15	31.44	30.39	50.30	35.10
an	.56	13.62	7.51	11.12	15.57	25.58	19.74	14.73	14.46	24.46	14.46	13.07	17.24	18.63	8.34	12.79
C	5.40	.31	----	2.50	----	----	4.0	----	----	----	----	----	----	----	----	----
di	----	----	.43	----	4.48	.89	----	5.26	14.47	6.18	1.73	1.52	7.01	9.18	6.05	5.31
hy	.70	.30	1.96	1.40	6.18	4.22	5.88	5.58	2.10	6.38	3.70	3.90	7.92	13.68	----	5.72
mt	----	.93	2.55	.23	3.71	3.02	3.25	4.41	1.62	2.55	----	----	5.57	5.34	----	3.94
hm	.63	.48	----	2.08	----	----	----	----	5.92	----	4.64	4.06	----	----	2.54	----
il	.15	.76	1.22	.76	1.98	1.67	.91	2.43	2.43	2.74	1.22	1.06	2.13	2.89	2.28	2.58
ti	.59	----	----	----	----	----	----	----	----	----	.78	2.35	----	----	----	----
ap	----	.33	----	.33	1.01	----	1.01	1.01	1.01	.34	1.01	.67	1.34	1.34	1.01	1.34
	SYMBOLS															
	I.(3)4.1.3	I.4''.2.(3)4	I''.4''.''2.3	I.4.2.3(4).	''II.4(5).2(3).3	I(I)(5).3.3	I(II).(4)5''.3.3	II.(4)5.2''.3	II.5.2''.''4	II.5.3.''4	(I)II.(4)5.2.3''	(I)II.4(5).2.3''	II.''5(2)3.3(4)	II''.''5.3.4	(I)II.5.''2.''4	II.''5.2.3''
	Liparose	Lassenose	Toscanose	Toscanose	Adamellose	Amiatose		Monzonose	Akerose	Andose	Monzonose	Adamellose	Shoshonose	Andose	Akerose	Monzonose
	MODES															
Plagioclase	----	7	----	21	----	----	----	----	3	----	20	20	30	1	2	66
(An content)	----	(53)	----	(28)	----	(55±)	----	(60±)	(43)	(50±)	(45)	(43)	(47)	(30)	(40)	(42)
Augite	----	----	----	----	----	----	----	----	7	----	4	7	7	9	1.5	8
Hypersthene	----	----	----	----	----	----	----	----	3	----	----	3.5	----	4.5	----	2
Hornblende	----	----	----	3	----	----	----	----	6	----	4	.5	----	----	4	----
Biotite	----	1	----	3	----	----	----	----	----	----	3.5	.5	----	----	1	1
Groundmass	----	92	----	70	----	----	----	----	81	----	68	69	60	84	----	----

[1] Orthoclase, 3.5.
[2] Olivine, 3.5.
[3] Olivine, 2.
[4] Nephelite, 1.99; wollastonite, 0.81; magnetite, 3.
[5] Quartz, 2; orthoclase, 18; magnetite, 3; antiperthite, 87; granitic groundmass.

TABLE 17.—*Analyses, norms, and modes of pre-Potosi volcanic rocks of the eastern part of the San Juan Mountains*—Continued

NOTES

1. Porphyry Peak rhyolite. Bonanza area. Ridge running southwest from summit of East Porphyry Peak. Groundmass is fluidal. Because the norm of this rock shows 5.4 percent of corundum the rock must be much altered or the analysis in error. Quoted from Patten (1916, p. 25). George Rohwer and E. Y. Titus, analysts.

2. Tracy Creek quartz latite (Sn 551). Beidell area. Hill 8500 on the north fork of Tracy Creek. Saguache quadrangle. Light neutral-gray. Felsitic, with a few phenocrysts 1 mm long. Has irregular small porous streaks with tablets of tridymite. George Steiger, analyst, 1919.

3. Intrusive Eagle Gulch latite. Bonanza area. Groundmass is a granular intergrowth of orthoclase, sodic plagioclase, and quartz. Quoted from Patten (1916, p. 44). George Rohwer, and E. Y. Titus, analysts.

4. Beidell quartz latite (DN 179). Beidell area. Hill on west border of San Luis Valley, south of Beidell Creek and one-quarter mile northeast of BM 7732. Pale brownish-drab. The rock has scattered small pores and widely spaced porous flow layers. Phenocrysts are as long as 4 mm. Plagioclase is white to glassy and moderately zoned, biotite is in glistening hexagonal plates and is not resorbed. The hornblende is much resorbed. The hornblende is brown and in small prisms. The groundmass has abundant small, fluidal oligoclase tablets and some biotite in a glassy or submicroscopic matrix. F. A. Gonyer, analyst, 1944.

5. Rawley andesite [quartz latite]. Bonanza area. Ridge near Superior mine. Quoted from Burbank (1932a, p. 21). J. G. Fairchild, analyst.

6. Squirrel Gulch [quartz] latite. Bonanza area. The groundmass is hyalopilitic and has plagioclase and magnetite microlites. Quoted from Patten (1916, p. 44). George Rohwer and E. Y. Titus, analysts.

7. Bonanza [quartz] latite. Bonanza area. Constituents of groundmass not recognizable except magnetite, secondary sericite, and calcite. Quoted from Patten (1916, p. 44). George Rohwer and E. Y. Titus, analysts.

8. Rawley andesite [quartz latite]. Bonanza area. Ridge just below Superior mine. Groundmass partly glassy. Quoted from Burbank (1932a, p. 21). J. G. Fairchild, analyst.

9. Tracy Creek quartz latite (Sa 557). Beidell area. Ridge north of Red Rock Creek, just north of the highest point. Second flow from the bottom. Gray. Dense and contains phenocrysts of plagioclase a few millimeters long, and abundant tiny hornblende needles. George Steiger, analyst, 1919.

10. Rawley andesite. Bonanza area. From point 3,900 feet southwest of the summit of Round Mountain. Groundmass shows plagioclase, and the secondary minerals, chlorite, calcite, and sericite. Quoted from Patten (1916, p. 54). George Rohwer and E. Y. Titus, analysts.

11. Quartz latite of lower unit of San Luis Hills (SLH 36). Northwest peak of Cerrito de la Culebra, south of the crest. Has a few small pores. Light vinaceous drab. Plagioclase phenocrysts, white, with some recurrent zoning, and chiefly less than 3 mm long. Biotite dull in hand specimen and almost completely resorbed. Resembles Beidell quartz latite of analysis 4. Groundmass contains irregular oligoclase crystals in a spongelike intergrowth of alkalic feldspar and cristobalite (?). Dusted with iron oxide. F. A. Gonyer, analyst, 1944.

12. Quartz latite of lower unit of San Luis Hills (SLH 3). Has some small irregular pores. Vinaceous drab. Has some inconspicuous phenocrysts of plagioclase and dull biotite. Plagioclase is in crystals as long as 2 mm; some are filled with inclusions of the groundmass. The biotite is fresh. The groundmass contains abundant tiny tablets of oligoclase in a submicroscopic groundmass, which is reddish from a dust of iron oxide. F. A. Gonyer, analyst, 1944.

13. Quartz latite of upper unit of San Luis Hills (SLH 26). Ridge northwest shoulder of Mesa de los Sauces at an altitude of 8,300 feet. Gray. Has a few rounded gas cavities as large as 2 mm. Shows phenocrysts 2 mm long of plagioclase, and dark pyroxene. The rock is seriate poyphyritic. The plagioclase is in stout tablets and is little zoned. Some have scattered inclusions of the groundmass and some have a thin layer of groundmass inclusions near their outer borders. The olivine is partly altered to iddingsite. The groundmass is submicroscopic and is clouded from a dust of iron oxide. F. A. Gonyer, analyst, 1944.

14. Quartz latite (SLH 68) of upper unit of San Luis Hills, Cerrito del Poncho. West of Rio Grande and on State line of New Mexico and Colorado at an altitude of 8,200 feet. Neutral gray. Shows few phenocrysts in the hand specimen. The phenocrysts are about 1 mm long. The groundmass contains abundant thin tablets of plagioclase, chiefly about 0.5 mm long, and augite and olivine in a clouded, submicroscopic matrix. F. A. Gonyer, analyst, 1944.

15. Syenite (SLH 61). San Luis Hills, north slope of Mesa Angostulla, 6 miles east of Manasa. Grains 0.25 mm long. The feldspar is chiefly albite with a little intergrown orthoclase. A few crystals of andesine are 1 mm long. J. G. Fairchild, analyst, 1923.

16. Diorite (SLH 134). San Luis Hills, north slope of Mesa Angostulla. Olive gray. Millimeter grained with a few feldspar laths as long as 10 mm and some finer interstitial microperthite. J. G. Fairchild, analyst, 1923.

THE SAN LUIS HILLS

The San Luis Hills are a group of rugged, barren hills that project abruptly, as much as 2,000 feet, above the flat floor of the San Luis Valley and stand in the southern part of the San Luis Valley, east of Conejos, on both sides of the Rio Grande and on both sides of the boundary between the States of New Mexico and Colorado.

The San Luis Valley is underlain by sands and gravels, which are underlain, in the canyon of the Rio Grande, by flows of the basalt of the Hinsdale formation. The hills represent the crests of mountains most of which are buried by rocks of Hinsdale age and younger. The elevation of the hills may be due to faulting but any major faults are covered and the present form of the hills is due largely to pre-Hinsdale erosion.

The hills consist of an older group of latites with associated stocks of diorite and syenite and a younger group of dark, mesa-forming olivine-quartz latites. The older group was deeply eroded and the stocks were exposed before the younger group was erupted. The age of these rocks is uncertain but they do not resemble the Potosi rocks to the west and are probably pre-Potosi in age.

CHEMICAL ANALYSES

In table 17 are given 7 analyses of rocks from the Bonanza area, 3 from the Beidell area, and 6 from the San Luis Hills, and on figure 44 fifteen of these analyses, together with the calculated compositions of some of the groundmasses, are plotted on a variation diagram.

SUNSHINE PEAK RHYOLITE

OCCURRENCE AND GENERAL CHARACTER

A rhyolite of uniform and distinctive character, which in part intrudes and in part overlies the rocks of the Picayune quartz latite, is confined to a comparatively small area in the northwestern part of the San Cristobal quadrangle and adjoining parts of the Lake City quadrangle. It forms the greater part of the rugged mountains north of the Lake Fork of the Gunnison River and it continues for a short distance north of the San Cristobal quadrangle into the Lake City quadrangle. Only a few projecting arms and small outliers are present to the south and east of the main Lake Fork and none of these has been found beyond the slopes immediately adjacent to the Lake Fork. The name Sunshine Peak rhyolite has been proposed for this rock from its extensive and characteristic development on Sunshine Peak.

It is difficult to distinguish between the intrusive and extrusive parts of this rhyolite, but much of the rock of Alpine Gulch and adjoining areas is intrusive and a great part of the rock to the south and west is extrusive. The intrusive parts of the rhyolite carry many inclusions of Picayune quartz latite. Some of these inclusions have been separated on the geologic map but many more, mostly small, are not indicated on the map.

The Sunshine Peak rhyolite is intruded by the granite porphyry of Alpine Gulch, which is no doubt closely related to it in age and is overlain by the rocks of the Alboroto rhyolite and by the Fisher quartz latite. Its age is therefore between that of the Picayune and Alboroto but cannot be determined more definitely. It resembles the Alboroto rocks and may be a basal part of the Alboroto.

PETROGRAPHY

The rocks of the Sunshine Peak rhyolite, whether extrusive or intrusive, except for local quartz latites in the vicinity of Williams Creek and east of Lake San Cristobal, are uniform in character, and differ considerably from the other rhyolites of the region. Nearly all the rocks are dense and without noticeable pore space, some are massive, others are flow breccias, and a very small part consist of tuff-breccias. Inconspicuous fluidal structure is not uncommon, and some of the flows at the base of the formation in the vicinity of Williams Creek have a more conspicuous fluidal structure.

The typical rocks range from nearly colorless to quaker drab; some are pale olive gray. The phenocrysts are commonly several millimeters across, are conspicuous, and make up from about a third to half the rock; they are chiefly smoky, embayed quartz, and glassy, white, or pinkish feldspar with a very little biotite. In much of the rhyolite of the Bent Creek area the feldspar is glassy and has the bluish iridescence of moonstone. The fragments in the flow breccias are partly of rocks from the Picayune quartz latite and other older formations, and partly of rhyolite similar to the host. Rare inclusions are more coarsely crystalline and a few are granites.

Phenocrysts of quartz and feldspar are commonly almost equal in amount; rarely does feldspar greatly exceed the quartz. The quartz is much fractured and resorbed so that many embayments of the groundmass project into the crystals. The feldspar is in well-formed crystals and is mainly microperthite, but the glassy feldspar is sanidine and some crystals of plagioclase are present. The microperthitic intergrowths are very minute and are chiefly orthoclase. The plagioclase is albite and albite-oligoclase. Biotite is in very small amount; apatite, zircon, iron ore, and very rare sphene are minor accessories. The groundmass is made up of quartz and orthoclase and is commonly very finely grandular to very finely micropegmatitic; less commonly it is fluidal and submicroscopic in crystallization but it is not glassy. Many of the rocks contain streaks and lenses in which the groundmass is much more coarsely crystalline. The rocks are commonly fresh but secondary chlorite, calcite, sericite, and epidote are developed in some of the rocks. An analysis, norm, and mode of a specimen of the typical Sunshine Peak rhyolite are given in table 21, column 58, in pocket.

On the slopes southeast of the Lake Fork the Picayune quartz latite and the Alboroto rhyolite are separated by a compact quartz latite that is characterized by conspicuous phenocrysts of quartz, much embayed by resorption. This quartz latite is commonly from 300 to 500 feet thick; it forms a strip about 5 miles long in the San Cristobal quadrangle and continues to the north for some distance into the Uncompahgre quadrangle. It is also present on the northwest slope of the Lake Fork east of Williams Creek where it is at or near the base of the Sunshine Peak rhyolite, notably southeast of Grassy Mountain where it separates a rhyolite of the Alboroto from the rocks of the Picayune.

North of Slumgullion Gulch this quartz latite is in large part intrusive but farther south it might be as easily interpreted as a flow overlying the Picayune quartz latite. It is commonly much altered. The freshest rock is light mouse-gray or a related color; it is compact and megascopically shows abundant phenocrysts, about 1 mm in length, of sanidine, white plagioclase, biotite, and embayed quarts. Microscopically the phenocrysts are seen to compose nearly half the rock; they are chiefly andesine with somewhat less quartz and sanidine and some biotite and green hornblende. The chief accessories are apatite, zircon, and magnetite. A specimen from southeast of Grassy Mountain shows abundant large sphenes, but this is exceptional. The groundmass is very finely crystalline and tends to be a spherulitic intergrowth of quartz and orthoclase. The biotite and hornblende are commonly much resorbed and the quartz is characteristically embayed from resorption. Nearly all the rocks are much altered with the development of chlorite, carbonate, kaolinite, and sericite; the hornblende is commonly completely decomposed, the biotite bleached and altered to chlorite, and the feldspar, notably the plagioclase, much kaolinized and sericitized.

Much of the rock slopes for some distance on both sides of Williams Creek (included on the geologic map in the Sunshine Peak rhyolite), differs considerably from the typical rhyolite, and is in large part porphyritic quartz latite resembling the overlying Fisher quartz latite. Exposures are poor throughout this area and the relation of the different rocks was not positively determined. However, the porphyritic quartz latites and rhyolites of the Sunshine Peak type seem to alternate in thin layers, chiefly flows and flow breccias but in part tuff breccias, and the whole is believed to represent a local development at the base of the formation. It is possible that a part of the rocks may represent slide from the overlying Fisher quartz latite or from remnants of that latite which filled in irregularities of the surface of the Sunshine Peak rhyolite; a part may possibly represent inclusions of rocks of the Silverton volcanic series.

The best section of these rocks was measured on the ridge just east of Williams Creek and this section, somewhat generalized, follows:

	Altitude feet
1. Landslide	10, 400
2. Quartz latite tuff	------
3. Biotite-augite-quartz latite	10, 300
4. Quartz latite tuff like No. 2	------
5. Biotite-augite-hornblende-quartz latite	10, 200
6. Quartz latite tuff like No. 2	------
7. Porphyritic rhyolite	10, 100
8. Biotite-augite-hornblende-quartz latite	------
9. Quartz latite	10, 000
10. Tuff-breccia of Picayune quartz latite	------
Total thickness (feet)	400+

The tuff of No. 2 is hard and is made up chiefly of light-colored quartz latites that have phenocrysts as much as several millimeters across. These are chiefly glassy andesine with considerable biotite and embayed quartz, more or less orthoclase and green hornblende, and rare augite and sphene. The groundmass is glassy in some fragments and is a finely crystalline aggregate of quartz, orthoclase, and plagioclase in others. Some of the fragments are darker and carry more augite, in addition to biotite, much magnetite, and some quartz and orthoclase; the groundmass is a rather coarse, matted aggregate of sodic plagioclase in rude laths with considerable interstitial orthoclase and some quartz. This type of tuff was found at two lower horizons in this section; it was also found in considerable thickness a quarter of a mile to the east.

The underlying biotite-augite-quartz latite (No. 3) is light purple-drab and is nearly half phenocrysts which are as long as 3 mm. Plagioclase is the chief phenocryst but biotite, brown augite, and quartz are abundant. The groundmass is very finely crystalline and is rhyolitic in composition. The rock is considerably altered and brecciated, and secondary calcite is abundant.

Beneath this is a small but unknown thickness of tuff-breccia similar to that of No. 2, and underlying the breccia there is another quartz latite (No. 5). Megascopically, this quartz latite resembles the latite of No. 3 except that it is less decomposed and carries scattered white plagioclase crystals as long as 20 mm. Phenocrysts make up about a third of the rock and sanidine is somewhat more abundant than embayed quartz; sodic plagioclase and biotite are subordinate. The groundmass is fluidal and brecciated and is very finely crystalline quartz and orthoclase. Similar rock is present at about the same altitude both to the east and west and at a much higher altitude in the drainage area of Bent Creek. It is a typical Sunshine Peak rhyolite and in places shows the bluish, iridescent sanidine.

The underlying flow is a rather dense, ash-gray quartz latite that carries scattered crystals of sanidine, stained red, as long as several centimeters, and smaller crystals of quartz and biotite. The smaller phenocrysts are chiefly plagioclase with much biotite, some resorbed brown hornblende, and augite, the latter much altered to carbonates. The groundmass is made up of tablets of plagioclase in a fine-grained to micrographic growth of quartz and orthoclase.

The flow (No. 9) immediately overlying the tuff of the Picayune quartz latite is a much-altered quartz latite, near the rhyolites in composition. It is half phenocrysts, few of them more than 2 mm long, of quartz, feldspar, and biotite. The feldspar is much altered and is in part orthoclase, in part plagoclase. The quartz is abundant and is greatly embayed from resorption. Besides the biotite, another dark mineral was present but it is completely decomposed. The groundmass is a spherulitic intergrowth of quartz and orthoclase.

In Williams Creek the basal flow is deep mouse-gray dense rock, showing megascopically many phenocrysts of different sizes, as long as several centimeters, of white plagioclase and others of biotite and augite in an aphanitic groundmass. It seems to be nearer the andesites in composition than the other rocks. A microscopic study shows that the rock is about a third phenocrysts of which andesine-labradorite in large crystals is the chief; but biotite, hornblende, and augite are abundant. The groundmass is a felted mass of plagioclase laths with some orthoclase and quartz. The dark minerals are more abundant than they are in the other flows and are variable in size. Both the hornblende and biotite are largely resorbed. The rock is a dark quartz latite. A flow of a very similar rock forms the knob that is surrounded by the 12,200-foot contour between Bent and Williams Creeks, and similar rock was found at the base of the section about a mile to the east and well up in the section on the ridge to the west.

POTOSI VOLCANIC SERIES

SUBDIVISIONS

Early in the survey of the Telluride quadrangle of the San Juan Mountains, the Potosi series of volcanic rocks was recognized and mapped as the Potosi rhyolite series (Cross and Purington, 1899, p. 5). Later the series was traced eastward into the Silverton and northeastward into the Ouray areas, and it was found necessary to change the name to Potosi volcanic series, because of the prevalence of quartz latites and smaller amounts of andesites in the series (Cross and Howe, 1905a, p. 10). As the survey was extended to the east, where the Potosi volcanic series is best developed, six major subdivisions of the series were established and mapped, and further subdivisions could be made. A preliminary nomenclature for subdivisions of the Potosi volcanic series was furnished to Patton (1917, p. 20) and that nomenclature will be used here, except that the name Summitville andesite will be replaced by Sheep Mountain quartz latite, because the rock near Summitville was later found to belong to the Conejos quartz latite. Too, the term "formation" for each of the units will be replaced by an appropriate petrographic term. In 1922 a table of the volcanic formations of the San Juan Mountains, as then understood, was published by Emmons and Larsen (1922, facing p. 12), and this table is reproduced with corrections and additions to show the usage proposed after the completion of the study of the volcanic rocks of the San Juan Mountains.

GENERAL CHARACTER

The rocks of the Potosi range from basalts or rhyobasalts, to quartz latites, to rhyolites. This classification follows Johannsen's quantitative mineralogical classification of rocks, making the lava types strictly parallel to the granular types, and using all the evidence available to interpret the mineral compositions of the groundmasses or the compositions they would have under normal conditions of crystallization. Neither andesites nor dacites are represented. Basalts are very rare and are all near the quartz latite border but pyroxene-quartz latites, not far removed from basalts, are abundant rocks. Approximate curves for the relative abundance of rocks of different compositions are given for the whole of the Potosi and for each of the subdivisions in figure 57. Each of the six mapped units contains rocks that cover almost the entire range from basalt to rhyolite. The three dark (quartz latite) members are made up largely of quartz latites that are nearer than, or almost as near to, the basalts as to the rhyolites. Nearly all of the rocks of the rhyolitic members are rhyolites or quartz latites near the rhyolites. There is a definite gap between the two groups within which few rocks are represented.

Most of the basalts contain some quartz and orthoclase, and where the average plagioclase has a composition of An_{50} these minerals are each present in the amount of several percent.

The rocks of the three rhyolitic formations (Treasure Mountain, Alboroto, and Piedra) of the Potosi volcanic series are much alike except for some differences in texture and mineral constituents. However, a given outcrop can commonly be correctly placed in the sequence, especially if a section of a number of beds or flows is studied. All three of these formations have local layers of dark quartz latites. The rocks of the three dark quartz latite formations (Conejos, Sheep Mountain, and Huerto) are much alike, though the Conejos has a greater variety of rocks and a greater proportion of breccia. In all three of these formations the chief and the average rock is a dark quartz latite, though lighter colored quartz latite is present. Rhyolites form local bodies of considerable size and basalts near the quartz latites are present in small amount in all three formations. In the parts to follow, the general character of each formation will be described first and, because many of the rock types are common to several of the formations, the detailed petrographic descriptions of all the volcanic rocks will be given in a separate part, for this will avoid much repetition and will bring out similarities and differences. The petrography of the larger intrusive rocks will be described with the general description of those rocks.

The Treasure Mountain rhyolite, the lower rhyolite bed of the Alboroto rhyolite, and the Piedra rhyolite are made up of regular, alternating, relatively thin flows, welded tuffs, and tuff beds. The flows are rarely much more than a few hundred feet thick. Many are less than 100 feet thick, but the rhyolite of the Treasure Mountain in the western part of the San Cristobal quadrangle, the basal rhyolite and the tridymite latite of the Piedra, and the rhyolites of the local volcano of the Alboroto near Creede, are much thicker, and the main latite of the Alboroto is commonly several hundred feet thick and throughout large areas it exceeds 1,000 feet in thickness. The tuff beds are in most places only a few hundred feet thick, but the main tuff layer of the Piedra is in places much thicker, as is the tuff at the base of the Piedra in the drainage basins of Cebolla and Cochetopa Creeks. The tuffs consist chiefly of pumice fragments and the walls that once surrounded gas bubbles and commonly have local irregular flows of glassy rocks with some dark quartz latites. Many of the welded tuffs have a basal zone of obsidian and resemble flows. The tuff in the upper part of the Alboroto is in thick beds and so closely resembles the associated flows that it is not always possible to distinguish between the two.

Dark quartz latites, as thin local bodies of gravel, breccia, and rare flows, are present at several horizons in the Treasure Mountain rhyolite and local volcanic domes of andesite are present in the Piedra near the base and above the tridymite latite. In nearly all cases, the andesites are associated with rhyolitic tuff beds.

TABLE 18.—*Correlation of the subdivisions of the Potosi volcanic series and younger volcanic rocks of the San Juan Mountains, Colorado*

[The waved lines indicate periods of erosion. Numbers indicate thickness, in feet, of units]

	Patton (1917) quoting unpublished names of Whitman Cross and E. S. Larsen, Jr., Summitville—Platoro district	Emmons and Larsen (1922), Creede district	Cross and Larsen (1935) preliminary report on San Juan area	Cross and Larsen, this report
Pliocene (?)	Hinsdale volcanic series.	Absent.	Hinsdale formation: Basalt. Rhyolite. Adesite. Los Pinos member.	Hinsdale formation: San Antonio Peak volcanic domes. Basalt and latite. Rhyolite.
			—Peneplanation—	—Peneplanation—
Miocene	Fisher quartz latite. 0–3,000+.	Quartz latite porphyry dikes. Miocene (?). Fisher quartz latite. 0–100±.	Fisher latite-andesite.	Fisher quartz latite and Los Pinos gravel.
	Absent.	Creede formation. 0–2,000±. Lake beds of tuff, with some flows of quartz latite in upper part.	Creede formation.	Creede formation.
	Potosi volcanic series. Piedra formation. 0–2,000+.	Potosi volcanic series: Piedra group: Nelson Mountain quartz latites. 0–350. Rat Creek quartz latite. 0–500. Quartz latite tuff. 0–500. Andesite. 0–500. Intrusive andesite. Tridymite latite. 0–400. Windy Gulch rhyolite breccia. 100–200. / Rhyolite tuff (to east). 0–200. Hornblende quartz latite. 200. / Mammoth Mountain rhyolite. 0–1,000.	Potosi volcanic series: Piedra rhyolite.	Potosi volcanic series: Piedra rhyolite: 1. Flows of hornblende-biotite-augite latitic rhyolites. Includes Nelson Mountain and Rat Creek quartz latites of the Creede district. 0–400. 2. Tuff. 0–800. 3. Local lenses of dark quartz latite. 0–500+. 4. Tridymite rhyolite. 0–400+. 5. Local dark quartz latite and rhyolitic tuff. Windy Gulch rhyolite breccia of the Creede district and hornblende-quartz latite. 6. Rhyolite, mostly in thick flows with some tuff. 0–1,400.

Miocene	Huerto formation. 0–2,000.	Absent.	Huerto andesite.	Huerto quartz latite: Three local cones of dark pyroxene- and hornblende-quartz latites. Most of them in the San Cristobal quadrangle. 0–2,500.
	Alboroto formation.	Alboroto group: Equity quartz latite. 0–1,000. Phoenix Park quartz latite. 0–500. Intrusive rhyolite. Campbell Mountain rhyolite. 0–1,000. Willow Creek rhyolite. 0–1,000. Outlet Tunnel quartz latite. 250–350+.	Alboroto quartz latite.	Alboroto rhyolite: 1. Biotite-hornblende latitic rhyolite. Makes up most of formation. Thick flows and tuff beds. Equity and Phoenix Park quartz latites. 0–3,000. 2. Tridymite rhyolite. Widespread thin flows and associated tuff beds. Found chiefly near the borders of the mountains. Includes Campbell Mountain and Willow Creek rhyolites and probably Outlet Tunnel quartz latite of the Creede district. 0–500.
	Absent. Absent.	Absent. Absent.	Sheep Mountain andesite. Treasure Mountain quartz latite.	Sheep Mountain quartz latite: Several local domes of dark quartz latite. Treasure Mountain rhyolite: Alternating flows and tuffs of rhyolite carrying biotite and augite with some thin layers of dark quartz latites.
	Summitville andesite. Treasure Mountain latite. 0–1,000. Palisade andesite.	Absent. Absent. Absent.	Conejos andesite.	Conejos quartz latite: A widespread complex of flows and breccia beds that were erupted from several centers. Grade to gravels near the borders of the mountains. Includes Summitville and Palisade andesites, and the Treasure Mountain latite of Patton.

THE RHYOLITE FORMATIONS

In the early stages of the mapping we had difficulty in distinguishing between the rhyolitic formations of the Potosi volcanic series on the basis of petrographic character, but after the formations were better known certain features were found throughout each of the formations as a whole, though individual flows cannot always be placed. The rhyolites are similar in all three formations and are not characteristic, but the rhyolitic quartz latites are mostly distinct, though the character of the sections is important.

In places some difficulty was found in distinguishing the Treasure Mountain rhyolite from the rhyolitic quartz latites of the Alboroto rhyolite, as in the hand specimen the two look very much alike in color, density, size and proportion of phenocrysts, and general appearance. However, the Treasure Mountain rock is chiefly in relatively thin flows, alternating with tuffs, but the Alboroto is mostly in very thick flows. Both rocks have biotite and plagioclase as the most conspicuous phenocrysts; the Treasure Mountain has augite as well, little or no orthoclase, and practically no quartz, hornblende, or sphene, but the Alboroto has orthoclase and quartz, considerable hornblende and sphene, and little or no augite, except in the flows of Snowshoe Mountain. In thin sections the rocks are very easily distinguished, but in the hand specimen it is commonly necessary to search carefully for grass-green augite in the Treasure Mountain or quartz, orthoclase, black hornblende, or yellow sphene in the Alboroto.

The rocks of the upper rhyolitic quartz latite horizon of the Piedra rhyolite are much like some of the Alboroto rhyolite, but they carry augite, as well as hornblende, and are in thin regular, mesa-forming flows, alternating with tuffs.

The lower rhyolite horizon of the Alboroto rhyolite is much like some of the rhyolites of the Piedra and Treasure Mountain, but the alternating flows and tuffs are more regular over a wide extent than is common in the other members. The tridymite rhyolite of this part of the Alboroto is much like the tridymite rhyolitic latite near the middle of the Piedra but it carries little plagioclase and little or no augite, although the Piedra rock carries considerable of both. The rhyolites and rhyolitic quartz latites of the Potosi volcanic series can usually be readily distinguished from the rhyolites and quartz latites of the underlying Silverton volcanic series or of the overlying Hinsdale formation although rare specimens may be indistinguishable. The differences are in large part textural.

THE QUARTZ LATITE FORMATIONS

The commonest rock of all three quartz latite formations is a dark pyroxene-quartz latite that contains conspicuous phenocrysts of tabular feldspar and is called the tabular feldspar-pyroxene-quartz latite. Some of the pyroxene-quartz latites have few feldspar phenocrysts or stout crystals of that mineral. These pyroxene rocks rarely grade into basalts with a more calcic feldspar, more olivine and pyroxene, and less quartz and orthoclase. More commonly they grade into hornblende-pyroxene rocks, which are nearly as abundant as pyroxene rocks, or to hornblende rocks which are less abundant. Again, they commonly grade into light-colored quartz latite, with more quartz and orthoclase and less femic minerals and less lime in the plagioclase. In such rocks hornblende is likely to be the chief dark mineral and biotite may be abundant. The groundmass is mostly made up of plagioclase laths imbedded in quartz and orthoclase, but in some rocks the groundmass is without the plagioclase laths and is rhyolitic. Some of these rocks have chilled basal layers of black obsidian carrying the usual phenocrysts. In some of the light-colored quartz latites the phenocrysts are large and conspicuous; such rocks make up most of the Sheep Mountain quartz latite of the Del Norte quadrangle and are present locally in the Conejos quartz latite.

Finally, the Conejos quartz latite contains a number of thick bodies of small horizontal extent, consisting of rocks near the rhyolites and even of rhyolites, and similar rocks make up the upper part of the Sheep Mountain quartz latite in the Cochetopa and Saguache quadrangles. These are mostly biotite rocks. They commonly contain a few small phenocrysts and many of them have a glassy groundmass. Where crystalline, most of the rocks have abundant laths of plagioclase in the groundmass, and even the glass contains the plagioclase laths—a texture rarely seen in the Treasure Mountain, Alboroto, or Piedra rhyolites. A few have textures much like those of the rhyolitic divisions of the Potosi.

In some of these rhyolitic rocks tridymite is abundant but it is not common in the darker rocks. Cristobalite is present as small spherulites perched on the walls of gas cavities in many of the quartz latites, and especially in the hornblende and biotite rocks, but, except for submicroscopic cristobalite in the groundmass, it probably rarely makes up more than 1 percent of the rock.

Locally the three quartz latite formations of the Potosi volcanic series can be distinguished by their petrographic character, but correlation cannot be made on the petrography alone except for short distances. For instance, the Sheep Mountain and Conejos quartz latite could probably be separated in detailed mapping in the Cochetopa and Saguache quadrangles.

The dark quartz latites of the Potosi volcanic series differ considerably from the coarsely porphyritic rocks of the Fisher quartz latite though local bodies of quartz latite with unusually large phenocrysts in the Potosi are much like the typical rocks of the Fisher, and some of the finer-textured rocks of the Fisher resemble the common rocks of the Potosi. The Potosi rocks can nearly everywhere be distinguished from the andesites and latites of the Hinsdale formation. The dark quartz latites of the Potosi can usually be distinguished from the rocks of the Silverton volcanic series and the San Juan tuff, though the pyroxene-quartz latite of the Silverton is similar to the tabular feldspar-pyroxene quartz latite of the Potosi.

AREA, THICKNESS, AND VOLUME OF THE POTOSI VOLCANIC SERIES

It is not possible to make accurate estimates of the area and volume of the formation of the Potosi volcanic series, but sufficient data are available to make rough approximations which may be in error as much as or even more than 50 percent in some cases, though they are generally more accurate. The data for the different formations of the Potosi are shown in table 19 and they indicate a total volume for the Potosi eruptions of 5,600 cubic miles. About the same result was obtained by estimating the area and thickness of the series and calculating the volume. The estimated diameter of the Potosi pile is about 135 miles, and the maximum thickness probably 6,000 feet. The estimated area is about 14,000 square miles and the estimated volume about 6,000 cubic miles.

The Conejos quartz latite underlies about two-thirds of the area occupied by the Potosi volcanic series and has about half the volume. The other dark members are very small. Of the rhyolitic members, the Alboroto is the largest and forms nearly half of the rhyolites and rhyolitic quartz latites. It underlies an area nearly as large as that of the Conejos (10,000 square miles) but has a lesser average thickness. The Piedra and Treasure Mountain rhyolites each has a volume of about 600 cubic miles.

TABLE 19.—*Estimated size of the domes of the formations of the Potosi volcanic series*

	Distance across (miles)	*Area covered (square miles)*	*Thickness in central part (feet)*	*Volume (cubic miles)*
Rhyolitic formations:				
Piedra	70	4,000–	2,500	600
Alboroto	110	10,000	3,000±	1,100
Treasure Mountain:				
Conejos dome	65	3,200	1,500	600
San Cristobal dome	40	1,200	2,000	
Saguache dome	20 x 10	150	300	
Total volume of rhyolitic rocks				2,300
Dark quartz latite formations:				
Huerto:				
Huerto Peak dome	42+	1,000	2,500	160
East of Lake San Cristobal	10	75	2,200	
Sheep Mountain:				
Carson cone	12	80	2,000	120±
Summitville cone (much has been removed by erosion)	6	30	600	
Del Norte and Saguache quadrangles		1,500±	1,000	
Conejos	120	10,000	4,000	3,000
Total volume of dark rocks				3,280
Total volume				5,580

CONDITIONS OF ERUPTION

Table 19 shows that the Potosi volcanic series consists of alternating groups of dark quartz latites and rhyolitic rocks. The dark rocks follow the rhyolites without an appreciable period of erosion but the rhyolites were separated from the underlying dark rocks by a considerable period of erosion. All the rhyolite formations, and in particular the Piedra and Treasure Mountain rhyolites, have local bodies of dark rocks, partly flow, partly clastic, mostly associated with rhyolite tuff beds. These dark rocks are similar to those of the quartz latite members, showing that the quartz latite eruptions continued intermittently during the time when the eruptions were predominantly rhyolitic. Rhyolitic rocks are also present in the quartz latite formation but they differ, for the most part, from the rhyolites of the rhyolitic formations and have some affinities with the dark rocks.

The rhyolitic formations formed broad, flat domes and were probably erupted from a few centers. The Piedra dome was about 70 miles across and more than 2,000 feet thick near its center which was close to the town of Creede in the eastern part of the Creede quadrangle. It was no doubt erupted from several vents. The Alboroto dome was about 100 miles across and it had a thickness near its central part of about 3,000 feet. It consists of two distinct units. The upper unit, which constitutes about three-fourths of the dome, is made up of thick flows and tuffs of rhyolitic quartz latite, centered in the Creede quadrangle, and its chief vents, which were probably few, were in the Creede quadrangle or very near it. The lower rhyolite units consist of local, steep volcanic cones and domes or lava plateaus. One cone is near Creede, one in Spring Creek in the Cochetopa quadrangle, and another in the Saguache quadrangle south of the Saguache River between Squaw and House Log Creeks. The rhyolite plateaus are on the borders of the Alboroto dome to the north in the Saguache River drainage area and to the east along the borders of the San Luis Valley. These rhyolites are in most places only a few hundred feet thick. The Treasure Mountain rhyolite accumulated as three or more domes that nearly merged at their bases. One dome, centered in the northwestern part of the Conejos quadrangle, was more than 65 miles across and had a maximum thickness of about 1,500 feet; another dome, centered near the head of the Rio

Grande, in the western part of the San Cristobal quadrangle, was about 40 miles across and had a maximum thickness of about 2,000 feet; a much smaller dome, centered near the town of Saguache, was about 20 miles across, and had a maximum thickness of only a few hundred feet.

Of the quartz latite formations, the Huerto and Sheep Mountain each accumulated as a few domes, with relatively smaller diameters and steeper slopes than the rhyolitic domes; the Conejos quartz latite accumulated around many vents, and the extrusive material from the several vents merged and formed a broad, relatively flat plateau. The Huerto formed three domes, the largest of which was about 40 miles across, 2,500 feet high, and centered in the southeastern quarter of the San Cristobal quadrangle. A smaller dome under Bristol Head on the northeastern flanks of the large dome was only a few miles across, and another small dome, probably isolated, situated east of Lake San Cristobal, to the north, was about 10 miles across and 2,200 feet high. The Sheep Mountain accumulated in three main areas. The largest is in the Del Norte, Cochetopa, and Saguache quadrangles and covered an area roughly estimated at 1,500 square miles, and had a maximum thickness of about 1,000 feet. It is in several isolated bodies and no doubt was erupted from several centers. A small, high volcanic cone of Sheep Mountain age is situated near the mining camp of Carson in the northwestern part of the San Cristobal quadrangle and was about 12 miles across and 2,000+ feet high. A third low dome accumulated in the southwestern part of the Summitville quadrangle and adjoining areas and was about 6 miles across and had a height of about 600 feet.

The Conejos quartz latite was extruded from a number of centers, about 10 of which have been found, and formed a great plateau about 120 miles across, and with a maximum thickness of more than 4,000 feet and a thickness of more than 1,000 feet throughout much of its extent. It was by far the greatest accumulation of dark rocks in Potosi time, as it made up about half the volume of the Potosi eruptions.

The layers of dark rocks within the rhyolitic formations are not intermediate between the dark and light types but are commonly made up of dark pyroxene quartz latites near basalts. They are thin and have a horizontal extent of only a few miles. The body in the Piedra near Bristol Head formed a low dome several hundred feet thick and about 10 miles across. It consists of flows and breccia beds and contains a variety of dark quartz latites. The body in the Piedra near Rio Grande Pyramid is nearly as large and is made up of breccia, all the fragments of which are similar. These dark rocks must have been erupted from local centers which were distinct from the rhyolitic centers but which extruded material while the nearby rhyolitic centers were also active.

It is an interesting fact, contrary to the commonly accepted experience of petrologists, that all the rhyolitic formations are regular, widespread formations, and consist in very large part of widespread, nearly flat, mostly thin flows, with alternating tuffs. As seen exposed for miles in canyon walls, they resemble alternating beds of sandstone and shale. The dark members are, except for the Conejos, local volcanic cones of no wide distribution and all three are made up of a chaotic aggregate of irregular flows and breccia beds.

CONTINUITY OF VENTS

There is no evidence that the same volcanic vents were sources of more than a single subdivision of the Potosi volcanic series, but it seems clear that the vents were active only during the formation of one of the subdivisions and for later eruptions new vents were formed. Even within some subdivisions the different rock types came from different vents. In Alboroto time the great flows of the characteristic quartz latite came from vents in or near the Creede quadrangle, but the tridymite rhyolites came from vents to the north and east, nearer the margin of the dome, and some local volcanoes made up entirely of quartz-bearing rhyolites are present near Creede.

The volcano in the Summitville quadrangle erupted the Sheep Mountain quartz latite which here is almost entirely a dark, tabular feldspar-pyroxene-quartz latite; the Carson volcano is made up chiefly of a lighter-colored pyroxene rock, different in appearance though very similar chemically; whereas the rock north of Del Norte is all a light-colored, coarsely porphyritic quartz latite, though still very similar chemically to the other two. The Sheep Mountain in the Saguache quadrangle has three horizons, a lower quartz latite, a middle dark quartz latite, and an upper rhyolite.

However, it must be kept clearly in mind that the rocks of each subdivision show considerable variation both in texture and composition and that some of the vents must have erupted material of greatly varying composition. The Sheep Mountain volcano of the Carson area, in the San Cristobal quadrangle, is a good example of this, and the dissected volcano is well exposed. Plate 3 is a map showing the chief rock types of this volcano. It is made up chiefly of dark pyroxene and hornblende-pyroxene-quartz latite but contains light-colored quartz latite, rhyolite, and basalt.

CONEJOS QUARTZ LATITE

DISTRIBUTION AND THICKNESS

The Conejos quartz latite is most widely distributed and best exposed and has its greatest thickness in the

Summitville, Conejos, and Del Norte quadrangles, and in a general way the corner common to these quadrangles was probably about the central part of the original Conejos volcanic pile. To the west it retains a great thickness as far as the central part of the San Cristobal quadrangle, but beyond that it rapidly becomes thinner and it probably never extended west of that quadrangle. This western boundary runs some degrees east of north, as the Conejos rocks are known only in the southeastern part of the Uncompahgre quadrangle. In the Cochetopa and Saguache quadrangles the formation extended nearly to the northern boundary of the quadrangles, but it is thinner and less regular in the northern part. Near the San Luis Valley the Conejos quartz latite dips under younger rock, apparently with undiminished thickness. To the south the formation becomes somewhat thinner in the extreme southern part of the Conejos quadrangle but it retains its character. It is known to extend about 40 miles south into New Mexico, but it becomes thinner and is predominantly a sand and gravel formation consisting chiefly of fragments of volcanic rocks. On the southwest its boundary is erosional.

In a general way its outcrops are confined to an area about 130 miles long in a north and south dimension. They are about 60 miles wide in the northern third, about 50 miles wide just north of the Colorado-New Mexico State line, but wedge out to a point in their southern extremity. The original pile of volcanic material probably had about the same general limits as the present outcrops. To the north it was limited in part by hills of older rocks, to the west it was clearly limited by hills of older rocks, and to the south it feathered out and gave place to water-worn material; but to the southwest it may have extended for some distance and to the east it probably extended for some miles. A reasonable assumption is that it was rudely circular in form but probably elongated in the north-south direction and somewhat more than 100 miles across.

Its thickness is irregular because both its base and its top are surfaces of erosion. The greatest thickness observed was about 4,000 feet in the basin at the head of Rio Blanco in the central part of the Summitville quadrangle. Nearly as great a thickness is exposed in the canyon of the Alamosa River and here the base is not exposed. A thickness of 3,000 feet or more is common in the central area, and this thickness continues to the north as far as Razor Creek Dome. The formation seems to become thinner in all directions from this central part but except on the extreme edges of the formation it is rarely less than 1,000 feet thick and averages considerably more than that.

The Conejos quartz latite is the most widespread of the volcanic formations of the San Juan Mountains, except for the andesite and latite of the Hinsdale formation and, also except for the andesite and latite of the Hinsdale, it crops out over the largest area. It is nearly everywhere much thicker than the andesite and latite of the Hinsdale, and in the area included in this study it probably represents a larger mass of extruded material than any of the other volcanic formations. It probably originally covered an area of about 10,000 square miles and the erupted material had a volume of about 3,000 cubic miles. The figures give only the order of magnitude of the erupted material.

GENERAL CHARACTER

In the early stages of the preparation of this report, the Conejos rocks were classed as andesites and quartz latites but, if the quantitative mineralogical classification of Johannsen is followed and the effusive rocks are classified in such a way as to make their main groups parallel to the corresponding groups of the granular rocks, nearly all of the Conejos rocks are quartz latites. Only a few of them, probably less than 1 percent, can be classified as rhyolites or quartz-bearing basalts. By far the greater part of the Conejos consists of quartz latites that are nearer to the quartz basalts than to the rhyolites. No andesites were found.

Fragmental beds make up considerably more than half of the Conejos quartz latite, and, although in the central, thickest part of the formation near the corner of the Creede, Del Norte, Summitville, and Conejos quadrangles, massive rock is more abundant than on the average, near the outer limits of the formation on the south, west, and north, clastic beds greatly predominate. In the central, thick part of the formation the breccia is mostly chaotic and pyroclastic, with angular fragments little modified by water transportation, and for any bed or group of beds consists almost entirely of one kind of rock which in many places is similar to that of the associated flows. Farther away from the center the tuffs are finer-grained and are better-sorted and bedded. They consist of subangular or even well-rounded fragments of a variety of rocks, which clearly have been transported by water, and they show some evidence of weathering. In the New Mexico area this tuff grades into sands and gravels in part derived from pre-Cambrian rocks.

The typical bedded tuff near the border of the formation is well shown in the great cliffs along the southwestern face of the mountains in the Summitville and San Cristobal quadrangles. In these cliffs the Conejos quartz latite is made up chiefly of a series of fairly well bedded, somewhat indurated tuffs, agglomerates, and breccias which consist of rounded to subangular fragments from a few inches to a foot or more across in a matrix of fine material. Generally both pebbles and matrix were derived from dark lavas, but in upper Weminuche Creek and south of Huerto Peak, and elsewhere near the base of the formation, the matrix consists in part of arkosic material derived from rocks similar to the granite nearby. A few pebbles of granite and quartzite are also present and some thin beds of arkose. At the base of the agglomerate on both sides of lower Williams Creek, in the San Cristobal quadrangle, and extending to the southeast, there is a considerable thickness of dark green, indurated tuff which is made up of small fragments of dark rocks and is characterized by abundant, rounded cavities about an inch across. A similar tuff was found east of Antelope Springs north of the Rio Grande.

Some of the indurated tuff beds are considerably altered but generally the pebbles are fairly fresh. Highly vesicular rocks are common. Most of the rocks are dark-green, gray, or red pyroxene-quartz latites. Brown hornblende is commonly present and may predominate over the pyroxene. The groundmass commonly contains much glass. Somewhat less common are tabular feldspar-pyroxene-quartz latites. The more siliceous quartz latites are light red, green, or gray, and are coarse grained. They contain abundant phenocrysts of andesine feldspar as much as an inch across, and considerable green hornblende, augite, and, in some specimens, biotite and quartz in a granophyric groundmass. Large crystals of sphene are common.

Beneath the typical Conejos quartz latite, in the southern part of the mountains, chiefly in the Pagosa Springs and Summitville quadrangles, there is in many places a considerable thickness of soft sands, clays, and gravels, made up chiefly of volcanic debris. These rocks have been included in the Conejos in mapping, although they may be considerably older than the main mass of the Conejos. They are rarely exposed and are commonly covered by landslide. They were found in the wash on the north slope of Quien Sabe Mountain in the northern part of the Pagosa Springs quadrangle, and in the Summitville quadrangle north of the forks of San Juan River and especially in the Chama River drainage basin. These beds seem to become thicker and more nearly continuous toward the south near the border of the Conejos. Similar beds were found north of the Rio Grande near the eastern border of the Creede quadrangle, where they are poorly exposed in road cuts and wash along the road in the valley of Baughman Creek about a mile above its mouth.

In the Chama River drainage basin the lower few hundred feet of the Conejos immediately overlying the Blanco Basin formation is a soft, friable, poorly bedded sand made up mostly of volcanic fragments and some layers and lenses of pebbles. The pebbles are well rounded, much altered, and are rarely more than an inch across and consist mostly of rhyolitic and other volcanic rocks. There are some layers of arkose near the base.

In the northwestern part of the Summitville quadrangle on the slope east of BM 7713 about 1 mile north of the forks of the San Juan River, a section of these beds of the Conejos quartz latite is better exposed than is usual. It shows, from top to bottom:

	Feet
1. Flows and flow breccia of dark quartz latite, the main part of Conejos.	
2. Conglomerate. Well-cemented; pebbles rarely a foot across, of dark hornblende and biotite quartz latites	50
3. Sandy tuff, rather well-bedded	5
4. Dark quartz latite conglomerate	25
5. Rhyolite tuff-breccia. Practically no bedding. Abundant fragments of pumice and bentonitelike material. A few pebbles of granite and other pre-Cambrian rocks	50
6. Grades into No. 5. Well-bedded rhyolite tuff with more fragments of pre-Cambrian rocks than no. 5. The lower part is well bedded and has about the texture of coarse sand, with some pebble layers made up mostly of pre-Cambrian rocks and containing some quartz latite and rhyolite. Lowest foot or two is shaly	50
Base not exposed.	

North of the Rio Grande, in the Creede and Del Norte quadrangles, in the basin of Baughman Creek, the lowest exposures of the Conejos quartz latite are arkose and shaly tuffs. They are poorly exposed and were seen chiefly on the banks of the creek. The thickness exposed is less than 100 feet. They are probably near the base of the Conejos.

LOCAL DESCRIPTIONS

SOUTHERN BORDER OF THE MOUNTAINS

In the great cliffs that form the southern border of the San Juan Mountains in the San Cristobal, Summitville, and Conejos quadrangles, the Conejos quartz latite consists predominantly of bedded tuffs with flows and pyroclastic beds. The lenses of lava range from single thin flows exposed in the cliffs for only a few miles to lenses made up of several flows, with associated pyroclastic beds that are several hundred feet thick and are exposed along the cliffs for many miles.

In the San Cristobal quadrangle the tuff is cut by a few basaltic dikes. In Upper Middle Creek it contains a thin flow of dark pyroxene-quartz latite, and a thin flow or sill of siliceous quartz latite about a mile south of Cache Lakes.

In the southern part of the San Cristobal quadrangle, a coarsely porphyritic variety of the dark tabular feldspar-pyroxene-quartz latite is at the base of the Conejos. East of Los Pinos River, at the head of Fall Creek, this rock overlies a very irregular surface of the pre-Cambrian granite and it is present at the base of the

Conejos, with some interruptions, southeast as far as Huerto Creek. In most places it is not more than 50 feet thick and is a single flow, but locally, as in the Weminuche Creek drainage basin, it is several hundred feet thick and is made up of a number of similar flows. Flows and chaotic breccia beds of a similar rock are present at the base of the Conejos in the cliffs on the south face of the mountains throughout the northeastern half of the Summitville quadrangle and are commonly several hundred feet thick.

In the southern part of the San Cristobal quadrangle in the drainage area of Huerto Creek, a great thickness of breccias in the Conejos quartz latite is overlain by a series of lava flows, with associated tuff-breccias. The upper part of these flows is made up of the tabular feldspar-pyroxene rock, and the lower part consists of pyroxene rocks and of lighter-colored hornblende-pyroxene-quartz latites. To the east, in the Summitville quadrangle, flows are more abundant throughout the Conejos where lenses made up chiefly of flows give conspicuous outcrops in contrast with those of the breccia. Some of these lenses of massive rock are several hundred feet thick, extend for several miles along the cliffs, and consist of several thin flows of the tabular feldspar-pyroxene-quartz latite.

SAN CRISTOBAL AND UNCOMPAHGRE QUADRANGLES

In the eastern part of the San Cristobal quadrangle, south of the Rio Grande in the drainage basin of Trout Creek, the Conejos quartz latite is made up chiefly of flows, breccias, and chaotic flow breccias of dark, highly vesicular quartz latite. Much of the rock is of the tabular feldspar-pyroxene variety. Farther north, south of Bristol Head, flows and breccias predominate but some tuff-breccia is present. The chief rocks are hornblende-pyroxene-quartz latite but some are dark pyroxene-quartz latites. Most of the rocks are altered and chlorite and calcite have developed.

Farther north in the southeastern part of the Uncompahgre quadrangle, chiefly in the drainage basin of Cebolla Creek, the Conejos quartz latite is made up largely of flows of the tabular feldspar-pyroxene variety but in the western part of the Conejos exposures, in the drainage areas of Mill Gulch and Brush Creek, and near Waterdog Lake, more fragmental beds and hornblende-pyroxene-quartz latites predominate.

In the eastern part of the Uncompahgre area, in the drainage basin of Rock Creek and the adjoining area, the main part of the formation consists of massive flows of pyroxene-quartz latite, but the lower few hundred feet is a local body of more siliceous rhyolitic tuff-breccia. The rocks are partly porphyritic, partly felsitic. Some dark quartz latites underlie this tuff.

COCHETOPA AND SAGUACHE QUADRANGLES

In the western part of the Cochetopa quadrangle, Sawtooth Mountain rises domelike to an altitude of 12,120 feet (Hayden), and consists mostly of dark rocks which attain a thickness of 2,000 to more than 3,000 feet. The forest cover is dense in many places and exposures are relatively poor; however, smooth slopes, such as commonly overlie breccia, predominate, and it is believed that most of the mass is made up of breccia. Where exposed, this breccia is chaotic and is poorly stratified generally, but evidence of sorting and stratification was observed in a few places. On the north slope a fine-grained, grayish augite-hornblende-quartz latite is the principal type in the prevalent breccia. This type of breccia prevails also on the east slope in exposures in Home Gulch and on the south slope. Ledges of massive rock occur here and there on the north slope, cap the ridge of a very even crest leading north of west from the summit, appear locally on other ridges, and on the south cap the main divide and some of the lateral ridges. Intrusive bodies are exposed in the breccia of the eastward-facing cliffs near the summit and such masses are probably distributed throughout the mass of the mountain.

In the northwestern part of the Cochetopa quadrangle north of Sawtooth Mountain at the head of North Beaver Creek, the breccia of the Conejos quartz latite is underlain by a flow of rhyolite. A similar rhyolite is present at the base of the Conejos at several places east of the mountain. This rhyolite is white and somewhat porous and carries abundant crystals of glassy sanidine and some biotite in an aphanitic groundmass.

Razor Creek Dome is composed of quartz latites more than 2,000 feet in maximum thickness. On the north side of Razor Creek Dome the lowest part of the Conejos shows scarce outcrops, but immediately above the shale on the northeast slope the rock seems to be a fine tuffaceous breccia. Above this there is a coarser chaotic breccia of angular fragments of red or gray porous hornblende-quartz latite and some dark volcanic matrix. This type of material continues for several hundred feet. At 1,100 feet altitude there is a massive flow of a pinkish gray pyroxene-quartz latite which probably continues along the northeast and north slopes of the hill. The same type of rock was observed for 300 feet up the hill, probably representing more than one flow. Above the first 20 feet this rock exhibits characteristic platy and fluidal structure. Both the flow structure and the extension of the flow indicate that it is nearly horizontal. The slopes above this horizon and below the capping flow are mantled with fragments of hornblende and biotite-augite rocks similar to the flow. This is believed to indicate a chaotic breccia not unlike the one mentioned as occurring below an altitude of 10,400 feet. The dome, whose altitude measured by barometer is 11,850 feet, is capped by a thin flow of gray biotite-augite-quartz latite. A similar type of massive rock forms the knoll which stands out rather strikingly on the north side of Razor Creek Dome.

The ridge 4 miles due north of Razor Creek consists chiefly of a breccia of light-colored rocks. In this area there is about 200 feet of the fine tuff-breccia at the base of the Conejos quartz latite overlain irregularly by a homogeneous flow breccia of hornblende-quartz latite cropping out in a ledge 30 to 40 feet thick.

The rocks of Razor Creek Dome and vicinity, whether fragmental or massive, are similar and are closely related genetically. The tuff-breccias seldom show even a suggestion of bedding and are usually characterized by intercalated massive flows such as might result from lava streams pouring over a rapidly accumulating bed of volcanic ejectamenta. The fragments in the breccias are almost invariably angular or subangular and are of many sizes from that of marbles to blocks several feet across. The massive flows are commonly local, pinching out laterally, although on the dome there are one or two which are more extensive. These flows may give way laterally, vertically, or in irregular patches to breccia of similar rock, doubtless broken up in the process of their eruption. The general character of the Razor Creek Dome mass strongly suggests that it had a vent or vents nearby and that its accumulation was rapid. It is believed that the present dome represents approximately the old volcanic center of eruption. The rocks are much like those of Sawtooth Mountain.

In the southern part of the Cochetopa quadrangle, the character of the formation is shown by the section on the north slope of Saguache Creek in the vicinity of Ducks Foot Creek. Here the lower 200 feet is a dark, somewhat brecciated, pyroxene-quartz latite of horizontal platy structure. This member seems to thicken to the south and east. It is overlain in Ducks Foot Creek by a thin, local flow of dull white, porous, fluidal rhyolite. Above the rhyolite there are about 500 feet of tuff and chaotic dark flow breccia, usually showing angular fragments such as would be expected of lava and volcanic ejectamenta, which had been accumulated rapidly over a rugged surface. The lower two-thirds of this are largely massive rock, locally brecciated, whereas the upper one-third consists of tuff-breccia, in part fairly well bedded, and made up of angular fragments of hornblende rock, averaging a foot across, embedded in a small amount of matrix. The rocks of the upper layer contain hornblende or hornblende and augite and are much like those of Sawtooth Mountain.

In the Saguache River drainage area, which is still farther south in the northern part of the Del Norte quadrangle and adjoining parts of the Saguache quadrangle, the Conejos quartz, latite is much thinner and clastic beds, mostly dark, form nearly the whole section.

In the Saguache quadrangle in the drainage basin of Middle Creek about a mile above the mouth of East Middle Creek there are exposures of a breccia that contains considerable light-colored quartz latites and vitrophyric rocks, and similar breccias, with associated flows, were found in the upper drainage basin of Sheep Creek, where the Conejos quartz latites come out from under the Alboroto rhyolite.

To the south, in the Del Norte quadrangle and adjoining parts of the Creede quadrangle, siliceous quartz latites make up a somewhat larger proportion of the Conejos, although here, too, they are much subordinate to darker rocks. Chiefly above the forks, in the upper drainage area of Carnero Creek, and in the upper drainage area of La Garita Creek, the lower exposures of the Conejos contain a considerable thickness of breccia whose fragments consist almost entirely of light-colored glassy quartz latites which closely resemble the Tracy Creek quartz latite. This latite breccia is both overlain and underlain by flows and breccia beds of normal Conejos rocks and it contains some interbedded flows.

NORTHERN PART OF DEL NORTE AND CREEDE QUADRANGLES

North of the Rio Grande, in the Del Norte and Creede quadrangles, the upper part of the Conejos is made up largely of the tabular feldspar-pyroxene-quartz latite. Some of these rocks carry hornblende. Much of the Conejos in the eastern part of the area in what is believed to be the lower part of the section is chaotic breccia, but flows are present; and in the high mountains near the western border of the quadrangle flows of tabular feldspar-quartz latite make up a large part of the material.

The flows capping the ridge between the Middle and South Forks of the Carnero, in the extreme northwestern part of the quadrangle, are dark-colored, vesicular hornblende-pyroxene-quartz latites which are basaltic in appearance and show few phenocrysts. Similar flows were found in Dry Gulch and in lower Carnero Gulch.

In this northern half of the quadrangle a few flows of hornblende-quartz latites are present, and large bodies of tuff-breccia made up of such rocks were found. These light-colored tuffs are similar to those of the Pinos Creek area to the south but are somewhat finer textured, and the fragments are better rounded, sorted, and bedded. Such breccias make up much of the drainage area of Little La Garita Creek extending into Poso Creek. They probably underlie the main mass of the pyroxene-quartz latite but seem to be, in part, interbedded with it. They also make up much of the slopes of main Carnero Creek and of the Middle Fork of Carnero Creek.

Near the mouth of Cave Creek, between flows of pyroxene-quartz latite, there are several hundred feet of a breccia whose fragments are made up almost entirely of glassy or felsitic quartz latite that is near a rhyolite in composition. A flow overlying this breccia is purple drab and carries a few crystals of andesine, biotite, and brown hornblende in a porous groundmass that consists of minute laths of plagioclase and orthoclase and grains of augite and iron ore imbedded in a small amount of quartz. Tuff-breccia similar to this was also found at an altitude of 10,700 feet in the northwestern corner of the quadrangle on the east side of the saddle between the South and Middle Forks of the Carnero.

About 10 miles northwest of Del Norte, Twin Mountains is made up of a rhyolite, more than 1,000 feet thick but of small horizontal extent, which seems to overlie irregularly the pyroxene-quartz latite of the Conejos. Some smaller bodies of similar rock, in part intrusive, are present nearby. This rhyolite is made up in large part of several irregular flows but contains some breccia and some intrusive bodies.

Somewhat similar flows cap the hill that is surrounded by the 9,000-foot contour line, about 1½ miles east of Tracy Creek and 1 mile north of the Saguache-Rio Grande county line. A dike of similar rhyolite passes east of this hill and extends to the northeast for about 6 miles.

A series of flows of light-colored quartz latites, at least 1,000 feet thick and exposed over an area about 5 miles across, is present in the northwestern corner of the Del Norte quadrangle and the northeastern part of the Creede quadrangle and extends from Boat Mountain north and east to the south fork of the Carnero and south almost to Cave Creek. This series overlies and is overlain by normal Conejos quartz latite. Like the other rhyolitic bodies in the Conejos it forms a local lens in the formation and no doubt accumulated around a local vent.

In the northern part of the Conejos quadrangle and in adjoining parts of the Summitville, Creede, and Del Norte quadrangles, the lower part of the Conejos quartz latite consists largely of tuff-breccia but in the upper part there is considerable massive rock. Probably marking the lowest horizon in this area is the light-colored, fine-textured, well-bedded tuff which shows poor outcrops in the gentle slopes just south of the Rio Grande and west of Pinos Creek. Only a few hundred feet of this tuff is exposed. Similar tuff crops out north of the Rio Grande between Woman Creek in the Del Norte quadrangle and Bear Creek in the Creede quadrangle. The material is a hornblende-biotite-quartz latite. Overlying this tuff is a great body of tuff-breccia carrying some small, irregular bodies of massive rock. It attains a thickness of more than 1,000 feet. Much of it is poorly bedded and sorted, and the fragments are chiefly subangular to angular, rarely rounded, and are for the most part less than a foot in diameter. The upper 100 feet or so of this tuff-breccia, just under the pyroxene-quartz latite flow, a few miles south of Del Norte, consists of a light-colored, fine-textured, well-bedded tuff. The tuff-breccia commonly shows poor outcrops but in the steeper canyons it locally shows the castellated forms and hoodoos with perched boulders characteristic of the moderately indurated tuff-breccias. The rocks of the tuff are chiefly light colored and hornblende is the most conspicuous dark mineral. This breccia forms the greater part of the Conejos of the drainage basins of both Pinos and San Francosco Creeks.

In upper San Francisco Creek and at the head of Lime Kiln and Raton Creeks there is a great amount of massive rock in irregular flows in the upper part of the breccia. These flows are in part tabular feldspar-pyroxene-quartz latite and in part lighter colored hornblende-pyroxene-quartz latite. Biotite is present in some of the flows.

Overlying this breccia regularly there is a series of flows with subordinate breccia that is made up largely of the tabular feldspar-pyroxene-quartz latite. This rock caps the ridge south of Observatory Hill near Del Norte and is present under the Alboroto rhyolite to the west of Pinos Creek.

In the northeastern part of the Summitville quadrangle the lower part of the Conejos quartz latite, at least 2,000 feet thick, is made up chiefly of breccia with some flows. The rocks are chiefly hornblende-pyroxene-quartz latites. Overlying this regularly there is a body of very irregular thickness of light-colored rocks, and overlying these there is a great thickness of flows of the tabular feldspar-pyroxene-quartz latite. A large body of this light-colored rock makes up most of the Conejos outcrops north of the Alamosa River from the west slope of the Continental Divide eastward to the fault at the Asiatic mine, and throughout this area it is commonly about 1,000 feet thick. To the southeast a thinner body of light-colored quartz latite forms a narrower strip from the head of Gold Creek southeast to the Conejos drainage area on both sides of Adams Park northeast of the fault. This rhyolite is cut out for a short distance by the pyroxene-quartz latite in the middle part of Adams Park, but in the lower part of the park it again comes out from under pyroxene rock and forms a large thick body on both sides of the Conejos River. It forms most of the Conejos rocks of Cornwall Mountain, which stands between the two faults, where it is at least 1,500 feet thick. Below Jasper, it is exposed for a short distance on the lower slopes of the Alamosa River where it lies beneath the pyroxene-quartz latite. This light-colored rock is very uniform in character, and even in the thick section of Cornwall Mountain nothing was seen to indicate more than one great flow. It is dense, shows a good fluidal banding, and looks like a rhyolite. In places there is a thin layer of dark glass at its base. The rocks are mostly red brown or less commonly light olive green, and they carry some small inclusions of andesite—in some places enough to make them flow breccias.

In the Conejos quadrangle hornblende-pyroxene-quartz latites, grading into pyroxene rocks or into hornblende rocks and lighter colored quartz latites, make up nearly the whole of the formation. Tuff-breccia greatly predominates in the southern part of the quadrangle, but flows are more abundant in the northern part.

In the northwestern part of the Conejos quadrangle, in the basin at the head of Rock Creek and extending northward into the drainage basin of San Francisco Creek and southward into the Alamosa River basin, there is a breccia, several hundred feet thick, made up almost entirely of fragments of glassy or felsitic rhyolite. It is probably at a higher level than the quartz latite described in the preceding paragraphs. This section contains much indurated light-pink tuff which contains crystals of biotite and feldspar and fragments of aphanitic rhyolite and some fragments of dark rock.

A few hundred feet of a welded tuff of rhyolitic latite is also present in the extreme northwestern part of the Conejos quadrangle about 500 feet beneath the crest of Bennett Peak.

Vitrous siliceous quartz latites and closely related rocks were found in the Conejos quartz latite in three widely separated areas, and probably at as many different levels in the formation. These rocks were found in the lower part of the formation in the basins at the head of Carnero and LaGarita Creeks which are in the northwestern part of the Del Norte quadrangle and adjoining parts of the Creede quadrangle; well up in the section in the basin at the head of Rock Creek, which is in the northwestern part of the Conejos quadrangle; and at or near the base of the Conejos, in the northern New Mexico area. Dikes and other intrusive bodies of this kind of rock are numerous in the vicinity of Twin Mountains.

Most of these rocks are in chaotic breccia beds whose fragments are as much as 2 feet across, are angular or subangular except in New Mexico, and are made up almost entirely of one kind of rock. These breccias lie between normal Conejos rocks and in places are interstratified with and grade into flows or breccias of such rocks. Massive rocks of this kind are scarce. In the New Mexico area the fragments are well rounded and the material was clearly water-laid, but elsewhere it is no doubt pyroclastic and shows little evidence of water transportation. Clearly, the rocks are of local origin.

In the Wolf Creek area, about a mile southwest of the southwest corner of the Conejos quadrangle, near the base of the material mapped as Conejos, there is a tuff of rhyolitic latite about 6 feet thick. This is a firm, even-grained pink rock, with crystals about a millimeter in length of oligoclase, microline-microperthite, biotite, and hornblende. Over this tuff there is a breccia made up mostly of angular fragments of pink rhyolitic latite, with some fragments of quartz latite and a few of pre-Cambrian rocks.

In the southern part of the San Cristobal quadrangle about a mile southeast of Cache Lakes there is a small flow or sill of a light-colored rhyolitic latite that has a few phenocrysts and resembles some of the rhyolites of the Piedra.

In the New Mexico area there is a variable thickness of gravels under the normal breccia of the Conejos quartz latite. In the lower part of these gravels pre-Cambrian rocks make up nearly all fragments, but higher up, volcanic pebbles become increasingly more abundant and for much of the gravel horizon most of the pebbles are rhyolite-latite. Dark quartz latites are present in small amount except in the upper part of the gravels where they predominate. Gravels of this kind were found at the base of the Conejos in the Wolf Creek basin, east of the Chama River, in the extreme northern part of New Mexico and extending up the Chama River into Colorado. They are also present near the base of the section in the basin of the Rio Brazos.

ASSOCIATED INTRUSIVE ROCKS

GENERAL STATEMENT

Many bodies of granodiorite and related rocks, believed to be of Conejos age, are present in or near the central part of the great dome of the Conejos quartz latite. Most of the large bodies are volcanic necks and no doubt represent vents through which Conejos rocks were erupted. Several large laccoliths, many dikes, and some less regular bodies, mostly near and closely associated with the necks, are present in the Summitville quadrangle.

The largest of the necks is in the northeastern part of the Summitville quadrangle and in outcrop is about 5 miles long and 2 miles across. Many of the necks are about a mile across. Such is the stock in the Bear Creek basin in the north-central part of the Summitville quadrangle, the neck in Cat Creek basin in the north-central part of the Conejos quadrangle, the neck near Summer Coon 7 miles north of Del Norte in the Del Norte quadrangle, that near Embargo north of the Rio Grande in the eastern part of the Creede quadrangle, that a few miles to the northwest in the drainage of Wanamaker Creek, and that near the mouth of Trout Creek south of the Rio Grande in the east-central part of the San Cristobal quadrangle. For several miles around each neck many dikes cut the older rocks. These dikes, for the most part, differ in composition only moderately from the rock of the main neck, but some differ appreciably in texture. The dikes are in part porphyritic quartz latites, somewhat nearer the rhyolites in composition than the granodiorite of the necks; in part they are dark pyroxene-quartz latites or basaltic rocks of about the same composition, or nearer the basalts, than the rock of the neck; in small part they are dikelike apophyses of the granodiorite itself and differ from it chiefly in their finer texture. The porphyritic quartz latite dikes are large conspicuous dikes—some of them more than 100 feet across and several miles in length—and they tend to radiate from the central neck. In the Summer Coon area north of Del Norte in the Del Norte quadrangle, these dikes crop out prominently and are conspicuously radiating, as shown on the geologic map (pl. 1). The dikes of dark pyroxene-quartz latite show poor exposures and are seen only in favorable outcrops and on close examination. They are mostly only a few feet across but are abundant and a traverse over good exposures for half a mile may show scores of them of somewhat variable texture and composition. For the most part the dikes do not cut the diorite of the central neck but seem to end before reaching it. The few dikes that are fine-textured apophyses of the diorite connect with the central neck.

More or less alteration and mineralization have taken place around these necks and nearly all the mining and prospecting of the area have been in these mineralized zones. None of the necks shows so little mineralization around them that there has been no prospecting. The relation between the mineralization and the volcanic necks is so close that in the field work we expected to find a volcanic neck wherever there was any considerable amount of prospecting. The alteration has affected both the intruded rock and the diorite itself. The altered zone is somewhat irregular and in places extends for a mile or more from the neck. In some of the areas the rock of the neck has itself been almost completely altered. The altered rock is usually nearly white and is partly alunitized, partly sericitized, partly altered to clay, and partly silicified. In places chlorite, uralite, and serpentine, have been developed. Pyrite and other sulfides have commonly been deposited. In the Embargo area north of the Rio Grande in the eastern part of the Creede quadrangle, zunyite in well-formed tetrahedrons was found associated with pyrite, alunite, and sericite.

Many laccoliths cut the sediments just under the Conejos quartz latite in the Summitville quadrangle, and they are believed to be of Conejos age although the evidence is not conclusive. A laccolith caps Jackson Mountain in the northwestern part of the Summitville quadrangle, and many sills are associated with it. Such sills are especially abundant in the ridge between the San Juan River and Turkey Creek. A large, dipping laccolith that seems to be associated with a local sharp tilting of the Conejos rocks is present north of Blanco Basin in the central part of the Summitville quadrangle. A few miles south a third and larger laccolith forms V Mountain. Each of these laccoliths underlies several square miles and each attains a thickness of several hundred feet. A smaller laccolith of a porphyritic rock crops out on the east side of Blanco Basin.

These laccoliths are not associated with many dikes, though the Jackson Mountain laccolith appears to have many associated sills. No extensive alteration was recognized around the laccoliths, and no mineralization. In these respects they differ much from the necks.

Except in the areas near the stocks, dikes are not abundant in the formation and the greater number of the dikes seem to be related to the volcanic necks.

By far the greater part of the rock of the necks and laccoliths is a gray pyroxene granodiorite or granogabbro, of about millimeter grain size and made up mostly of andesine feldspar containing considerable augite and hypersthene and a small but variable amount of quartz and orthoclase. A few have a more calcic feldspar and approach the gabbro in composition, and some have more quartz and orthoclase and are monzonites or quartz monzonites. Biotite is present in many of the rocks in small amount. In many the pyroxene is more or less altered to hornblende and in others the hypersthene is altered to bastite. Many of the stocks are made up of several closely related intrusive rocks.

The large neck in the northeastern part of the Summitville quadrangle is composed mostly of quartz monzonite, but the rock varies appreciably both in texture and mineral composition and the relation between the different rocks is not clear. The western part of this intrusion is a darker-colored pyroxene diorite.

Dark pyroxene granodiorites, resembling the tabular feldspar pyroxene-quartz latite both in texture and mineral composition, and somewhat richer in dark minerals and lime than the other diorites, make up the western part of the large Summitville neck, the V Mountain laccolith, the laccolith north of Blanco Basin, and the neck south of the Rio Grande in the eastern part of the San Cristobal quadrangle.

Most of the smaller dikes around the stocks are dark-colored pyroxene-quartz latites and a few are hornblende-bearing quartz latites. Many of these dikes are of the tabular feldspar type, but other kinds of pyroxene-quartz latite are present. The larger radiating dikes are mostly lighter-colored porphyritic hornblende-quartz latites or related rocks.

AGE

The available evidence of the age of the granodiorite intrusive bodies is not quite conclusive, but for most of the volcanic necks it is sufficient to show without much doubt that they are of Conejos age. Most of these necks are in or near the central thick part of the great Conejos volcanic dome where the centers for the volcanic material would be expected. They intrude Conejos rocks. The rocks of the volcanic necks are similar chemically and mineralogically, and in some places texturally, to the extrusive rocks of the Conejos quartz latite. They are also like some of the quartz latites of Sheep Mountain and Huerto age, but most of the volcanic necks are in areas where the two latter quartz latites are either absent or very thin. The Huerto quartz latite seems never to have covered the area in which most of the necks are found and the Sheep Mountain seems to be less well developed in this area than to the west and north.

More positive evidence of the age of many of the necks is available. The diorite of Trout Creek in the San Cristobal quadrangle, and the diorite of Wanamaker Creek in the northern part of the Creede quadrangle are overlain, after considerable erosion, by the Alboroto rhyolite, as are also the mineralized aureoles and associated dikes of the bodies near Summer Coon north of Del Norte, and Embargo, northwest of Del Norte. The neck in the Cat Creek basin in the northern part of the Conejos quadrangle and that in the Bear Creek basin in the north-central part of the Summitville quadrangle seem to have their mineralized aureole and associated dikes truncated by the Treasure Mountain rhyolite. The similarity of the different necks is sufficient to indicate a close relationship in age and origin. The great intrusive neck in the northeastern part of the Summitville quadrangle is placed in the Conejos chiefly because of its similarity to the other necks. However, in this area there are dikes that are so similar in texture and mineral composition to the Fisher quartz latite nearby as to leave little doubt as to their age, and the latter rocks are locally altered and mineralized. The neck and some of the minor intrusive bodies are believed to be of Conejos age from the similarity of the rocks to the granodiorites of known Conejos age, but the dikes of porphyritic quartz latite are almost certainly of Fisher age.

In general the necks are made up mainly of a single intrusive rock though many show one or more smaller parts of somewhat different age and kind. The large Summitville neck is more complex. The dikes that surround the necks are more varied and probably represent intrusions of somewhat different age. The evidence seems clear that the Conejos centers of eruption did not continue beyond Conejos time and there seems to be no tendency for later eruptions to come through the old Conejos vents, nor is there any evidence of extensive differentiation in the vents. The Summitville center may be an exception to this, though it seems more probable that the proximity of the Conejos and Fisher centers was a coincidence.

The laccoliths all intrude pre-Conejos rocks and offer little evidence of their age. The body north of Blanco Basin seems to have disturbed the Conejos rocks much as it did the sediments and in such a way as would be expected if there was no great load of overlying rocks. Otherwise, the laccoliths are placed with the Conejos intrusive bodies chiefly on account of their petrographic similarity to the Conejos necks. Each of the laccoliths is simple and shows little variation in texture and no appreciable variation in composition.

THE V MOUNTAIN LACCOLITH

The laccolith of V Mountain lies at the southwest border of the volcanic area in the southern part of the Summitville quadrangle, 10 miles from the south and 12 miles from the west border of the quadrangle. It is a roughly oval mass having a maximum width of 2 miles and a length of nearly 4 miles. It rises to a height of 10,715 feet above sea level and has a thickness of 500 to 700 feet. The laccolithic mass is bounded on almost all sides by nearly vertical cliffs averaging about 500 feet in height, and the top is nearly flat but dips gently to the north. The laccolith of V Mountain was intruded approximately at the contact with the sedimentary rocks and overlying Conejos quartz latite, but it has been almost completely uncovered. Remnants of sediments overlie it in a number of places. The rock of V Mountain is remarkably uniform in composition and texture as no differentiation has been recognized, but specimens collected near the top of the mountain are somewhat finer grained than the average rock.

An analysis, norm, and mode of a specimen (SV 218) of the typical rock are given in table 21, column 2, in pocket. The rock seems to be a granular variety of the tabular feldspar-pyroxene-quartz latite, somewhat nearer a gabbro than the usual rock, and it is much like the rock of the Trout Creek stock, to be described, but has smaller plagioclase phenocrysts (An_{60}, 5 mm long), and is not distinctly porphyritic. The average size of the grains is about 2 mm. The orthoclase and microperthite are interstitial, and orthoclase free from intergrown albite is more abundant than microperthite. The magnetite forms large irregular grains. The hypersthene is partly altered to bastite. The rock is a granodiorite.

SQUARETOP MOUNTAIN LACCOLITH

A body of granodiorite lies just east of Squaretop Mountain and northwest of Blanco Basin in the central part of the Summitville quadrangle only a few miles north of V Mountain. It is roughly rectangular and has a length northeast-southwest of about 2 miles and a width of 1.5 miles. The borders seem to be overlain on nearly all sides by Tertiary sediments, and locally small remnants of the same sedimentary group rest on it, showing that the slope of the outcrop is largely the uncovered top of the mass and that the diorite body is laccolithic. In Oil Canyon the walls which are of the granodiorite show many irregular inclusions of sedimentary rock, and apophyses of granodiorite extend into the sediments. On the west side of the mass, the Conejos quartz latites overlying the laccolith are turned up toward the intrusive body. The laccolith forms a scarp on the northwest side of Blanco Basin. Its surface is a dip slope and the intrusion clearly tilted the intruded rocks to rather steep angles locally.

The rock is dull gray, with phenocrysts of different sizes, some as long as 10 mm. The groundmass crystals are less than 1 mm in diameter. The microscope shows a rock with a low dark-mineral content. Augite forms about 2 percent, bastite varieties of serpentine derived from hypersthene 4 percent, and magnetite about 2 percent of the rock. There are some quartz and orthoclase in the groundmass. The rock differs somewhat in texture from the V Mountain diorite and is lower in pyroxene, especially augite, and probably lower in orthoclase, but is otherwise similar.

AGE OF THE LACCOLITHS

The V Mountain and Squaretop Mountain laccoliths are of the same kind of rock, have similar relations to the adjoining rocks and are believed to be of about the same age. Both cut the youngest sediments but not the Conejos quartz latite, although the Squaretop laccolith has tilted the Conejos rocks. The rock of both is similar in chemical and mineral composition and in texture to the tabular feldspar-pyroxene-quartz latite of the Conejos, but this type of rock is equally abundant in the Sheep Mountain and the Huerto quartz latites. It is similar to the rock of the intrusive bodies to the north that are known to be of Conejos age. The laccoliths are near the thickest, central part of the Conejos dome but Huerto rocks are not exposed within 25 miles and there they are very thin. Sheep Mountain rocks are exposed within a few miles but no thick body of Sheep Mountain rocks is exposed within nearly 20 miles and the intrusive bodies seem to be under the edge of the Sheep Mountain dome. These laccoliths are therefore believed to be Conejos in age.

JACKSON MOUNTAIN LACCOLITH

A complex laccolithic mass occupies an area of several square miles in Jackson Mountain in the western part of the Summitville quadrangle. The largest intrusive body of the area is near the crest of the peak and has a thickness of several hundred feet, but the presence of many sills is shown by float in the shales lower down on the flanks of the mountain. The shales seem to be domed sharply and it is probable that other laccolith-like masses have not been uncovered by erosion, and that the Jackson Mountain intrusive mass is a composite laccolith.

The bluff west of the forks of San Juan River is composed of shales containing at least 20 sills 1 to 4 feet thick of a rock closely related to that in Jackson Mountain 2 miles to the southwest.

The thick body near the crest of Jackson Mountain is represented by specimen Sv 2038. It is a brown fine-grained porphyritic rock with large conspicuous white phenocrysts. These are orthoclase, having a maximum length of 30 mm and plagioclase and quartz as long as 10 mm. All are conspicuously rounded and the quartz is surrounded by reaction rims. Quartz phenocrysts form 1 percent of the rock, those of orthoclase 3 percent. and those of plagioclase 1 percent.

The groundmass is composed of feldspar crystals less than 0.5 mm in diameter and black hornblende needles 2 mm long. The microscope shows approximately the following mineral composition:

Mode of syenite porphyry of Jackson Mountain

Quartz	3
Orthoclase	62
Plagioclase (Oligoclase)	22
Augite	2
Biotite	2
Hornblende	5
Apatite	1
Magnetite	1
Total	100

The quartz occurs in well-rounded crystals with reaction rims of augite and biotite. The orthoclase occurs in rounded phenocrysts and as the main feldspar of the groundmass. Plagioclase (An_{30}) forms a small proportion of the feldspar phenocrysts and euhedral tabular crystals in the groundmass. Both orthoclase and plagioclase are clouded through partial alteration. Hornblende forms euhedral needles varying in size from 0.02 to 4 mm in length and occurs both as phenocrysts and in the groundmass. It is light reddish brown and probably is near barkevikite in composition. Biotite forms irregular bodies having about the same color as the hornblende. Apatite is abundant.

Specimens from different parts of the Jackson Mountain laccolith are all of the same type, but the porportion of phenocrysts and dark minerals differs greatly. In specimen 2037, collected at the northwest point of Jackson Mountain, phenocrysts form 25 percent of the rock.

Specimen 2040, collected 1.5 miles west of the mouth of Turkey Creek, is from a thin lower sill in the east flank of Jackson Mountain. It is a rock of the same type as that just described, but is darker and has few phenocrysts of quartz and feldspar. The mineral composition is about as follows:

Mode of lower sill of Jackson Mountain

Quartz	4.5
Orthoclase	31
Plagioclase	40
Biotite	7
Hornblende	17
Apatite	.5
Total	100.0

The rock from the forks of the San Juan River is closely related to those in Jackson Mountain, but it is fine grained and the feldspar is predominantly plagioclase.

GRANODIORITE OF CANYON DIABLO

North of the mouth of Canyon Diablo near the headwaters of Middle Fork of the Conejos River in the northeastern part of the Conejos quadrangle, there is a sill-like body of granodiorite about 1 mile long and 0.25 mile wide that cuts Conejos tuff breccia. This is a dark-gray rock composed largely of crystals about 1 mm in diameter. The microscope shows a rock of approximately the following composition:

Mode of granodiorite

Phenocrysts:	
Labradorite	55
Augite	9
Hypersthene	5
Biotite	1
Magnetite	5
Groundmass:	
Quartz, Plagioclase, Orthoclase	25
Total	100

The biotite is in fan-shaped aggregates. The groundmass is a fine-grained aggregate of quartz and plagioclase, with some orthoclase. The rock is very similar to the granodiorite of V Mountain though it has more quartz and some biotite. It is probably of about the same age.

THE SYENOGABBRO LACCOLITH EAST OF PLATORO

On the slopes east of the sharp turn in the Conejos River and a few miles east of the mining camp of Platoro, near the western border of the Conejos quadrangle, a laccolithic body of syenogabbro about 2.5 miles long and more than 500 feet thick, intrudes the Conejos quartz latite. The typical rock is dark brownish gray, and has an average grain of about 2 mm. The rocks tend to be porphyritic. The mineral composition is:

Calcic labradorite (An_{66})	82
Alkalic feldspar, interstitial	10
Augite and hypersthene	4
Magnetite	4
Total	100

The rock is a syenogabbro, very low in dark-mineral content. Some parts of the rock are lighter colored and have calcic andesine feldspar and are therefore diorites or granodiorites.

THE GRANODIORITES IN THE CENTRAL PART OF THE SUMMITVILLE QUADRANGLE

A number of small bodies of granodiorite crop out in the drainage basin of Bear Creek and adjoining areas of the north-central part of the Summitville quadrangle. The largest of these lies near the head of Bear Creek; another is a half mile to the north, east of Crater Creek; another near the mouth of Bear Creek; and one east of Montezuma Peak.

The Bear Creek mass lies near the head of Bear Creek, one of the headwater streams of the East Fork of the San Juan River in the north-central part of the Summitville quadrangle. The main mass has a length of about 1.5 miles, a width of 0.5 mile, and forms the prominent ridge running north-northwest from Montezuma Peak on the east side of Bear Creek. A smaller tongue of granodiorite extends west from the southwestern part of the main mass and forms a part of the lower ridge on the west side of the creek. The highest point on the granodiorite ridge rises to a height of 12,500 feet, and 2,000 feet of granodiorite is exposed. Many dikes and other small intrusive bodies cut the Conejos quartz latite in the neighborhood of the main mass.

The granodiorite is a dark-gray millimeter-grained rock and is everywhere more or less altered. The original rock consists largely of andesine in stout tablets, and contains about 25 percent of dark minerals of which biotite, hypersthene, and augite are in about equal amount and magnetite is in considerably less amount. There is about 5 percent of quartz and a little orthoclase in small interstitial grains. Quartz makes up as much as 15 percent of some of the rocks. The biotite is fresh and in irregular crystals, the hypersthene is completely altered to bastite or to hornblende, and the augite is more or less altered to green hornblende. Secondary pyrite is present in some of the diorite.

A specimen from the east slopes of Bear Creek at an altitude of 12,000 feet has approximately the following composition:

Quartz	4
Orthoclase	7
Andesine (An_{40})	64
Biotite	8
Augite	4
Secondary hornblende	10
Magnetite	3
Total	100

A rock from the south end of Silver Lake carries crystals of feldspar as long as 15 mm and contains somewhat more quartz than the average content of the neck. The rock contains more biotite than those described in the preceding paragraphs but is otherwise similar.

A large number of dikes cut the Conejos quartz latite near the Bear Creek neck and these are mostly within a few miles of the neck. Most of them are less than 50 feet across. The greater part are pyroxene-quartz latite porphyries with some biotite and are the porphyritic equivalent of the granodiorite. Some are olivine-bearing pyroxene granodiorites with a very fine groundmass and are much like the tabular feldspar-pyroxene-quartz latites. Others are hornblende-pyroxene rocks and some are lighter colored, coarsely porphyritic quartz latites.

The granodiorite of Bear Creek cuts Conejos rocks but neither it nor its associated dikes cut the Treasure Mountain rhyolite and it is without much doubt of Conejos age.

One half mile north of the Bear Creek stock, east of Crater Creek, is a mass of diorite not more than one-eighth of a mile long. This is a fine-grained, nearly black diorite without phenocrysts and its crystals average 1 mm in diameter. It is similar in composition to the Bear Creek rock but differs slightly as the following Rosiwal determination indicates:

Mode of Crater Creek diorite

Andesine (An_{40})	80. 0
Augite	12. 5
Biotite	1. 5
Magnetite	6. 0
Total	100

It contains some orthoclase and no quartz. The habit and relations of the mineral are as in the Bear Creek rock.

Specimen 180 collected 50 yards south of the road in the East Fork of the San Juan River, about 200 yards east of the Quartz Creek trail, is from a small unmapped mass of granodiorite similar to that of the Bear Creek stock.

The rocks around the Bear Creek neck and the rock of the neck itself are much altered and enough mineralization has taken place to encourage considerable prospecting. The chief secondary minerals observed were calcite, sericite, quartz, chlorite, epidote, and pyrite.

On the East Fork of the San Juan River opposite the mouth of Bear Creek there is a small mass of rock similar to that of the Bear Creek area but with a little more orthoclase. The exposed part is about 0.25 mile in length, but a small part of the mass is covered by alluvium on the south side of the stream.

A small mass of granodiorite is just north of the head of Alamosa Creek, 1 mile east of Montezuma Peak in the north-central part of the Summitville quadrangle. The greatest length is not over 0.25 mile, and the entire stock is uniform in texture and mineral composition. The rock is blue-gray, with andesine and hornblende easily distinguishable in the hand specimen. The microscope shows a rock with small amounts of augite and hornblende and much magnetite. Feldspar forms about 85 percent of the rock. Andesine in euhedral crystals forms about one-half of the body of the rock, and a fine-grained aggregate of orthoclase, plagioclase, and quartz fills the interspaces between these phenocrysts. A large number of andesitic dikes cut the Conejos quartz latite for a mile or so around this neck, and only a few of them are shown on the map. They show some tendency to radiate from the neck.

A large dike of quartz latite about 500 feet across and nearly a mile long is mapped in the central part of the northeast quarter of the Summitville quadrangle, and about 2 miles east of Montezuma Peak. The dike is nearly vertical and strikes east-northeast, and its conspicuous vertical, fluidal, platy structure stands out in marked contrast to the horizontal layering of the effusive rocks. The western end of this dike is concealed by alluvium. To the east it cuts a light-colored Conejos quartz latite, and farther west it cuts pyroxene-quartz latite of the Conejos. The rock is nearly black and carries about 10 percent of phenocrysts of white andesine and green hornblende and some biotite. The groundmass is very fine grained and is made up largely of anhedral andesine grains, with some orthoclase and quartz.

Another dike in this area cuts the dike described in the preceding paragraph at its eastern part, but cuts

Conejos quartz latite in its western part. It is about 25 feet wide and forms a prominent wall in places 100 feet high, where it cuts the Conejos. It is a coarse-grained pyroxene latite and carries 20 percent of phenocrysts as much as 10 mm across of andesine, augite, and hypersthene. There is some brown hornblende, much resorbed. The groundmass is rather coarse and is made up of euhedral grains of andesine and augite, anhedral magnetite, and some interstitial orthoclase. Similar dikes were found nearby.

MONZONITE OF WEIGHTMAN FORK

A triangular mass of granodiorite about 0.75 mile in length is cut by the canyon of Weightman Fork in the northeast part of the Summitville quadrangle, northeast of Elephant Mountain. The rock is similar in appearance and mineral composition to the granodiorite east of Bear Creek. It is a dark-gray rock, with mineral grains averaging about 1 mm in diameter and a small proportion of phenocrysts reaching a diameter of 3 mm. The microscope shows approximately the following composition for the typical rock:

Quartz	4
Orthoclase	7
Andesine	64
Augite	7
Hypersthene altered to bastite	11
Magnetite	6
Biotite	1
Total	100

The rock varies somewhat both in texture and mineral composition. Some specimens have more biotite than pyroxenes and show an ophitic texture.

The border phase of the monzonite is represented by specimen Sv 1066 collected 20 feet from the contact on the western border of the intrusive stock. This is a blue-gray rock, with many phenocrysts as much as 2 mm in diameter and many grains of pyrite 1 mm in diameter. The microscope shows a rock composed of corroded phenocrysts of andesine, augite, and biotite forming about one-third of the rock in a groundmass that is a mosaic of interlocking grains of feldspar and quartz. Quartz is abundant and forms about one-third of the groundmass.

Many of the rocks are much altered, and chlorite, epidote, calcite, sulfides, and leucoxene have developed.

ALAMOSA RIVER STOCK

The intrusive mass in the drainage basin of the Alamosa River in the northeastern part of the Summitville quadrangle is about 5 miles long and 2 miles across and is the largest of the bodies believed to be of Conejos age. This neck varies more in composition than do most of the smaller volcanic necks and it no doubt is the result of several closely related intrusions. The extreme western part is a dark pyroxene granodiorite porphyry near a gabbro, is of uniform character, and resembles the intrusive mass of V Mountain except for its finer texture. The main body is made up mostly of granodiorite with abundant orthoclase, but it varies greatly from place to place both in mineral composition and texture. Parts are fine grained, almost aphanitic; others are coarsely granular; others porphyritic. The differences in the proportion of dark minerals are small, but the quartz and orthoclase are in variable amount. The different types commonly grade into one another, but in places intrusive relations are shown. It seems evident that the Summitville mass is a complex stock resulting from several intrusive impulses closely following one another in time. This relationship has probably been complicated by a limited amount of differentiation in place. In some cases the granodiorite porphyry is intrusive in the granodiorite, in others the reverse appears to be true.

A typical granodiorite is represented by a specimen (129) collected north of the Alamosa Creek south of a small lake 1.25 miles above Gilmore. The rock is medium gray and formed of mineral grains averaging about 2 mm in diameter. The minerals plagioclase, augite, biotite, and magnetite can all be recognized in the hand specimen. The minerals are in approximately the following proportions:

Quartz	6
Orthoclase	14
Andesine	53
Biotite	3
Augite	16
Hypersthene altered to bastite	3
Magnetite	5
Total	100

Large individuals of quartz inclosing feldspar are molded between older minerals. Orthoclase forms large anhedral grains inclosing smaller euhedral plagioclase crystals in much the same manner as does the quartz. Andesine (An_{40}) is subhedral to euhedral. Biotite is in irregular reddish-brown grains often intergrown with augite and magnetite. The rock is fairly fresh but the augite is partly altered to chlorite, with some epidote, and the hypersthene is altered to bastite. Almost all of the diorites carry 4 to 5 percent of quartz, most often in microperthitic intergrowths with orthoclase.

Specimen 133 collected on Gold Creek at an altitude of 10,850 feet, has a similar composition to the rock just described, but it contains about 6 percent of bastite derived from hypersthene.

A granodiorite with more quartz and orthoclase (Sv 1125) was collected from the talus from a cliff 0.25 mile south of Gilman on the trail leading to the mines of Klondike Mountain. The rock is bluish gray and differences in the color of the feldspar give it a somewhat mottled appearance. Plagioclase occurs in distinct euhedral tabular plates of gray, and orthoclase in anhedral grains of a pinkish gray. The grain is medium coarse and individual grains average about 3 mm in diameter. A microscopic study shows the presence of minerals in approximately the following proportions:

Quartz	7
Orthoclase	32
Andesine	34
Pyroxene	17
Biotite	4
Magnetite	6
Total	100

The quartz occurs largely as a coarse-grained micropegmatite of quartz and orthoclase between andesine grains. Orthoclase occurs as micropegmatite and as anhedral grains. Augite forms subhedral to anhedral crystals and crystal aggregates often intergrown with biotite and magnetite. Biotite occurs as irregular grains usually intergrown with augite. For the most part, magnetite is abundant and intergrown or inclosed in augite. The rock is fresh and the only evidence of change is the alteration of part of the pyroxene to a fibrous bastite. In some of the rocks biotite exceeds the pyroxene in amount. An analysis of the granodiorite from near the sawmill above Stunner is shown in table 21, column 31, in pocket. It confirms the microscopic determination. The norm differs from the mode chiefly in the absence of biotite in the norm.

The granodiorite porphyry is represented by a specimen (1104) collected 100 yards west of the Eurydice mine house on Telluride Mountain east of Stunner. The rock is a fine-grained light porphyry with phenocrysts averaging about 1 mm in diameter and reaching a maximum diameter of about 4 mm. The microscope shows a rock composed of about 40 parts phenocrysts to 60 of groundmass. The groundmass is composed predominantly of plagioclase and smaller amounts of quartz, augite, and biotite. The grains of the groundmass are anhedral and the structure decidedly granular. The phenocrysts, largely andesine, are subhedral.

A specimen (1122) collected from the Gilmore stock on the east edge of the flat 0.25 mile east of Gilmore is a fine-grained granite porphyry. The average size of the mineral grains is about 1 mm and phenocrysts reach a maximum diameter of 4 mm. The color is a pinkish gray, with conspicuous greenish areas of augite and chlorite as much as 3 mm in diameter. The microscope shows minerals present in approximately the following proportions:

Quartz	12
Orthoclase	43
Plagioclase	32
Biotite	2
Augite	6
Magnetite	5
Total	100

The plagioclase, having a composition of sodic andesine, forms subhedral phenocrysts having an average length of about 1.5 mm. Individual crystals are rarely in contact, but are surrounded by a zone of orthoclase and quartz grains. Quartz occurs in irregular-shaped grains averaging 0.2 mm in diameter, disseminated in the orthoclase, but without showing microperthitic intergrowths. Orthoclase, which is dull pink in the hand specimen and slightly gray in thin section, forms anhedral grains slightly larger than the quartz. Biotite, augite, and magnetite commonly form aggregates which reach a maximum diameter of several millimeters, but which seem to be younger than the plagioclase and of the same generation as the orthoclase. Augite is anhedral, pale green, and partly altered to chlorite.

Many dikes of quartz monzonite porphyry are present near the main quartz monzonite body and they are particularly well shown on the south and east side of the stock (Patton, 1917, p. 40–46).

There are many dikes around the Summitville neck chiefly of dark quartz latite. Some of the larger dikes north of Alamosa Creek are of a coarsely porphyritic quartz latite that is so similar both in texture and composition to the Fisher quartz latite that they are believed to be the intrusive equivalent of the Fisher extrusives.

There is a large amount of altered rock within a few miles of the Summitville neck, particularly north of it. One large area of altered rock is east of and another is west of Lookout Mountain. Another large body of altered rock is northwest of the mining camp of Jasper. The altered rocks are bleached white and are made up mostly of quartz, sericite, clay, and alunite. They commonly retain the texture of the original rock. Sulfides are abundant. Considerable mining and prospecting have been done in the neighborhood of this neck and the old mining camps of Summitville, Jasper, Stunner, Gilmore, and Platoro are near it. Many of the small streams draining the areas underlain by the altered rock are highly mineralized and two have received the name of Bitter Creek and one that of Iron Creek.

The age of the Alamosa intrusive mass is somewhat uncertain. It cuts Conejos rocks and has greatly altered them. Some of the large dikes in its vicinity are almost identical with the Fisher rocks and some of the alteration of this vicinity has affected the Fisher rocks. It is clear that some intrusion took place during

Fisher time, but the main stock is much like the other Conejos stocks and is believed to be of Conejos age.

MONZONITE OF CAT CREEK

A body of monzonite, rudely triangular in shape and about 2.5 miles across, is situated in the basin of Cat Creek in the north-central part of the Conejos quadrangle. It forms a rugged topography with relief of about 1,000 feet.

This neck intrudes the Conejos quartz latite, sends many dikes into that formation, and has extensively altered it. It is nowhere in contact with the Treasure Mountain rhyolite but none of the dikes cuts the Treasure Mountain. Alteration has not affected the Treasure Mountain rocks, although for a distance of 2 miles they are from 0.3 to 1 mile away from the main intrusive mass. This neck is in the central thick area of the Conejos and its rock is similar to the other intrusive rocks believed to be of Conejos age, and to the normal pyroxene andesite of the Conejos. The stock is therefore believed to be of late Conejos age.

The Conejos rocks around the neck and to some extent the monzonite itself have been extensively altered. Silicification, sericitization, and alunitization are the chief types of alteration, and considerable pyrite has been developed. Some rocks are now made up of about equal amounts of quartz and alunite. In the monzonite sericite, epidote, chlorite, and calcite have been extensively developed.

The monzonite of Cat Creek is uniform in composition but it ranges in texture from 2 mm-grained to almost aphanitic in the border rock and from equigranular to conspicuously porphyritic.

This rock shows biotite and plagioclase in the hand specimen and under the microscope is seen to have about the following mineral composition:

Calcic andesine	72
Perthite	16
Biotite	2
Pyroxene (now calcite and chlorite)	8
Magnetite	2
Total	100

The microperthite is made up of oligoclase, and orthoclase and is interstitial to the andesine crystals.

Some quartz latite dikes cut the Conejos effusive rocks near the Cat Creek intrusive mass. A small dike north of the dam of the Terrace Reservoir is a pink biotite rock with about 30 percent of phenocrysts as much as 10 millimeters across and carries much tridymite in the gas cavities.

THE SUMMER COON STOCK

The Summer Coon stock, 7 miles north of Del Norte, is situated in an area of low relief, underlain mostly by tuff-breccia of the Conejos quartz latite. The main stock forms a hill several hundred feet above the general level and the larger radiating dikes crop out as nearly continuous walls or form sharp ridges.

The main intrusive neck is about 1.5 miles long north and south and 1 mile wide east and west. Many dikes of quartz latite porphyry radiate from the center. Only the larger dikes are shown on plate 1, and most of them are from 25 to several hundred feet in width and from 1 to 5 miles in length. The long dike that spreads over a large area at its northern end in the La Garita valley is not much wider in this part than to the south, but it turns somewhat and much of the outcrop is nearly a dip slope. These dikes so far as observed all end in the breccia before reaching the central neck, and at least one fingers out toward the neck.

Hundreds of small dikes of dark quartz latite, most of them only a few feet across and having poor outcrops, cut the breccia near the volcanic neck and gradually become less abundant a few miles away. For the most part they tend to radiate from the neck but less strikingly so than the light-colored dikes. It was not possible to show them on the geologic map. The one long dike of soda rhyolite seems to be older than the neck and is cut by it. The intrusive rock and the surrounding breccia are much altered by hydrothermal action. Clearly, the dikes cut well up into the Conejos quartz latite but they do not cut the Sheep Mountain quartz latite.

The central stock at Summer Coon ranges in composition from an augite diorite porphyry to an augite-biotite granodiorite porphyry. In texture it is always seriate porphyritic and the phenocrysts are commonly less than a millimeter in largest diameter, rarely a centimeter. Much of the rock of the stock and of the adjoining breccia and flows is altered to nearly white, quartz-alunite rock, or to quartz-sericite rock, or to more complex alteration products. This alteration and poor exposure have made it difficult to map the stock accurately, and the boundaries shown on the map are only approximate.

The dark purplish-gray augite diorite porphyry forms much of the southern part of the stock and is probably the chief rock. The phenocrysts, which are mainly less than a millimeter across, make up somewhat more than half the rock and are chiefly andesine-labradorite, with much augite in irregular grains that include magnetite aggregates. There is some hypersthene. The groundmass is fine granular and is made up chiefly of andesine, with considerable augite and accessory magnetite, quartz, orthoclase, biotite, and apatite. Aggregates of magnetite and augite indicate that another dark mineral, probably hornblende, has been completely resorbed. Irregular areas of the rock have an even granular texture.

The granodiorite porphyry, which is quaker drab, was found chiefly in the northern part of the stock. Besides being lighter colored than the diorite, its plagioclase phenocrysts are somewhat more sodic, augite is somewhat less abundant, biotite much more abundant and is present both in scattered phenocrysts and in the groundmass, and the groundmass contains considerably more quartz and orthoclase and a few crystals of zircon. Much of the rock is altered, and some prospecting has been done. The most conspicuous type of alteration has been to a nearly white rock which is a rather coarse aggregate of quartz and alunite in nearly equal amounts. In some brecciated zones of this alunitized rock the spaces between the fragments are filled with alunite of a friable, sugary texture. Other parts of the body have undergone sericitization, with development of varying amounts of carbonates, chlorite, epidote, and iron stain. In an unusual type of alteration the plagioclase crystals are partly replaced by biotite and the augite is completely decomposed. In most of the rocks the hypersthene crystals are altered to aggregates of strongly birefracting, chloritic plates which are optically negative, have a small axial angle, and the acute bisectrix normal to the plates.

The radiating dikes of light-colored quartz latite porphyry are much more resistant to weathering than the surrounding breccia and they commonly stand out as conspicuous walls and make the most prominent topographic features of the area between La Garita and Old Womans Gulches.

The rocks of most of the dikes of quartz latite porphyry are much alike. In color they are chiefly light purple drab to light mouse gray and nearly all show some irregular gas cavities. They have abundant white plagioclase crystals as much as 3 mm across, and considerable biotite and hornblende. Phenocrysts make up somewhat less than half the rock and are chiefly sodic andesine with considerable biotite and green hornblende, accessory apatite, magnetite, and rare zircon. Both the biotite and the hornblende are partly resorbed. The groundmass is fine and somewhat irregular in texture. In some of the rock it is made up of nearly parallel laths of plagioclase and orthoclase imbedded in a spongelike mass of quartz; single quartz individuals inclose several feldspar crystals. In some the quartz and orthoclase are in less regular areas; in some glass is present. Grains of ore are scattered through the groundmass and biotite is present in the groundmass of some of the rocks. The cavities contain some cristobalite. Some of the rocks carry little hornblende, others brown hornblende. Some have augite in the groundmass.

In addition to the light-colored dikes there are hundreds of small dikes of dark pyroxene-quartz latite and basalt and some of hornblende rocks, few of them more than 10 feet across. They show some tendency to radiate from the center but their outcrops are poor and they are not indicated on the geologic map. The pyroxene rocks are dark-gray or greenish-gray dense rocks which carry abundant tabular crystals of plagioclase and considerable augite in a microgranular groundmass. The phenocrysts are as much as 3 mm in longest dimension, and make up about a third of the rock. Those of labradorite are a little more abundant than those of augite, which in turn are in excess over hypersthene. The groundmass is made up chiefly of andesine laths, with some augite, magnetite, apatite, and biotite, and from a few percent to 30 percent of interstitial quartz and alkalic feldspar. In some the groundmass is a clouded glass. Many of the rocks are much altered with development of green chlorite, serpentine, and calcite. Quartz phenocrysts much resorbed are present in small amount in a few of the rocks. Some of the rocks are basalts and carry a more calcic feldspar, and some olivine in both phenocrysts and in the groundmass. The olivine is partly altered to serpentine with a birefringence of about 0.01, a serpentine or chloritic mineral with a birefringence of about 0.04, and a clouded, nearly isotropic material. Dikes of hornblende rock are less common. They carry about 10 percent of labradorite phenocrysts, nearly as much green hornblende, some biotite and magnetite in a fine-textured groundmass made up chiefly of felted oligoclase laths, with magnetic dust, chlorite, pale biotite, and probably some quartz and orthoclase.

MINOR INTRUSIVE DIKES OF THE DEL NORTE QUADRANGLE

Besides the dikes of latite porphyry immediately around the Summer Coon and Embargo necks there are a few dikes of similar rocks south of the Rio Grande and a great number of them to the north in the lower basin of Carnero Creek. They are of Conejos age, are much like the dikes about the Conejos necks, and their abundance in this area suggests a center in this vicinity.

The large dike in the basin of Schrader Creek, which is in the extreme western part of the Del Norte quadrangle south of the Rio Grande, is a hornblende-quartz latite. It is light drab to purple drab, has some small pores and contains abundant crystals, as long as 3 mm, of white plagioclase and hornblende. Phenocrysts make up somewhat less than half the rock and are variable in size. Labradorite is in moderate excess over deep-brown hornblende, which is more or less resorbed; augite is in minor but variable amount and hypersthene and resorbed biotite are rare. Iron ore and pleochroic apatite are accessory. The groundmass is very fine-grained to submicroscopic and contains some plagioclase laths and probably considerable orthoclase and quartz. The vesicles contain some cristobalite, also secondary carbonates and chlorite.

The small mapped body just below the forks of Los Pinos Creek is of a similar rock but the plagioclase phenocrysts are andesine labradorite, the hornblende is green, and the groundmass is microgranular quartz and orthoclase.

Several dikes, not mapped, just south of Del Norte are hornblende-pyroxene-quartz latites. They are dense, quaker-drab to black rocks which carry abundant phenocrysts of calcic andesine, somewhat fewer phenocrysts of augite and partly resorbed brown hornblende, and a few phenocrysts of hypersthene in a groundmass that is made up largely of andesine laths with some submicroscopic interstitial material. They contain less quartz and orthoclase than the rock of Schrader Creek.

THE EMBARGO INTRUSIVE CENTER

An important center of eruption is situated about 9 miles west of the Summer Coon center in the drainage basin of Embargo Creek, north of the Rio Grande and in the extreme eastern part of the Creede quadrangle. This center has much in common with the Summer Coon stock and the zones of minor intrusive bodies that surround the two stocks coalesce. The central stock of granodiorite porphyry in Embargo Creek is shown on the map, but it and the surrounding rocks are so much altered that the exact boundaries are somewhat generalized. As in the Summer Coon area, the largest, most conspicuous dikes are of quartz latite porphyry and they radiate from the center, though less strikingly so than at Summer Coon. Many smaller dikes of darker quartz latites surround the center. One irregular body of rhyolite porphyry, nearly as large as the main granodiorite porphyry, and some associated dikes of rhyolite porphyry are present a few miles south of the main stock.

The Embargo dikes cut the Conejos quartz latites but not the Alboroto rhyolite, which is observed only on the extreme borders of the center. Their close similarity to the Summer Coon, Wanamaker Creek, and other intrusive centers of Conejos age leaves little doubt of their age.

The main intrusive body is about a mile across and nearly circular in outline. The conspicuous latite porphyry dikes are especially abundant to the southeast and west of the main stock, and they are much less conspicuously radiating than are those around the Summer Coon center. The rhyolite porphyry dikes are mostly near and associated with the large body of that rock.

The rock of the stock is an augite granodiorite porphyry much like the main rock of the Summer Coon stock. The approximate mineral composition, in percent, of the typical rock is: Andesine-labradorite 60, augite 14, hypersthene 5, biotite 3, magnetite 3, orthoclase 8, and quartz 7.

Much of the stock itself and large bodies of the surrounding rocks are altered to white rocks made up in places chiefly of quartz and sericite, in others of quartz and alunite, or of quartz, sericite, and alunite. Pyrite and other sulfides are also present and in one specimen a considerable amount of zunyite in well-formed tetrahedrons as much as 2 mm across. It is isotropic and has an index of refraction of 1.588, the same as that of the original zunyite from the Zuni mine, Silverton, Colo. This is the third district from which zunyite is reported, all in the San Juan Mountains of Colorado. The zunyite is associated with mottled aggregates of sericite and large tablets of alunite and pyrite, all of which replace the feldspar phenocrysts of the original porphyry.

Many veins cut the altered rocks, and much prospecting and some mining have been done. The old mining camp around this neck, chiefly on the south and southeast part of the altered area, is called Embargo.

The quartz latite porphyry dikes are like those around the Summer Coon center and need no further description. They are in an area of considerable relief and hence form somewhat less conspicuous outcrops than do the similar dikes near Summer Coon, which are in an area of little relief. As in the Summer Coon area, many small dikes of pyroxene-quartz latite, some of basalt, and a few of hornblende-quartz latite cut the Conejos rocks for several miles around the central stock.

A large number of dikes, sills, and less regular bodies of rhyolite, like those near Summer Coon, cut the Conejos in the drainage area of Sietz Creek, both in the Creede and adjoining parts of the Del Norte quadrangles. A larger, lenslike body of similar though more coarsely crystalline rhyolite porphyry, about a mile long and 0.5 mile wide, forms a prominent hill just south of the mouth of Seitz Creek. These rocks are described on a later page.

THE RHYOLITE CENTER OF TWIN MOUNTAINS

Many dikes and less regular bodies of rhyolite, like the flows that cap Twin Mountains, which are north of the Rio Grande in the western part of the Del Norte quadrangle, cut the Conejos quartz latite in the vicinity of Twin Mountains. They are most abundant north and west of Twin Mountains. The largest dike is east of Old Womans Creek, strikes about northeast, is more than 6 miles long, and seems to be cut by the stock of the Summer Coon area, although the relation of this dike to the stock was not positively determined because of poor exposures and decomposition of the rocks. Smaller dikes are abundant in the head of Old Womans Creek and to the west. Some of the bodies in this area seem to have been irregularly intruded and in places it was difficult to distinguish between intrusive rock and flow rock. A larger, lenslike body of similar though more coarsely crystalline rhyolite porphyry, about a mile long and 0.5 mile wide forms the prominent hill just south of the mouth of Seitz Creek, in the Creede quadrangle. The flows of rhyolite in this area are of a very similar rock and are probably the extrusive equivalent of the dikes.

The rocks of the smaller bodies are rather dense, pale quaker drab or pallid brownish vinaceous, and have a dull luster and a rough fracture. They carry a very few phenocrysts, as long as 5 mm, of oligoclase-andesine, and very little biotite. Apatite and magnetic iron ore are rare accessories. The groundmass is made up largely of minute oligoclase laths and some orthoclase imbedded in a small amount of quartz. In some specimens the matrix is glass or tridymite. Rare specimens have a few pores which are lined with cristobalite. The rocks are rhyolites and are similar to the rhyolites of Twin Mountains and to the Tracy Creek quartz latite. An analysis of a specimen from the dike near Summer Coon is shown in table 21, column 19. A number of small dikes in Seitz Creek, a few miles northwest of Twin Mountain, which are not indicated on the geologic maps, are somewhat similar, but are vesicular, have a few large phenocrysts of hornblende, and carry a little more biotite, which is in the groundmass.

The large lens south of the mouth of Seitz Creek is made up of a dense, nearly white rock that carries about 10 percent of phenocrysts of calcic oligoclase as long as 3 mm, a few of biotite, and a few of quartz, all in a coarse granophyric groundmass that contains many indistinct laths of sodic plagioclase. There is a little zircon, apatite, and magnetite. Near the contact and in the dikelike apophyses, the rock contains fewer phenocrysts and the groundmass is finer grained and contains many small irregular plates of biotite.

THE GABBRO OF LA GARITA CREEK

The body of gabbro a few miles north of Summer Coon in the valley of La Garita Creek is probably also of Conejos age. The rock is dense, dark olive gray, and carries abundant tabular feldspar and seems granular in the hand specimen. It is somewhat irregularly granular and the crystals average about 0.5 mm in longest dimension. Stout, tabular crystals of labradorite make up a little more than half the rock, augite about a quarter, olivine a somewhat less amount, magnetic and orthoclase several percent each, and apatite less than 1 percent. The olivine is largely altered to serpentine.

THE ROYAL PARK INTRUSIVE CENTER

About 10 miles north of the Embargo stock in the drainage area of the south fork of Carnero Creek below Royal Park, a small volcanic stock with associated dikes is poorly exposed. It is much like the Embargo and Summer Coon stocks but on a smaller scale and has fewer associated dikes. The central intrusive rock is a granodiorite porphyry, much like that of the Wanamaker Creek stock to be described on a succeeding page. Some of the porphyritic dike rocks are much like the rock of the central stock but have more quartz and biotite, and the hypersthene and other dark minerals are mostly in the groundmass, which is granophyric. The biotite is much resorbed. Some of the dikes are pyroxene quartz latites which originally had much hornblende, now represented by skeletons of magnetite. A dike crossed by the road 100 yards north of the forks is of a rhyolite like that of the Seitz Creek area. It is red brown on the fresh fracture but weathers gray. The usual altered rock is around the central stock and some prospecting has been carried on. As elsewhere, the stock cuts the andesites of the Conejos quartz latite.

WANAMAKER CREEK CENTER

About 9 miles northwest of Embargo in the north-central part of the Creede quadrangle in the upper drainage area of Wanamaker Creek, there is another stock with associated dikes. It and the associated dikes are partly covered by Alboroto and Piedra rhyolites. The intrusive mass is certainly pre-Alboroto and is without much doubt Conejos. As usual there is much alteration and some mineralization around the stock, and the old mining camp of Wanamaker was located in this area.

The central stock, which is about a mile long and half a mile wide, is a granodiorite porphyry, much like that of Embargo and Summer Coon but carrying some biotite and considerable quartz and orthoclase. The rock is light greenish gray, granular to seriate porphyritic, and plagioclase crystals as long as 5 mm grade into the much smaller insterstitial plagioclase. The orthoclase is in large individuals which are interstitial to and surround the plagioclase and dark minerals. The quartz is partly intergrown with the orthoclase and partly in small interstitial grains. The biotite is in large individuals which mold around the plagioclase. It is partly altered to chlorite. The hypersthene is mostly altered to bastite and parts of the rock are altered to calcite, chlorite, epidote, and other minerals. The approximate composition, in percent, is: oligoclase-andesine 50, orthoclase 20, quartz 10, augite 10, hypersthene 4, biotite 4, and magnetite 2.

Near the contacts and in the dikelike apophyses the rock is porphyritic and carries about 30 percent phenocrysts of plagioclase in a very fine groundmass. A few dikes of quartz latite porphyry, like that at Summer Coon, were found.

THE SYENOGABBRO PORPHYRY OF TROUT CREEK

A large stock of somewhat different rock is cut by Trout Creek south of the Rio Grande in the extreme eastern part of the San Cristobal quadrangle. It clearly intrudes Conejos rocks but its eroded surface is in most places overlain by the younger Alboroto rhyolite. It is therefore as late as Conejos in age and younger than Alboroto. The two andesitic units with extrusive rocks of about the same composition as the intrusive and within the age limits established for the intrusive are the Conejos quartz latite and the Sheep Mountain quartz latite. Because the Conejos is well developed in this area and the Sheep Mountain is not present for many miles, the stock is believed to be of Conejos age.

The stock is exposed for a distance of 2 miles and a width of nearly a mile, and its boundaries are nearly everywhere with overlying, younger rocks. It is therefore one of the largest of the stocks of Conejos age.

Because the intruded Conejos rocks are poorly exposed around the intrusive center, few dikes are shown though they may be as abundant as around the other stocks, but covered by younger rocks.

The rock of the intrusive stock differs somewhat both in texture and composition. It is a dense, dark-gray rock containing many large tablets of feldspar in a granular groundmass, and closely resembles the dark varieties of the tabular feldspar-pyroxene-quartz latite but is coarser-grained. The coarser rock is fairly even grained, but some of the rock is porphyritic. An analysis, norm, and mode of a typical specimen are shown in table 21, column 1, in pocket.

In the hand specimen the rock is deep slate olive. The abundant plagioclase phenocrysts are tabular and as much as 15 mm long and 3 mm thick. The microscope shows that the plagioclase phenocrysts are not strongly or uniformly zoned but show patchy extinction, some recurrent zoning, and commonly have a narrow, uneven outer zone that is more sodic than the main part. Most of the grains of the groundmass are about 0.3 mm across. The groundmass plagioclase (An_{40}) crystals are nearly equant and are little zoned. The groundmass contains augite, hypersthene, orthoclase, biotite, magnetite, and a trace of quartz. The augite molds about the feldspar, the hypersthene grains are largely altered to a brownish platy material, perhaps nontronite. The orthoclase is interstitial and is in fairly large patches. The small amount of biotite grows around the magnetite. The rock is nearer to a gabbro (or basalt) than any of the Potosi volcanic series selected for analysis. It is a syenogabbro.

The proportion of constituents and the texture differs considerably. East of the knob on the 9,500-foot contour which is east of Trout Creek and at 9,200 feet altitude, a small exposure was seen of a sharp contact between two kinds of granular rock of different texture and color. The dark rock is similar to the main rock of the stock, described above, except that it has more biotite, and the phenocrysts are andesine-labradorite. The light part is 0.5 mm-grained, is hypidiomorphic granular, and is made up mostly of orthoclase, with some intergrown plagioclase, some sodic plagioclase in separate crystals, and considerable quartz and biotite, and some pyroxene. It is a quartz syenite.

The rock ranges from a syenogabbro to a quartz syenite and averages in composition a syenogabbro containing some quartz.

The rock is commonly more or less altered. The pyroxene alters to chlorite, or serpentine, or hornblende. There is commonly secondary sericite, chlorite, pyrite, and calcite, and in some places biotite, rarely piedmontite, and other minerals. Extreme alteration gives rise to sulfides, alunite, sericite, quartz, and other minerals. Some prospecting has been done in the stock.

COCHETOPA AREA

Intrusive rocks of Conejos age are not common in the Cochetopa and Saguache quadrangles. They are more abundant than usual in the Agency Peak and Razor Creek Dome areas, and centers for the eruption of Conejos rocks are believed to have been present in both of these areas. The intrusive bodies are chiefly small dikes but plugs are also present. The rocks are mostly hornblende-augite-quartz latites, but the stock of Razor Creek is a quartz-bearing augite monzonite. Their similarity to the surrounding Conejos rocks makes it seem probable that they are the intrusive equivalent of the intrusives of Conejos age. The most important areas of intrusive bodies are near the mouth of West Pass Creek, in Salt Trough Gulch, in the basins of East Razor Creek, and of Barnett and Needle Creeks.

A short distance northeast of the Flying M ranch below the mouth of West Pass Creek, there is an area in which dikes are abundant. These dikes strike in various directions but the larger ones strike east and west or northwest-southeast. They range in width from a few feet to 50 feet and in length from 100 yards to more than a mile. The rocks are hornblende-pyroxene-quartz latites. They are porphyritic and are characterized by an abundance of black, needlelike hornblende crystals, together with labradorite, augite, hypersthene, and iron ore. The groundmass is cryptocrystalline. The abundance of the dikes and their similarity to the Conejos extrusive bodies suggest the proximity of a center of eruption but no large body of intrusive rock was found.

In the large eastern fork of Salt Trough Gulch there are many dikes as long as a mile, which strike about northeast and by erosion of the surrounding softer tuffs make prominent walls from 4 to 20 feet across. Petrographically the rocks are much like those of the dikes described in the preceding paragraph, but they carry little hypersthene and some biotite.

In the drainage basins of Needle and Barnett Creeks there are many dikes, some of which are large and make prominent topographic features, such as a wall 100 feet or more in height. The dikes strike in various directions but most commonly nearly north and south. In the Barnett Creek basin several of the dikes are more than 100 feet across, are considerably brecciated, and contain many foreign inclusions near the borders. These bodies were not carefully mapped, but they appear to differ greatly in thickness and even to pinch out entirely in one place to reappear farther along the strike. The rocks range in color from pink to gray, and many of them are fluidal. They are much like the other dikes of the area described in the preceding paragraphs, but are hornblende-biotite-quartz latites and contain much biotite and only some augite. Glass is present in the groundmass of some and tridymite or chalcedony in others.

By far the largest and most significant intrusive body in the Razor Creek Dome area forms the hill immediately north of the junction of the eastern fork of Razor Creek and the north-side gulch which contains the trail to Needle Creek. The rock of this body is mostly granular but ranges from hornblende-pyroxene latite to pyroxene monzonite. The body is irregular and about half a mile across in an east-west direction. The common rock is gray, fine grained, and seriate porphyritic, with crystals from a fraction of a millimeter to 2 mm across. It is made up about half of laths of andesine-labradorite, about 7 percent of augite, a little less of altered hypersthene and biotite, and a few percent of magnetite imbedded in large individuals of orthoclase and a little quartz. Orthoclase makes up one-fifth or less of the rock and the rock is a quartz-bearing monzonite, although locally it is a granodiorite.

The rock near the contact is a porphyry with finely crystalline groundmass. It carries about 20 percent of labradorite phenocrysts and about as much hornblende, now almost completely resorbed and represented by a fine aggregate of pyroxene, magnetite, feldspar, and remnants of hornblende, with the outline of the original crystal. The rock has some biotite. The monzonite is more or less altered and secondary chlorite, calcite, epidote, sericite, and iron oxide are abundant in some parts.

A few miles to the southeast in the basin west of Spanish Creek about a mile south of the old sawmill, there is a unique, conical knoll rising about 40 feet above the base of its talus slope, and about 100 feet in diameter at its base. It is a plug of augite latite, much like the contact rock of the Razor Creek stock. It is a dense, black rock of uniform texture except for rare quartz crystals, much resorbed. The rock contains crystals as much as 0.3 mm across. It is made up of andesine-labradorite, augite, olivine, and apatite in a vague matrix of glass. Hornblende and biotite may have been present. The olivine is much altered to serpentine, and there is secondary chlorite, calcite, and ferritic material. This rock is not like any of the Conejos extrusives.

COMPARISON OF THE INTRUSIVE AND EXTRUSIVE ROCKS

The rocks of the stocks and laccoliths are similar to, but not identical with, the extrusive rocks. Rocks near gabbro are much more abundant in the intrusive bodies than in the extrusive rocks, although some of the darker varieties of the tabular feldspar-pyroxene-quartz latite probably have about the same composition and much the same habit as the syenogabbros and granogabbros. Many of the rocks of the stocks, such as the monzonites, syenites, diorites, and some of the granodiorites, have little free silica, and the extrusive rocks in the same general range are rich in free silica.

Mineralogically, pyroxene is common in the granular rocks and biotite and hornblende more abundant in similar extrusive rocks. The free silica is quartz in the intrusive rocks and more commonly tridymite or cristobalite in the extrusive rocks. Some of the intrusive rocks have very little dark mineral.

RELATION OF OUTCROPS TO TOPOGRAPHY

The greater part of the Conejos quartz latite is made up of tuff and breccia beds that are only moderately indurated but there are some bodies of hard lava flows or intrusive rocks. In general, the bodies of hard, massive rock do not occupy regular layers in the tuffs nor is there any regularity in the succession of the beds. For the most part the massive rocks form thick, lenslike, or irregular bodies that have small lateral extent. There are no widespread cliff and bench-making flows such as characterize the Treasure Mountain, Alboroto, and Piedra rhyolites of the Potosi volcanic series.

In the great cliffs at the southwestern face of the mountains extending nearly across the San Cristobal and Summitville quadrangles, the Conejos quartz latite is at the base of the volcanic section; it is made up very

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FIGURE 11.—Fourmile Creek, Pagosa quadrangle, falls 800 feet over cliffs of breccia of the Conejos quartz latite to the underlying sediments. The steep cliffs shown are about 2,000 feet high and are at the southern boundary of the volcanic rocks.

largely of tuff and breccia and is commonly from 1,000 to 3,000 feet or more thick. It forms the chief part of the great cliffs and palisades that are such striking features of this southern face, and the deep rugged canyons of the major streams. These cliffs are as high as 4,000 feet, slopes of 2,000 feet to the mile are common, and steeper cliffs 1,000 feet high are present. Canyons 1.5 miles across and 2,000 feet deep are numerous. Most of the canyons would be impassable on horseback and difficult on foot if it were not for the many trails constructed by the United States Forest Service or by prospectors. A horse can be taken to the top of the cliffs only in a few places where trails have been constructed. In many places it is difficult to scale the cliffs on foot. In this southern area there are few bodies of massive rock except at the base and top of the formation and the rocks are of fairly uniform hardness for great thicknesses. In the Summitville quadrangle massive rock is present in places in the tuff and it crops out as nearly vertical cliffs overlain by a slope gentler than the average. These tuffs, in common with the other slightly indurated tuffs, weather into striking and characteristic forms with great rounded pinnacles, and spires, and form great palisades. Large blocks of lava, perched on long slender pedestals like mushrooms on long slender stems, are common. The cliffs have few plane surfaces and they are carved by closely spaced, sharp, steep gulches showing curved faces with few sharp angles. This results in a fluted appearance or, in places, a surface simulating a pipe organ. A vertical section across the cliffs is a smooth curve flatter near the top and nearly vertical for the main cliff. A large amount of talus and wash lies at the base of the cliffs. The general form of these surfaces can be seen from the topographic maps of the San Cristobal and Summitville quadrangles.

In much of the New Mexico area the Conejos quartz latite is made up of alternating thick bodies of soft gravels and thin layers of much harder breccia and flow rock. The beds are nearly flat and the harder layers form more or less continuous cliffs and the softer gravels form gentler slopes with cliff exposures only in favorable places.

The central part of the dome in the basins of Conejos and Alamosa Creeks and north in the Rio Grande basin is an area of high mountains and deep canyons, and the Conejos quartz latite has a large amount of massive rock, mostly in very thick bodies of small horizontal extent. Intrusive stocks are also present. One great mountain will be made up mostly of massive rock, while an adjoining mountain will be mostly breccia. The result is a varied and irregular scenery and topography and on the whole less rugged than on the southern face of the mountains. Some deep canyons are cut in breccia; elsewhere the breccia shows poor outcrops and rounded, gentler slopes. Some of the thinner, more regular flows make cliffs and benches and some mesas, but such features are much less well developed than in the Treasure Mountain and Piedra rhyolites of the Potosi volcanic series. Some of the thick bodies of massive rock form great cliffs and canyons, such as that canyon cut in the pyroxene-quartz latite flows by Wightmans Fork of the Alamosa River, below the old mining camp of Summitville. In general, this central area of Conejos rocks is characterized by variable topography.

In most parts of the area to the north in the Del Norte and Saguache quadrangles, the relief in the areas of Conejos rocks is much less and the topography nearly mature. The tuff commonly shows poor outcrops with gentle slopes, while the massive rock forms the higher hills and more rugged topography.

Figure 11 shows a characteristic outcrop of Conejos quartz latite.

SOURCE OF MATERIAL

It is reasonable to expect that the chief centers of eruption for the Conejos quartz latite are in the central, thick part of the Conejos dome. This seems to be confirmed by the location of the centers of eruption that have been found. The volcanic necks and the associated intrusive bodies of Summitville, Cat Creek, Summer Coon, Embargo, Trout Creek, and Wanamaker Creek were no doubt among the chief volcanic centers, but the Rio Blanco area, the Royal Park area, the Montezuma Peak area, and centers covered by later rocks may have extruded much material. In addition, there must have been many local centers for some of the less common rocks, such as the rhyolites. Probably most of the rocks of this sort are very near their source. Centers for the rhyolite must have been near the breccia deposits of this rock in the area at the head of Carnero Creek and near the head of Cat Creek. New Mexico was probably a source for the basal rhyolite gravel of this area. Several sources for the light-colored latites must have been in the corner of the Conejos, Summitville, Creede, and Del Norte quadrangles and elsewhere.

TREASURE MOUNTAIN RHYOLITE

DISTRIBUTION, THICKNESS, AND VOLUME

The Treasure Mountain rhyolite is one of the most widely distributed volcanic formations of the San Juan Mountains. It has been mapped from a point somewhat northwest of Ruffner Mountain in the northeastern part of the Telluride quadrangle to, and a little beyond, the southeastern part of the Conejos quadrangle—a distance of about 120 miles. This extent is exceeded only by the Hinsdale, Conejos, and Alboroto formations. The outcrops are mostly of only moderate size, except for those on the eastern flanks of the range just west of the San Luis Valley. It therefore does not underlie so great an area as some of the other formations.

Its most northeasterly known extent is in the Saguache quadrangle where it is mapped only in the southern part, although it is present to the north in the area mapped as undifferentiated volcanics. To the south it pinches out rapidly. Farther south it is again present in the drainage area of the Rio Grande about South Fork, and to the south along the east flanks of the mountains it covers a large area extending for about 10 miles south of the State line into New Mexico. Along the southwest face of the mountains it is present as a relatively narrow band in the northern part of the Summitville quadrangle and in the Pagosa Springs quadrangle. It is absent in the extreme southeastern part of the San Cristobal quadrangle, but again appears in the drainage basin of Huerto Creek and continues northwest to the head of Weminuche Creek. Farther northwest it underlies a large area in the western part of the San Cristobal quadrangle and adjoining parts of the Needle Mountains and Silverton quadrangles, chiefly in the upper basin of the Rio Grande. Still farther west it caps many of the high mountains in the eastern part of the Telluride quadrangle and adjoining areas.

The formation originally accumulated in two large and one or more small volcanic domes, the largest of which centered in the northwestern part of the Conejos quadrangle, a smaller one centered to the west near the southeastern corner of the Silverton quadrangle, and a small dome centered south of the center of the Saguache quadrangle.

The approximate form and size of the Treasure Mountain domes at the end of Treasure Mountain time can be determined with reasonable assurance. Erosion between Treasure Mountain and Sheep Mountain eruptions was so slight that where Sheep Mountain quartz latite overlies the Treasure Mountain rhyolite, there is little difficulty. Even where the Alboroto rhyolite or later formations of the Potosi volcanic series overlie the Treasure Mountain, there was not a long enough interval of erosion to do more than deeply dissect the domes. However, where the rocks of the Hinsdale formation directly overlie the Treasure Mountain rhyolite, the two are separated by an interval long enough to develop the San Juan peneplain, and it is difficult to reconstruct the Treasure Mountain domes. This is true for much of the dome in the Conejos quadrangle and adjoining areas. Even for this dome, the Sheep Mountain is present on the east flank and the Alboroto on the north. The regular succession of the flows and the fact that the upper surface seems to parallel the flows give some basis for believing that not much of the dome has been removed by erosion, but any estimate of its height and volume is a minimum one.

By far the greatest of the domes was in the southeastern part of the area included on the map (pl. 1). It covered nearly or quite all of the Conejos quadrangle, extended for about 10 miles into New Mexico, and for an unknown but probably short distance to the east of the Conejos quadrangle. It covered most of the southwestern quarter of the Del Norte quadrangle, more than the northeastern half of the Summitville quadrangle, the northeastern corner of the Pagosa quadrangle, and most of the southern half of the Creede quadrangle. It will be referred to as the Conejos dome. It was probably more than 65 miles across and had a maximum thickness of at least 1,500 feet. The thickness was probably not much more than this, as the Summit peneplain is sensibly parallel to the flows and seems not to bevel them as it would if much of the crest had been removed. It was thus a very gentle, broad dome or plateau with an average slope of only about 50 feet to the mile. The material erupted from this vent had a volume of about 400 cubic miles or more.

The form of the dome indicates the center must have been in the northwestern part of the Conejos quadrangle. However, no large-sized rhyolitic intrusive bodies or other evidence of proximity to a volcanic vent have been found in this area. Nor is there any evidence that a number of smaller vents were the source of this great dome.

To the west, north of the Conejos dome and separated from it by only a few miles, is the next largest dome. It covered most of the San Cristobal quadrangle, except the extreme northern and extreme eastern parts and it extended to the west across the Silverton quadrangle. It is called the San Cristobal dome. It was about 40 miles across and had a maximum thickness of 2,000 feet. It covered an area of 1,200 square miles and had a volume of 200 cubic miles. Its center was near the west border and the north-south center of the San Cristobal quadrangle. No large intrusive bodies or other evidence of a center for rhyolitic eruptions were found in this area.

Another dome lies chiefly in the southern half of the Saguache quadrangle and will be called the Saguache dome. It was about 20 miles long in a north-south direction, and somewhat narrower. It covered an area of about 150 square miles. Somewhat isolated bodies of this rock were found farther north and west and are believed to occupy local basins. These rocks are only a few hundred feet thick and the total volume is only a few cubic miles.

In table 20 are assembled the data for the size of the different domes. It must be remembered that these dimensions are only approximate.

TABLE 20.—*Approximate size of the volcanic domes of the Treasure Mountain rhyolite*

Dome	*Diameter of base (miles)*	*Area of base (square miles)*	*Height (feet)*	*Volume (cubic miles)*
Conejos	65	3, 200	1, 500	400
San Cristobal	40	1, 200	2, 000	200
Saguache	20 x 10	150	300	5
Total		4, 550	------	605

OUTCROPS, EROSION, AND SCENERY

In color the outcrops are light, nearly white to pale reddish for the rhyolite tuffs, darker-red-brown for most of the flows, and gray to dark gray for the quartz latite layers. Broken cliff outcrops are common, with benches or mesas at the top of some flows and welded tuffs. The flows are hard rocks with only moderate fluidal banding and vertical sheeting, and they form good cliffs. The tuff layers are poorly bedded, thick, and relatively soft; they show steep slopes, in places with fluted or badland forms; elsewhere they form gentle soil- or talus-covered slopes. In La Jara Creek and its tributaries, and elsewhere, the Treasure Mountain rhyolite forms the walls of the deep narrow canyons.

GENERAL DESCRIPTION

The Treasure Mountain rhyolite is made up in most places of a series of alternating flows, welded tuffs, and tuff beds of rhyolite and rhyolitic quartz latite. Tuff probably makes up more than half of the material in most sections. Generally the flows and welded tuffs are 100 feet or less in thickness but some are as much as 200 or 300 feet, and the tuff layers are locally somewhat thicker. The broken cliff exposures along canyon walls, such as those on both sides of the Conejos River, appear as regular layers of hard flow rock and softer tuff beds simulating alternating beds of sandstone and shale. Even some dark layers in the tuff seem to be widespread and regularly bedded. However, a comparison of detailed sections not many miles apart seems to show some irregularity in the succession (see fig. 12).

Most of the thick regular lava flows and welded tuffs are of a remarkably uniform character throughout the Treasure Mountain rhyolite, from Potosi Peak to the slopes west of the San Luis Valley, and from the top to the bottom of the section. They are biotite-augite-tridymite rhyolitic quartz latite which megascopically closely resembles the typical rhyolitic quartz latite of the Alboroto, but carry somewhat different phenocrysts. Most of these rocks are dense, nearly white, pink, or red-brown, and they consist of about a third phenocrysts, mostly from 1 to 3 mm long, in a groundmass

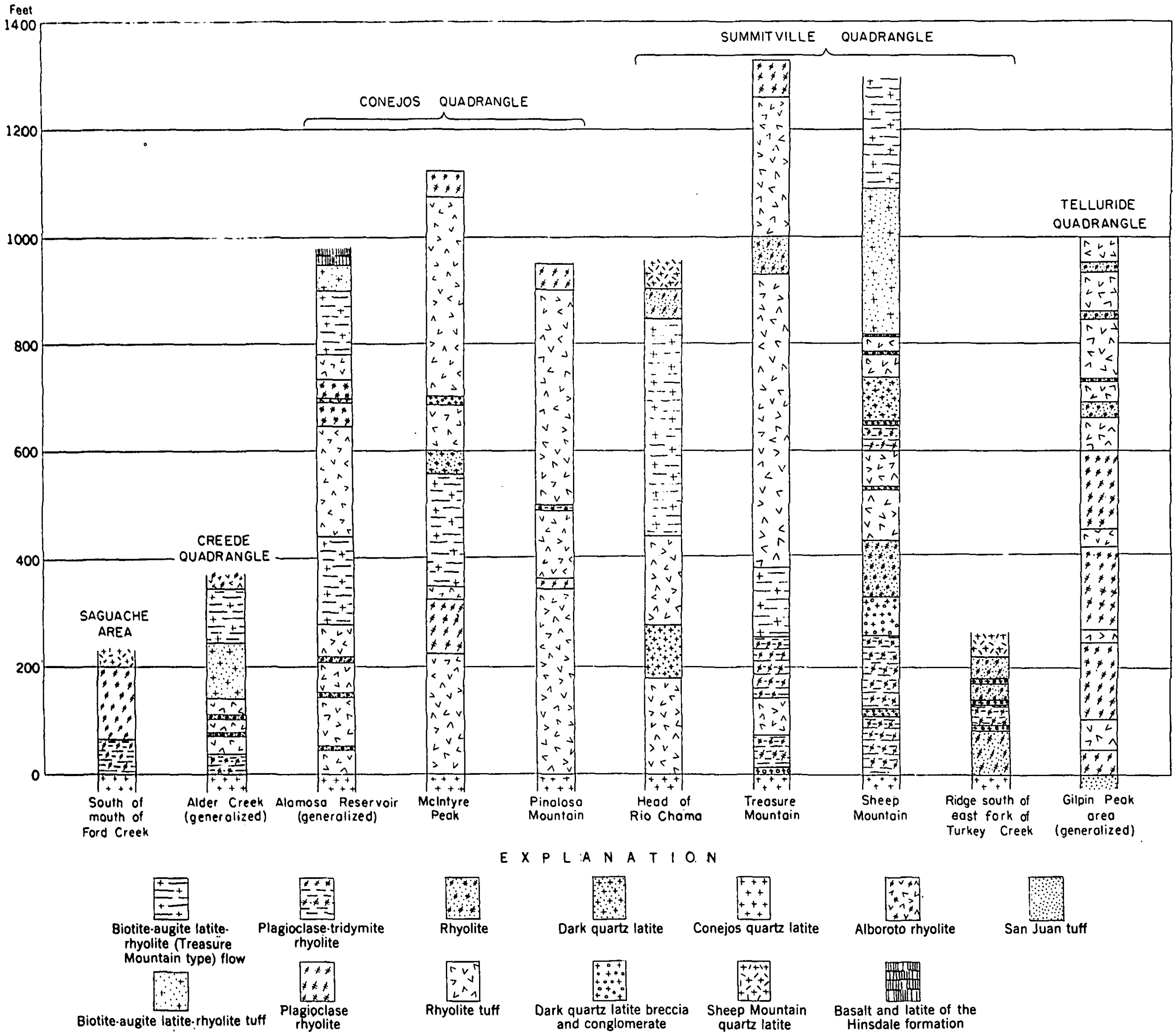

FIGURE 12.—Comparative sections of the Treasure Mountain rhyolite. The sections are somewhat generalized.

that is distinctly fluidal. The chief phenocrysts are white andesine; some are black, glistening biotite, and inconspicuous green augite. Phenocrysts of orthoclase are present in some of the rocks but are rarely abundant, and quartz and hornblende phenocrysts are rare. Some of the rocks contain a few inclusions and some have white, porous blotches.

Most of the other flows of the Treasure Mountain rhyolite differ from those just described chiefly in that they have fewer phenocrysts, more orthoclase, a more sodic plagioclase, and little or no augite. Every gradation from the rock described above to biotite-tridymite rhyolites containing few phenocrysts are present. For the most part the rhyolites are more porous and more distinctly fluidal than the rhyolitic latites. Glassy zones are common at the base of the flows and inclusions are abundant in some of the flows. An uncertain amount of the material called flows may be welded tuffs.

In the Rio Grande drainage area in the western part of the San Cristobal quadrangle a very thick flow of cavernous plagioclase rhyolite forms nearly all the thick section.

The tuffs are for the most part in thick layers with little bedding. They are consolidated to rather coherent rock. The most common rock consists mostly of fragments of pumice with some finer material and, in places, some fragments of denser rhyolite and rhyolitic quartz latite and rare dark quartz latite. The fragments are seldom more than an inch or two across. Locally the tuffs are fine ash and are then likely to be thinner bedded. Some of the more indurated and welded tuffs are difficult to distinguish from the flows. In the Conejos River basin, layers of the tuff, which are as thick as 25 feet, carry a large amount of fragments of a black, highly vesicular quartz latite glass. These layers are continuous for miles and no doubt represent local pyroclastic eruptions of the dark rock during the period of rhyolite tuff eruption. A flow of a similar dark rock was found in the McIntyre Peak section. In the northwestern part of the Summitville quadrangle several layers of dark quartz latite conglomerate are present in the tuffs or between rhyolitic flows. Some floes and pyroclastic beds of pyroxene-quartz latites are also present in the section of this area, as shown by the sections of figure 12. Dark rocks are present in the Treasure Mountain rhyolite in the southern part of the San Cristobal quadrangle and in the Ute Creek drainage of that quadrangle. They are also present farther west. Most of the dark rocks are similar to the tabular-feldspar-pyroxene-quartz latite. The dark flow under McIntyre Peak is a black, basaltic-looking rock.

The general and variable character of the formation is shown by the sections in figure 12. In comparing the sections it must be remembered that none of them was from cliffs with perfect exposures; some were made hastily and some were pieced together from discontinuous exposures or from general descriptions. It is clear that sections, even though separated by no great distance, differ considerably in detail, but they all show a succession of flows and tuffs of very similar character.

DESCRIPTION OF THE AREAS

NEW MEXICO AREA

The Treasure Mountain rhyolite in the head of Antone Creek, that to the north near Sublette, and that in the drainage area of the upper Brazos River is in part tuff with more or less pebbles, and in part flows or welded tuffs. At the base of the formation in the gulch below Sublette, there are about 25 feet of gravel made up of pebbles of dark quartz latites and over this there are about 15 feet of rhyolite tuff and then 25 to 50 feet of rhyolitic welded tuff. Some gravel lies between this and the andesite and latite of the Hinsdale formation. In the head of Nutritus Creek to the south there is much more rhyolite tuff. The same tuffaceous rhyolite extends to the west and is found in several places on the upper Brazos River. The pebbles are mainly light-colored rhyolites and light-colored quartz latites with large phenocrysts. The welded tuff is widely distributed and is a pale brownish-pink to pale pinkish-gray, rather dense biotite-augite-tridymite rhyolite.

SOUTHEASTERN AREA

The Treasure Mountain rhyolite of that great area west of the San Luis Valley from the Rio Grande to the New Mexico line and west into the drainage basin of the Chama River are remarkably uniform in their general character though they differ in detail from place to place. As shown by some typical sections in figure 12, the formation is made up of alternating tuffs, flows, and an uncertain amount of welded tuff. The chief flows are of the biotite-augite-tridymite rhyolitic quartz latite.

LOWER RIO GRANDE DRAINAGE BASIN

In the lower Rio Grande area, in the Creede and adjoining parts of the Del Norte quadrangle, the most complete and representative section available is that in Alder Creek basin. The lowest part of the Treasure Mountain rhyolite present only locally, is a fine-grained rhyolitic flow breccia containing many fragments of dark quartz latite. Over this, and more widely distributed, usually about 100 feet in thickness, there are white, finely porous rocks with characteristic subconchoidal fracture. They range in composition from a rhyolite flow or welded tuff to an indurated rhyolitic tuff. The rhyolite flow (or welded tuff) is a light-gray rock made up mostly of groundmass of submicroscopic texture but carrying some poorly-formed phenocrysts, mostly less than 0.5 mm across, of oligoclase-andesine, quartz, and biotite, rare augite (?), and iron oxide. Patches of tridymite and inclusions of dark quartz latites are present. The associated tuffs are thin bedded, of very fine texture, indurated, but porous, and are made up mostly of glass, but carry abundant fragments of plagioclase, biotite, and augite as well as some of dark quartz latite. In Beaver and Race Creeks similar rocks are present and are characterized by lenses of black glass. Epidote and chlorite are common alteration products. Above this rhyolite and tuff horizon there are several hundred feet of the Treasure Mountain type of rhyolitic quartz latite. The lower hundred feet of this is a porous yellow tuff with subangular fragments of dark quartz latite as much as 0.75 inch across. Above the tuff is a flow of similar rock. This section, much generalized, is shown in figure 12. In many parts of the area the formation is thinner and the upper part is made up of alternating flows and tuffs of rhyolitic latite.

NORTHWESTERN PART OF THE SUMMITVILLE QUADRANGLE

In the northwestern part of the Summitville quadrangle, chiefly in the drainage basin of the San Juan River, about 2,100 feet of Treasure Mountain rhyolite lies between the Conejos and the Sheep Mountain quartz latite. It becomes rapidly thinner to the northwest and pinches out before the San Cristobal quadrangle is reached. Three sections of the formation in this area are shown in figure 12. The sections under Treasure Mountain and under Sheep Mountain are only 5 miles apart, yet they show considerable difference. The lower 200 feet of the two sections are much alike but above that there is more dark quartz latite and more flow rock in the Sheep Mountain section. In comparing the two sections it must be remembered that it is difficult to distinguish some of the indurated tuffs from some of the flow breccias, and that some of the rhyolite is not very different from the rhyolitic quartz latite. The rocks are mostly much like those to the east and are typical Treasure Mountain rocks. The two flows at the base of the sections are fluidal rocks with porous streaks and lenses. They contain about 25 percent of phenocrysts of oligoclase-andesine, and biotite and rare hornblende in a groundmass that is submicroscopic in the dense parts but is coarsely crystalline, spongelike, or spherulitic orthoclase and tridymite in the porous lenses. Quartz may also be present. Inclusions of dark rocks are common in the lowest flow. The dark quartz latites of the sections are of the tabular feldspar-pyroxene type.

The rocks of the Summit Peak area are mostly the Treasure Mountain type of latite, though some specimens carry phenocrysts of quartz and orthoclase. On the ridge south of the east fork of Turkey Creek the formation is only 300 feet thick and is made up mostly of the rhyolites; in Turkey Creek the formation is much thicker and the exposures are mostly of the rhyolitic quartz latite.

SOUTHERN PART OF THE SAN CRISTOBAL QUADRANGLE

East of Weminuche Creek and extending northwest into the basin of Pine River and east as far as Huerto Creek a body of Treasure Mountain rhyolite overlies the Conejos quartz latite and is overlain by the Alboroto rhyolite. East of Weminuche Creek the Treasure Mountain is approximately 500 feet thick; under Saddle Mountain it is about 1,000 feet thick, and only a few miles to the east on the opposite side of Huerto Creek it is entirely absent.

The rocks of this area are much like those of the Treasure Mountain rhyolite in the Rio Grande drainage area to the northwest, but the formation as a whole and the individual layers are thinner. The rocks are in considerable part tridymite rhyolite and plagioclase-tridymite rhyolite; many of them have fluidal texture and large irregular gas cavities. Latites of the usual kind are also present. A flow of tabular feldspar-pyroxene-quartz latite which wedges out to the west is present under Saddle Mountain, while to the east the underlying rhyolitic quartz latite flows wedge out and the dark rock merges with those of the Conejos quartz latite. Farther northeast, west of Huerto Creek, another dark rock comes in but this overlies two flows of rhyolite similar to those over the dark quartz latite to the southwest, and the northern dark rock is believed to be at a higher horizon in the Treasure Mountain than the southern.

UPPER RIO GRANDE AREA

In the Upper Rio Grande area, chiefly in the San Cristobal quadrangle but extending into the Silverton and Needle Mountains quadrangles, the Treasure Mountain rhyolite occupies much of the drainage area of Ute Creek, most of the slopes of Pole Creek Mountain, and much of the drainage area of Pole Creek, and extends a little north of the Continental Divide into the drainage area of the Lake Fork of the Gunnison River.

The Treasure Mountain rhyolite differs greatly in thickness. South of Pole Creek Mountain more than 2,000 feet of these rocks are exposed, while only a few miles to the east, near the forks of Lost Trail Creek, they wedge out entirely. Throughout this area one comparatively thin flow underlies the Sheep Mountain quartz latite, and the rapid increase in thickness of the whole section to the west is caused by other successively lower flows abutting against the older rocks. It seems highly probable that the rather steep dip of the base of the Sheep Mountain is due to tilting, and that the Treasure Mountain was deposited against a westward sloping mountain which has since been tilted in such a way as to make its surface nearly flat.

In general, the layers are comparatively thin and seem to be fairly regular, but in the upper drainage area of the Rio Grande there are some thick flows. Commonly the rocks are reddish brown or brick red but some are almost pure white. Some of the rocks are porous, some are cavernous, and a few are dense. Nearly all show fluidal banding. Plagioclase-tridymite rhyolite and related tridymite rhyolitic latites are the most abundant rocks, but tridymite rhyolites and, rarely, quartz-rich rhyolites are present. Rarely the latites carry some augite and are then similar to the tridymite rhyolitic quartz latite of the Piedra rhyolite. Zones of black glass are common at the base of the flows.

Rhyolites with little or no tridymite are not uncommon. On the ridge a few miles south of Wolf Mountain there is a fluidal rhyolite with a distinct, thin platy structure, and abundant large flattened spherulites and lithyophysae lined with drusy quartz crystals. It is overlain by a considerable thickness of glass made up of alternate thin bands, white, yellow, and olive green in color. Rhyolites with little or no tridymite are present in many other places.

The cavernous rhyolite forms the middle flow of the section west of Lost Lakes. A flow of dense rock of similar character immediately underlies the Sheep Mountain from Lost Trail Creek to Pole Creek Mountain, and similar rocks were found at the base of the Treasure Mountain east of Weminuche Creek. They are no doubt present at many other places.

Rhyolitic latites, much like the Treasure Mountain type but with more phenocrysts of orthoclase and rare quartz and augite, are present at the base of the Treasure Mountain between Cataract and Mill Gulches and in the lower part of the section of lower Pole Creek. They are present higher in the section on the peak about a mile and a half west of south of Wolf Mountain. A considerable thickness of these rocks is present over the dark quartz latite at the head of Ute Creek.

The dark quartz latite at the head of Ute Creek in large part lies directly on the pre-Cambrian rocks but locally rests on rhyolites of the Treasure Mountain. Its position in the section as a part of the Treasure Mountain is therefore established. It is made up in large part of breccia but contains some flows. The fragments in the breccia are of many types of hornblende-quartz latite, pyroxene-quartz latite, and black basaltic quartz latites; pebbles of quartzite and granite are found near the base. The fragments are somewhat rounded and are imbedded in an abundant, soft, sandy matrix.

The flows are more nearly alike and are chiefly the dark, olivine-bearing, tabular feldspar-pyroxene-quartz latite. A flow over the small outcrop of syenite in the north fork of Ute Creek differs somewhat from the other flows in that it lacks olivine and has some determinable quartz in the groundmass.

WESTERN AREA

Remnants of Treasure Mountain rhyolite cap some of the ridges in the Telluride quadrangle and in adjoining parts of the Silverton, Montrose, and Ouray quadrangles, and they probably at one time covered most if not all of these quadrangles and extended for an unknown distance north, south, and west. If they ever covered the northeastern part of the Silverton quadrangle or the eastern part of the Ouray quadrangle they were removed by erosion before the Alboroto rhyolite were extruded, as in that area the Alboroto rocks lie directly on the San Juan tuff. The separation of the latites of the Treasure Mountain and Alboroto of this western area is believed to be essentially correct although the evidence is chiefly petrographic and neither formation is entirely characteristic in this area.

The rocks of this western area are similar to those to the east, at the head of the Rio Grande Valley, although the cavernous rhyolite, which makes up so much of the formation in the latter area is much less abundant, and a rhyolitic latite with abundant phenocrysts is more abundant. The rocks are much altered, the plagioclase is albitized, and there is much secondary calcite, sericite, and chlorite. Throughout the area there are three divisions in the Treasure Mountain rhyolite. The lower division is seldom more than 100 feet thick and is made up of alternating thin flows and flow breccia and beds of gravellike tuff. The flows are pinkish, have a marked fluidal texture, carry more or less included fragments, and grade into the flow breccias. They carry abundant phenocrysts of andesine and orthoclase in nearly equal amounts and some of biotite in a fine-grained groundmass made up of quartz and orthoclase. The tuff is poorly consolidated and consists of more or less rounded fragments of rhyolitic latite, mostly from 1 to 6 inches in diameter, and some of dark rocks in a fine matrix of similar material. The layers are from 1 to 5 feet thick.

The middle part is made up of a few massive flows of rhyolitic latite each from 100 to 200 feet thick and aggregating as much as 500 feet or more, and separated by tuff or dark quartz latite. The rocks resemble the Treasure Mountain type of latite but are too much altered for a detailed comparison. Any augite that may have been present is now completely gone.

The upper part, which is about 400 feet thick on Whitehouse Mountain in the Ouray quadrangle, is made up of thinner flows with tuff layers here and there. The rocks are mostly rhyolitic latites, but the massive flow near the middle is less siliceous, and the flow that caps Whitehouse Mountain is a rhyolite with some plagioclase and much orthoclase and quartz. All the flows carry inclusions of dark rocks and of rhyolite.

AREAS OF THE COCHETOPA AND SAGUACHE QUADRANGLES AND NORTHERN PART OF THE DEL NORTE QUADRANGLE

On both sides of Saguache River below the mouth of Middle Creek, several hundred feet of rhyolites believed to belong to the Treasure Mountain rhyolite, overlie the Conejos quartz latite and underlie a variable thickness of dark quartz latites that are believed to be of Sheep Mountain age. These are in turn overlain by Alboroto rocks. To the south the Treasure Mountain becomes thin and pinches out in the basin at the head of Tracy Creek. A small outcrop of similar rocks in the head of Saw Log Creek is believed to be an outlier. To the north and west this formation covers considerable areas but, as no base map was available at the time of the study of this area, the rocks were not everywhere separately mapped.

The rocks are chiefly rhyolite, with a few phenocrysts of biotite and plagioclase, grading in one direction into rhyolitic latites and in the other into rhyolites. Typical rhyolitic latite of the Treasure Mountain was not found, though some of the layers are not very different. A good section from the steep slopes south of the mouth of Ford Creek is shown in figure 12. The lowest flow is about one-third phenocrysts, chiefly of andesine with less of quartz, biotite, augite, and orthoclase. Overlying this is a porous tridymite rhyolitic latite with 25 percent of phenocrysts, and abundant glassy orthoclase. This is overlain by a red-brown welded tuff which carries about 15 percent of phenocrysts of orthoclase and oligoclase in a glassy groundmass.

In the area north of the Saguache River, where the volcanic rocks have not been subdivided, the Treasure Mountain rhyolite seems to be rather widely distributed although it is irregular in thickness, is not everywhere present, and seems to have filled in local basins. It was recognized at a number of places in the upper drainage basin of Indian Creek. In the drainage area of Big Bend Creek and in that of the Bald Mountain fork of Long Branch a quartz-biotite rhyolitic latite separates the Conejos and Sheep Mountain quartz latites, but in the main fork of Long Branch it appears to be absent. In the drainage area of Big Bend Creek a similar rock is underlain by a rhyolite breccia.

The rock in the Bald Mountain fork of Long Branch varies from a light to dark purplish-pink, commonly breaks easily and with uneven fracture, and is frequently cavernous on weathered surfaces. It has a fluidal texture and carries abundant phenocrysts of feldspar, quartz, and biotite. Rocks resembling this type occur in Big Bend Gulch and in parts of the Middle and Jacks Creeks basins.

Another type of marked characteristics occurs in Wolverine and Slane Gulches. It is gray and distinctly porphyritic, and the microscope shows its phenocrysts of quartz and oligoclase to be very much broken and its biotite tablets twisted or bent; the groundmass exhibits pronounced fluidal texture. No orthoclase phenocrysts have been observed in this rock. The groundmass is submicroscopic and, by reason of the low iron content, it is not so much obscured by ferritic or trichitic particles as is common in other types. This variety of rhyolitic latite occurs also near Tomichi Creek east of Cochetopa Creek and about 5 miles south of Cochetopa Dome in and near Rock Creek.

Rocks believed to belong to the Treasure Mountain but differing decidedly in texture from the types above described occur on the slopes of Antora Peak. They have abundant phenocrysts, are commonly dark gray or reddish, and the groundmass is commonly dark brown or reddish with many trichites and indistinct ferritic particles, emphasizing the streaks of light and dark brown. Some are dense and others variably porous. The phenocrysts are about the same as in other types.

The bare shoulder (above timber line) south of the Indian Creek-Bonanza trail and about 4 miles S. 4° E. of Antora Peak, is made of a fluidal platy biotite rhyolite, with pink felsitic groundmass. The flow or welded tuff is 40 feet thick and is underlain by a soft, poorly exposed breccia in which a number of loose pebbles of pre-Cambrian schist were found. Exposures of this type of rock occur definitely under westward-dipping hornblende-biotite rhyolitic latite, 1 mile south of this point. It is also seen in several places on the slopes at the head of the Indian Creek basin, in small thin patches resting on a very steep surface. Very similar rock occurs on a ridge at 13,000 feet altitude (by barometric measurement), running southwest from Antora Peak, upon which is a knob of altered quartz latite resembling some Conejos rocks. It is possible that a more detailed study of this locality would show that this is another example of the irregular surface upon which the Treasure Mountain rocks were extruded. From the neighborhood of the saddle through which the Indian Creek-Bonanza trail passes northward beyond Antora Peak, the ridges and heights are in large part made of a light-colored, fluidal, and frequently platy rhyolitic latite or rhyolite. Indeed it is not improbable that Sheep Mountain is also capped with this material. This rock breaks easily and produces great quantities of debris, so that the mountains, particularly from the west and north, seem to be made entirely of it. However, examination south of Antora Peak showed the flow to be relatively thin and to rest on an uneven, undulating surface which has a general structure away from Antora Peak. As a rule this rock is easily recognized by its light-colored fluidal texture and platy structure. Occasionally it has a pinkish tone and breaks with a more irregular fracture. Near the base of the layer it contains a considerable quantity of foreign fragments. The rock is usually more or less altered and consists of subhedral phenocrysts of quartz, orthoclase, soda-plagioclase, and biotite (altering to chlorite) in submicroscopic groundmass. It contains considerable calcite and an unusual number of fine grains of zircon. The stratigraphic position of this member is not understood further than that it overlies, with marked unconformity, the dark quartz latite porphyry of the east side of Antora Peak, and it resembles in many respects the rhyolitic latite of the Treasure Mountain described in the preceding paragraph.

The small body in Saw Log Creek is made up of several thin flows. A flow of tridymite rhyolite is pale quaker drab and is made up of spherulites as much as several millimeters in diameter and has lithophysal cavities. Some of the spherulites consist of concentric, onionlike shells, and the layers are separated by connected cavities. All the cavities are coated with a layer of white tridymite, as thick as a half a millimeter, and also with drusy, hexagonal plates of tridymite. The rock carries a very few crystals of orthoclase and biotite. Under the microscope the large spherulites are seen to be made up of a complex of smaller spherulitic growths. Tridymite forms about a quarter of the rock.

Another specimen from Saw Log Creek is a purple-drab rhyolitic latite that is made up of abundant phenocrysts as much as 2 mm in longest dimension, chiefly andesine with considerably less quartz and a little orthoclase, biotite, and brown hornblende. The chief accessory is sphene, and there is some apatite, iron ore, and zircon. The groundmass is clouded and very finely crystalline.

CONDITIONS OF ACCUMULATION

The Treasure Mountain domes were broad and had gentle slopes and, for the most part, the individual layers of flow rock or tuff were rather thin, regular, and widely distributed so that a section across the domes resembles a section across a group of sedimentary rocks. Indeed, most of the domes, particularly the one in the Conejos area, were so broad and low that they might properly be called plateaus.

In spite of the extensive erosion that has cut many deep canyons through the Treasure Mountain rocks, no centers of eruption for these rocks have been found, no craters have been recognized, and no extensive intrusive bodies of Treasure Mountain age or other evidence of the exact vents has been found. It seems highly probable that if there had been many vents or even if there had been a few large vents with large craters, and large or complex throats, some evidence of them would be exposed. The evidence indicates a few vents with relatively small throats and little intrusive rock, though great quantities of rock were erupted. This view is in harmony with the regularity and thinness of the flows and tuff layers, and the fine even texture of most of the tuff, indicating quiet eruptions of fluid lava or regular throwing out of small fragments, mostly of pumice, and occasional great eruptions of gas-charged fragmental material to yield the welded tuffs.

The presence in the tuff layers of several widespread thin layers of dark pyroxene-quartz latite or basaltic rocks, partly as beds of well-rounded pebbles, partly as pyroclastic material, and partly as flow rock, is difficult to explain. Differentiation within the volcanic vent seems highly improbable. The local eruption of an andesitic magma, probably from a separate vent and from a different deep magma chamber, seems to be the best explanation. The problem of the alternation of rhyolitic and andesitic rocks is discussed in another part of this report. It is believed that separate vents existed for rhyolitic and quartz latite rocks and that through one of the Conejos vents there was faint activity into Treasure Mountain time.

SHEEP MOUNTAIN QUARTZ LATITE

NAME AND DEFINITION

In the list of provisional and field names for the formations of the Summitville quadrangle furnished by the authors to Patton and published by him (1917, p. 20), the dark quartz latite unit between the Treasure Mountain and Alboroto rhyolites was called the Summitville andesite, and the great flows of quartz latite (called andesite) around the old mining camp of Summitville were believed to occupy this position in the section and to be a part of the quartz latites a few miles to the west under Sheep Mountain and called in the field the Sheep Mountain andesite. A more thorough study of the rocks of the Summitville quadrangle and adjoining areas, and of their relations to each other, has shown that the great flows of quartz latite near Summitville (to which the name Summitville andesite was applied), as well as the rhyolitic rocks underlying them and originally believed to belong to the Treasure Mountain, belong to the Conejos quartz latite. The name Summitville andesite was also used by Emmons and Larsen (1923, p. 12) and by Knowlton (1923, p. 184) for the quartz latites that lie between the Treasure Mountain and Alboroto. Because the quartz latites near Summitville at first placed in this position in the section have been found to lie below the Treasure Mountain and to belong to the Conejos, the name Summitville is not appropriate for the dark rocks that lie between the Treasure Mountain and Alboroto rhyolites, and it has been proposed that the name Sheep Mountain quartz latite be used for this formation because of its development under Sheep Mountain in the northwestern part of the Summitville quadrangle. The whole Potosi section and the relation of the Sheep Mountain quartz latite to the other formations is very well shown in the cliff exposures under and near Sheep Mountain. The name Sheep Mountain quartz latite will therefore be applied to that unit of dark quartz latites belonging to the Potosi volcanic series and normally lying between the Treasure Mountain and Alboroto rhyolites.

The Sheep Mountain quartz latite overlies the Treasure Mountain rocks rather regularly but it is overlain rather irregularly by the Alboroto rhyolite. This indicates a short period of erosion between the eruptions of the Sheep Mountain rocks and the Alboroto rhyolite.

DISTRIBUTION AND THICKNESS

The Sheep Mountain quartz latite is present in three widely separated districts. The rocks of each district are clearly closely related and have many features in common, but the rocks of one district differ appreciably from those of the other districts. They clearly represent rocks from three distinct volcanoes or groups of volcanoes.

The most westerly body is in the west-central part of the San Cristobal quadrangle, mostly in the basin of Lost Trail Creek. Its base dips at a considerable angle to the east but it overlies the Treasure Mountain rhyolite regularly and without erosion, for the underlying Treasure Mountain flows dip, as does the base of the Sheep Mountain. This body was erupted from a center in the drainage area of Lost Trail Creek and it lenses out rapidly to the south and east and probably in other directions, although it is limited on the west and north by erosion. The maximum distance across the outcrops is about 10 miles and it is believed never to have had a much wider distribution. It occupies an area of about 30 square miles and originally covered an area of about 80 square miles. Its maximum thickness is about 2,000 feet. It had a volume of about 12 cubic miles.

Some miles to the southeast, in the northwestern part of the Summitville quadrangle and adjoining parts of the Creede and Pagosa Springs quadrangles, there is another body of Sheep Mountain rocks. It crops out in the cliffs along the south face of the mountains through a distance of about 10 miles. To the east it wedges out and to the west it is cut out by the Alboroto in the Pagosa Springs quadrangle. To the south the volcanic rocks have been removed by erosion and to the southeast an outlier of the Sheep Mountain is present at the head of the Chama River. To the north it is probably present under the Alboroto rhyolite for only a short distance, as it has not been found in the canyons to the north of the divide. Much of it may have been removed by erosion, but an estimate of the total area of the dome is 50 square miles, and its volume 3 cubic miles. This Sheep Mountain quartz latite was deposited on a level surface of Treasure Mountain rhyolite but is overlain rather irregularly by the Alboroto rhyolite. Its thickness is fairly uniform from place to place, and it is probably in most places about 500 feet. It is about 800 feet under Sheep Mountain and may be even thicker east of Turkey Creek.

The largest areas underlain by the Sheep Mountain quartz latite are in the northeastern part of the San Juan Mountains scattered over an area about 60 miles in extent in a north and south direction and 20 miles or more in an east-west direction. They lie mostly in the Del Norte and Saguache quadrangles but partly in the eastern part of the Creede and Cochetopa quadrangles. These rocks in most places overlie the Conejos or older formations with extreme irregularity but in the northern part of the Del Norte quadrangle and adjoining parts of the Saguache quadrangle they overlie the Treasure Mountain rhyolite with little irregularity. The different outcrops are separated by no great distance and the rocks of the whole region have much similarity, are closely related, and may originally have covered much of the intervening area, but erosion has left only remnants of the original bodies.

South of the Rio Grande the Sheep Mountain underlies only a few small areas between Pinos Creek and San Francisco Creek and several areas near Del Norte. Just north of Del Norte is a somewhat larger mass. The largest body mapped underlies about 50 square miles and forms a strip from Carnero Creek, in the northern part of the Del Norte quadrangle, north for about 20 miles to the Saguache River. Small outliers were mapped to the west, as far as Bowers Peak and the drainage area of Groundhog Creek, in the eastern part of the Creede quadrangle. To the north this formation has been mapped on both sides of Poison Creek and Ford Creek, on the divide at the head of Jacks Creek, and north of Cochetopa Pass, all north of the Saguache River. It also underlies a part of the area mapped as undifferentiated volcanic rocks in the mountains north of Saguache Creek in the Saguache quadrangle, but it was not separately mapped in this area, because at the time of the geological reconnaissance no suitable base map was available and the section was imperfectly understood. In this area it probably forms most of the mountains on the divide as far east as Antora Mountain. It caps much of the mesa country east of Ford Creek. In parts of this area it overlies the Treasure Mountain rhyolite with regularity but over large areas it directly overlies the Conejos quartz latite or other rocks older than the Treasure Mountain, and it is then conspicuously irregular at the base. Owing to this irregularity at the base, the formation is probably not continuous along the divide.

In this whole northeastern area, the Sheep Mountain quartz latite varies greatly in thickness, for both the base and the tops are strikingly irregular. In places it is about 1,000 feet thick. In this whole area of the Del Norte, Saguache, and Cochetopa quadrangles so much of the formation has been removed by erosion that no close approximation of the area and volume of the original body can be made, but the order of magnitude of the area must have been about 1,500 square miles and of the volume 110 cubic miles. The total area underlain by the Sheep Mountain rocks therefore was of the order of magnitude of 1,600 square miles and the total volume about 120 cubic miles.

RELATION TO OTHER ROCKS

Where the Sheep Mountain quartz latite overlies the Treasure Mountain rhyolite the base is regular and the Sheep Mountain rocks appear to have followed closely after the Treasure Mountain with little time for erosion. These relations are especially well shown in the west-central part of the San Cristobal quadrangle, in the Lost Trail Creek area where the clastic rocks of the Sheep Mountain rest on a gently dipping flow of rhyolitic latite of the Treasure Mountain over nearly the

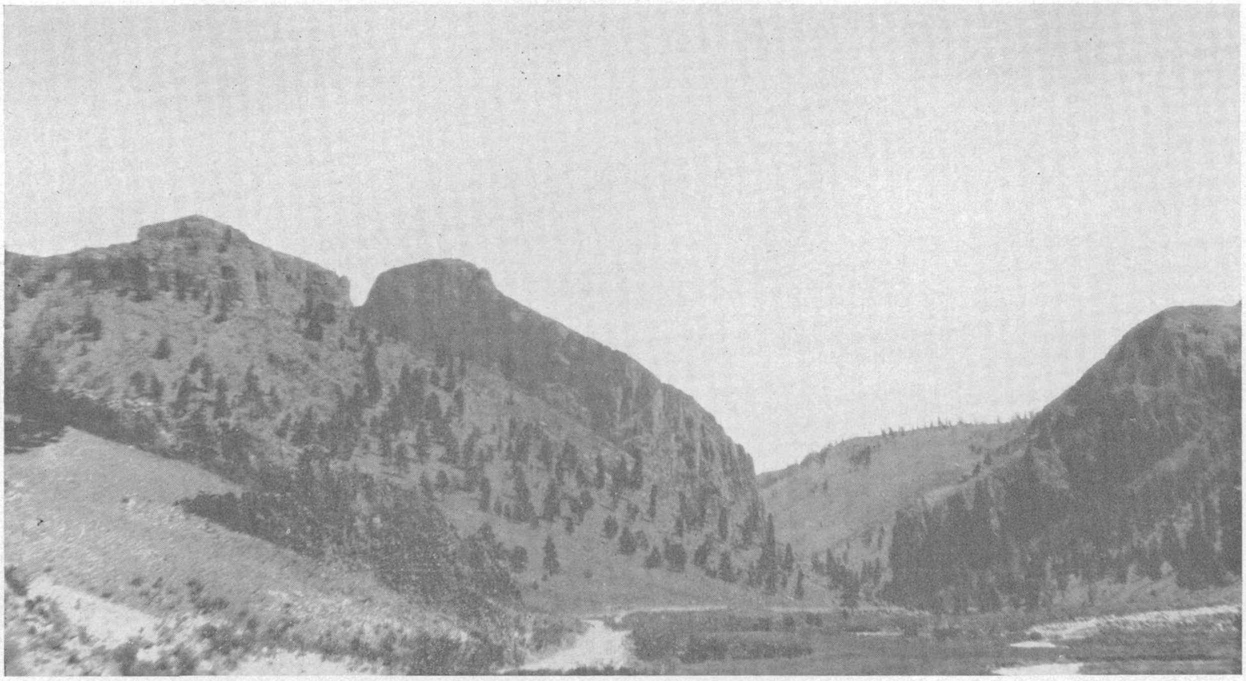

FIGURE 13.—Irregular base of Sheep Mountain quartz latite, looking down Carnero Creek at a gap a few miles above La Garita in Del Norte quadrangle.

whole area. Similarly, in the northwestern part of the Summitville quadrangle, the pyroxene-quartz latites of the Sheep Mountain rest regularly on the Treasure Mountain, and in the northern part of the Del Norte quadrangle and adjoining parts of the Saguache quadrangle, where the Treasure Mountain rocks are present, the base of the Sheep Mountain is regular.

Yet, wherever the Treasure Mountain rhyolite is absent and the Sheep Mountain quartz latite overlies the Conejos quartz latite or older rocks, its base is conspicuously irregular and it clearly filled in deep valleys and buried a topography of considerable relief. Locally the mountains must have risen at least 1,000 feet above the bottoms of the canyons.

This irregularity at the base of the Sheep Mountain quartz latite wherever the Treasure Mountain rhyolite is absent is well shown in the southwestern part of the Del Norte quadrangle in the basin of Pinos Creek near the town of Del Norte, and especially in the northern part of the Del Norte quadrangle in the lower canyon of Carnero Creek, and in the northeastern part of the Creede quadrangle in the basin of Groundhog Creek. It is also well shown farther north near Cochetopa Pass and elsewhere in the Cochetopa and Saguache quadrangles. In the lower canyon of the Carnero these irregular relations are spectacular, and the light-colored massive flows of Sheep Mountain quartz latite plunge hither and thither over steep slopes of the underlying darker quartz latite breccia of the Conejos. The relations are well shown on the geologic map (pl. 1) and in figure 13.

The striking difference in the character of the base of the Sheep Mountain quartz latite where it overlies a regular surface of Treasure Mountain rhyolite and where it overlies an irregular surface of older rocks can be easily seen from the geologic map (pl. 1) by comparing the base of the Sheep Mountain in the San Cristobal and Summitville quadrangles with that in the Del Norte and Creede quadrangles, and especially by comparing the areas in the Del Norte and Saguache quadrangles where the Treasure Mountain is present, with adjoining areas where the Sheep Mountain flows overlie older rocks.

The Sheep Mountain quartz latite is in many places overlain by Alboroto rocks but this upper contact is not so well exposed as the lower. However, the upper contact seems to have been a surface of only moderate relief, as may be seen from the geologic map. The chief mountains of this pre-Alboroto surface corresponded to the Sheep Mountain volcanic piles which were only moderately modified by erosion. The character of this contact is discussed in greater detail in the chapter on the Alboroto rhyolite.

THREE DIFFERENT AREAS

The Sheep Mountain differs so greatly in the three areas that no single description will cover them all. They are nearly all quartz latites and occupy the same position in the section but further than that there is little similarity.

THE CARSON VOLCANO

A deeply dissected volcano of Sheep Mountain age lies northwest of the center of the San Cristobal quadrangle, mostly in the drainage area of Lost Trail Creek. The old mining town of Carson is near the center of the volcano. The cone is well exposed and many cliffs show sections from near the top to near the bottom. Chaotic breccia makes up the greater part of the material but small bodies of massive rock, mostly with irregular relations, and in part flows, in part intrusive, are scattered through the breccia, especially near the center of the volcano. The details of these are shown in plate 3 on which the massive rock has, for the most part, been separated from the breccia and the bodies of massive rock have been divided into five types: rhyolitic, light-colored quartz latites, dark hornblende-quartz latites, dark pyroxene-quartz latites, and granodiorites. Figures 14–16 illustrate rocks of the Carson volcano.

The massive rocks are partly clearly intrusive dikes, sills, of less regular bodies, and partly irregular flows. No attempt is made on the map to distinguish extrusive from intrusive bodies. Most of the bodies are small—much less than 100 feet thick and rarely as much as 2 miles in horizontal extent. Many of them are only 5 to 20 feet thick and half a mile in length.

Dark quartz latites make up by far the greater part of the massive rocks. Most of them are dark gray to black, dense rocks, with a smooth conchoidal fracture, and carry inconspicuous crystals of tabular feldspar as much as 2 mm across. They are much like the tabular feldspar-pyroxene-quartz latites, but have smaller phenocrysts and seem to be more finely crystalline. An analysis and description of such a rock is given in table 21, *column* 6, *in pocket*. Some of the rocks show more or less hornblende and a few have conspicuous black hornblende. Others are red-brown. Some few are highly vesicular, others have a fluidal structure, and some have a rough fracture. A few show some biotite in the porous parts.

The lowest flow of the body mapped northwest of Heart Lake carries some olivine, as does the small body at an altitude of 12,000 feet on the ridge southeast of Bent Peak. Lighter colored quartz latites were found chiefly on the slopes south and southwest of Bent Peak, where they underlie a moderate-sized area and form a dipping, sheetlike intrusive. A similar quartz latite forms two bodies between the forks of Pole Creek and a very small body south of the head of Pole Creek. These rocks are light gray to red-brown and carry abundant phenocrysts as long as 10 mm. They resemble some of the quartz latites of the Fisher Mountain quartz latite and also the light-colored quartz latites of the Sheep Mountain in the Del Norte, Cochetopa, and Saguache quadrangles.

The rhyolites are light-red or gray fluidal rocks that carry a few phenocrysts of white plagioclase, glassy sani-

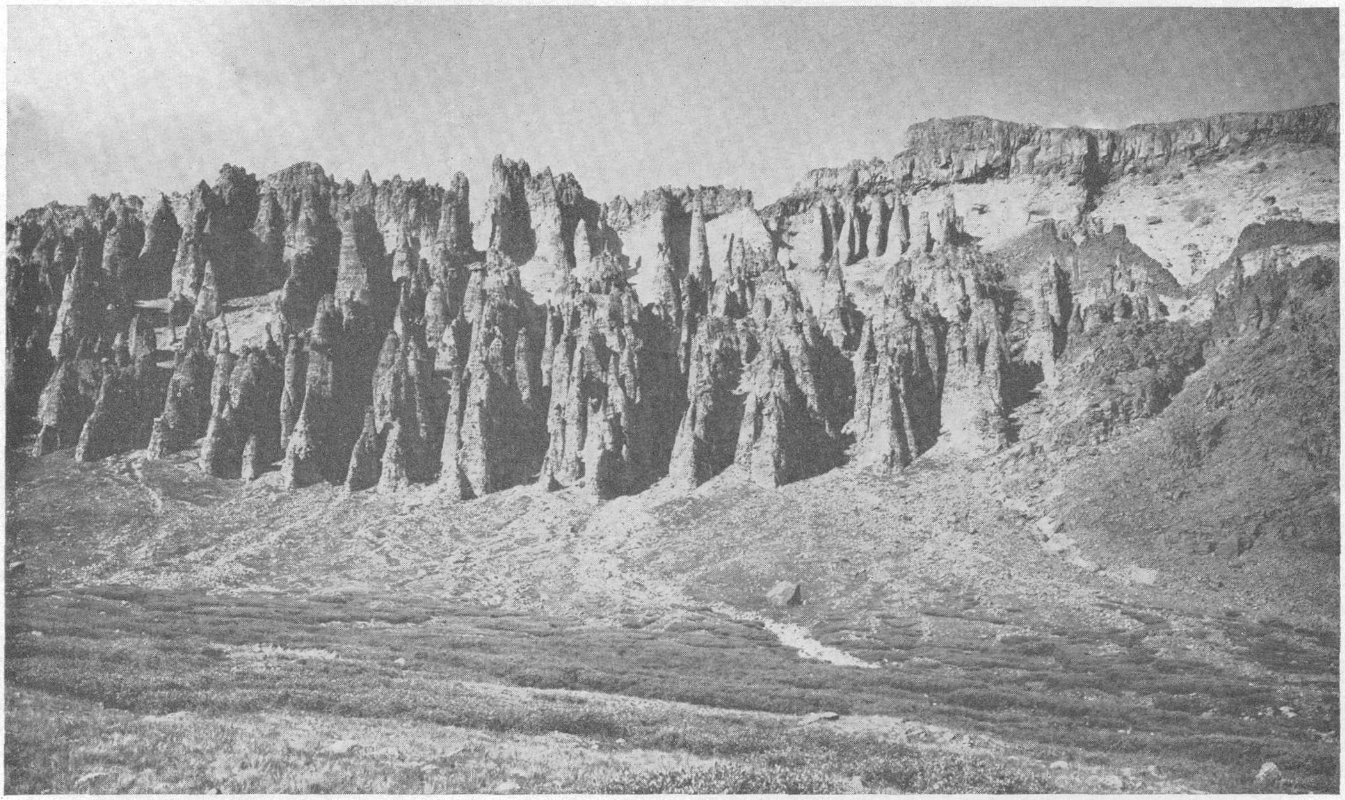

FIGURE 14.—Weathering of Sheep Mountain quartz latite tuff breccia of the Carson volcano in the western part of the San Cristobal quadrangle. This view, at an altitude of 12,600 feet on the forks of West Lost Trail Creek, shows a dike, a sill, and a flow in the breccia.

FIGURE 15.—Cliffs facing the Rio Grande west of Lost Trail Creek, as viewed from their southern base. San Juan tuff is at the base, overlain by massive flow (?) of Treasure Mountain rhyolite, and capped by agglomerate from the Carson volcano of Sheep Mountain quartz latite.

dine, and biotite in a felsitic groundmass. The breccia is pyroclastic and shows little bedding or other evidence of being worked over by water. It is poorly sorted and fragments a foot or more across are imbedded in a finer matrix. The fragments are angular and light gray. The breccia weathers into the hoodoo forms common to the volcanic breccias but, because there are no thick sections of breccia except east of Pole Creek Mountain, the castles and spires are less common than in the thicker accumulations of breccia. East of Pole Creek Mountain some very characteristic weathering forms are present.

The fragments are nearly all of the same rock types as are present in the massive bodies, and the proportions of the different kinds of rock are about the same. Glass is more abundant in the fragments of the breccia than in the massive rocks. The fragments of the breccia look much lighter in color until a fresh fracture is seen, for a thin outer skin is commonly bleached. As in the massive rocks, hornblende-pyroxene rocks predominate, pyroxene-quartz latites are less abundant, and hornblende-quartz latites and rhyolites are subordinate. Both the larger fragments and the matrix of the breccia show little alteration except around areas of mineralization, in which respect they differ considerably from the breccia of the San Juan tuff.

The three intrusive bodies are of granodiorite. An analysis and description of the rock of the stock in West Lost Trail Creek are given under table 21, column 13, in pocket. Because mineralization and alteration have taken place near these stocks, there is now much prospecting near them.

BRECCIA AND FLOWS NEAR SHEEP MOUNTAIN

The body near Sheep Mountain is made up of dark flows and chaotic breccia and brecciated flows of the tabular feldspar-pyroxene andesite. The breccias consist of large angular fragments with little matrix, and commonly the fragments seem to be welded together as if the rocks were brecciated during flow or had been deposited while still hot enough to weld. Little tuff-breccia is present. The individual flows or breccia beds are mostly thin and nearly level, but they seem to be of small areal extent, so that the character of the section changes rapidly from place to place. The outcrops are dark and the formation, even the breccias, is resistant and forms prominent cliffs. In this area the Sheep Mountain quartz latite overlies the Treasure

Mountain rhyolite with little irregularity and is overlain regularly by the Alboroto rhyolite.

A flow from an altitude of 10,800 feet near the trail to Four Mile Creek has a few stout crystals of sanidine, as much as 15 mm across, rare phenocrysts of embayed quartz, and some of resorbed biotite and hornblende.

The limited extent of this body, the uniform character of the rocks, and their considerable difference from the rocks of the other bodies of the Sheep Mountain quartz latite indicate these rocks were probably erupted from a local vent or group of vents. The flatness of the base of the formation and the rather uniform thickness make it seem probable that the cone must have been broad and flat.

THE NORTHEASTERN AREA

The quartz latite and rhyolite of the Del Norte and Saguache quadrangles and of adjoining areas is by far the most extensive of the three areas of the Sheep Mountain quartz latite. In this area the Sheep Mountain can be separated from the Conejos quartz latite, even where the two dark formations are in contact. The flows of the Sheep Mountain are more massive, the rocks are somewhat different from most of the rocks of the Conejos, and where the Sheep Mountain rocks do not overlie the Treasure Mountain rhyolite they overlie a very irregular surface of the Conejos.

The rocks of this area are much lighter colored than are the rocks of the Sheep Mountain area. For the most part the formation is made up of great flows, in part brecciated during flow, but some breccia beds and some thin flows are present.

The body at the head of Bennett Creek in the southwest corner of the Del Norte quadrangle is in large part a single great flow of a rather dense, pale purple-drab quartz latite which carries abundant crystals of white plagioclase as much as 3 mm across, and prisms of black hornblende, with some flakes of biotite and pyroxene.

The rocks around Del Norte are somewhat different and they are placed in the Sheep Mountain quartz

FIGURE 16.—Agglomerate of Sheep Mountain quartz latite of the Carson volcano. The view is to the east from the west side of Lost Trail Creek about half a mile south of the mouth of West Lost Trail Creek in the San Cristobal quadrangle.

latite because of their general similarity to the Sheep Mountain rocks of this northern area and because of the irregular way in which they overlie the Conejos quartz latite. The flows forming Observatory Hill, just south of Del Norte, clearly overlie the Conejos very irregularly. The main flow is a purple-drab to dull-gray, fluidal, banded, platy rock with alternate, highly vesicular bands.

The main body north of Carnero, and extending north to the drainage area of Saguache Creek, is made up in large part of rather thick flows with subordinate thin flows and tuff-breccias. The huge mass of quartz latite at the mouth of the canyon of Carnero Creek is probably a single flow nearly 400 feet thick. It is homogeneous and was at first thought to be intrusive. It carries abundant large phenocrysts and resembles some of the rocks of the Fisher quartz latite. The walls of the canyon show peculiarly well-developed jointing, with persistent flow lines or sheeting structure either vertical or dipping at low angles into a great syncline, the trough of which is nearly north and south across the narrow part of the canyon. The mass as a whole resembles a great granite boss with rounded joint planes standing out as steplike features. This same type of rock can be followed up the hill to the northwest from the canyon, as tongues resting on the rather steep slopes, and it makes up most of this formation for some miles to the north and northwest.

The flow capping the high mountain at the head of Saw Log Creek is a highly vesicular black, basaltic rock whose position in the section is uncertain but which has not been separated from the latites. It is very fine textured and is made up largely of plagioclase laths, pyroxene, serpentinized olivine, iron ore, and apatite.

In the area north of the Saguache River the rapid reconnaissance indicates that the Sheep Mountain quartz latite is made up of three units or groups of rocks that differ appreciably from one another. All of these groups are widely distributed.

The rocks of the lower unit are highly felsic, with a greatly subordinate development of biotite, hornblende, and augite, chiefly in small phenocrysts. As a group these rocks are characterized by the preponderance of the dense, gray, pinkish or reddish felsitic groundmass and the small size of the phenocrysts of plagioclase and mafic silicates. The groundmass of some flows is highly laminated and exhibits fluidal structure but it is more commonly massive. The rocks are quartz latites. This unit reaches a thickness of several hundred feet and is probably nearly continuous along the north slope of the Cochetopa Hills. In the basin of Long Branch it is about 400 feet thick and its base is a short distance above the lower forks of the creek. It is also widely distributed on the south slope in the drainage areas of Findley, Ford, Middle, and Jacks Creeks and is present over the Treasure Mountain rhyolite south of the Saguache River. Similar rock was found on the eastern flank of Sawtooth Mountain and on the northeastern slope of Razor Creek Dome. It had a very wide distribution and throughout was rather uniform in character.

The middle unit of this area is made up of a series of related flows of dark pyroxene- and hornblende-augite-quartz latites. The prevalent rock contains phenocrysts of augite and hornblende, is pink to gray, of uneven fracture, and characterized by scattered vesicles of about a millimeter in diameter. The phenocrysts are mostly less than 1 mm in length but rare augite crystals are 5 mm long.

This unit forms the greater part of the crest of the higher ridges. It is made up of several flows, some of which are extensively brecciated, and it reaches a thickness in places of more than 1,000 feet. It caps the divide from Middle Creek westward at least to the head of Slane Gulch, except in a low saddle at the head of Long Branch and Jacks Creek where a white biotite-quartz latite belonging to the lowest unit is present. In East Pass Creek and to the south and west there are conspicuous flows whose character suggests this horizon. However, the Conejos quartz latite of this area has similar rocks.

The upper unit of the Sheep Mountain quartz latite of the area north of Saguache Creek is a flesh-colored biotite rhyolite. It has a smooth fracture, and is commonly dense, although the weathering out of the feldspar and biotite phenocrysts may give it a pocked appearance in the outcrops. It breaks up readily, covering the surface with talus, and for this reason is seldom seen in large exposures.

ASSOCIATED INTRUSIVE ROCKS AND SOURCE OF THE MATERIAL

Both the petrographic character of the material and the distribution of the rocks show that three groups of volcanoes contributed to the Sheep Mountain quartz latite. The best exposed of these is in the basin of Lost Trail Creek in the San Cristobal quadrangle where the Sheep Mountain rocks clearly represent a low volcanic cone which is made up mostly of clastic material but has some flows and some intrusive bodies. The remaining part of the cone is about 10 miles across and it is bounded by erosion except on the east where it pinches out between the Alboroto and Treasure Mountain rhyolites. It is believed never to have had a much wider distribution. The maximum thickness exposed is about 2,000 feet but the original height of the cone is uncertain. The intrusive bodies near the old mining camp of Carson probably represent the throats of the old volcano. In this area there are many small bodies of intrusive rock, partly dikelike in form, but mostly sill-like, or less regular bodies. They were probably shallow intrusive bodies and in many places it is not possible to distinguish the intrusives from the flows. The two have not been separated on the geologic map (pl. 1). These small intrusives are mostly pyroxene-quartz latites, hornblende-pyroxene-quartz latites, and light-colored quartz latites, but there are a few rhyolites.

Besides the small intrusive bodies there are three bodies of granular rock. One is north of the mining camp of Carson in Wager Gulch, another near Carson on the south side of the divide, and a third in the basin of West Lost Trail Creek. There is much altered rock around the intrusive bodies, especially near Carson, and the old mines and prospects are in or very near these bodies.

The intrusive body in Wager Gulch is small, but poor exposures and alteration make its mapping uncertain. It is a dense, dark-green rock that shows few phenocrysts and in the hand specimen looks like an andesite. It consists of about 20 percent of phenocrysts as long as 20 mm, most of which are andesine, and some of augite, hornblende, and biotite. Both the hornblende and biotite are so much resorbed that only remnants and skeletons remain. The plagioclase also shows resorption borders. The groundmass is fine grained and is made up mostly of andesine in stout laths, but has some grains of augite, rods of hypersthene, and plates of biotite. There is about 10 percent of interstitial quartz and some orthoclase. There is much secondary calcite, green hornblende, and chlorite. The rock is a pyroxene-biotite granodiorite porphyry.

The body south of the Continental Divide is somewhat larger, being about half a mile across. It is also somewhat coarser in texture and it contains more quartz and orthoclase, and is a biotite-pyroxene granodiorite porphyry. It is a dark-gray to greenish-gray rock, with many plagioclase phenocrysts as long as 3 mm in a fine-grained to aphanitic groundmass. The phenocrysts are variable in amount and they grade into the crystals of the groundmass. Andesine-labradorite makes up more than half the rock; augite hypersthene, and some biotite and magnetite are also present. The groundmass makes up about a third of most of the rock and consists of grains about 0.2 mm across of quartz and orthoclase. Some of the rocks have a greater proportion of groundmass, in which case some plagioclase, biotite, pyroxene, and magnetite are present.

The rocks are considerably altered and show a rather complex history. Biotite and hornblende were the first minerals to crystallize, but before the groundmass crystallized the hornblende was almost completely resorbed and the biotite largely resorbed. As the pyroxene crystallized biotite and hornblende were resorbed. The plagioclase phenocrysts crystallized after the biotite and hornblende. After the solidification of the groundmass the pyroxene, especially the hypersthene, was attacked by solutions and altered to serpentine, biotite, and some hornblende and chlorite. Calcite was also formed about this time. Some of the rocks show veinlets of biotite and pyroxene cutting feldspar and the other minerals.

The body in West Trail Creek is about half a mile across. It cuts the San Juan tuff and probably the tuff of the Sheep Mountain quartz latite and is believed to be of the same age as the intrusive bodies near Carson. It is somewhat similar to the other intrusive rocks but has a more calcic feldspar and more pyroxene. It is a granogabbro porphyry. The rocks change from light to dark gray or olive gray and range from even, millimeter-grained to prophyritic with a fine-grained groundmass. All the rocks shown nearly parallel orientation of the plagioclase tablets. The composition in percent, is about 50 labradorite, 25 augite and hypersthene, 2 biotite, 3 magnetite, and 10 to 20 quartz and orthoclase. The orthoclase exceeds the quartz in amount. There is accessory apatite. The biotite is pale, strongly pleochroic, and borders the magnetite as a reaction rim. The quartz and orthoclase are interstitial in the granular rocks and form the groundmass in the porphyritic rocks. The rocks are much fresher than are those near Carson, but the hypersthene is partly altered to bastite and there are some secondary calcite, chlorite, and other minerals. There is little altered rock around this stock. An analysis of this granodiarite porphyry is given in table 21, column 13.

The Sheep Mountain rocks of the northwestern part of the Summitville quadrangle and adjoining areas are dark pyroxene-quartz latites, mostly flows, and no doubt came from one or more vents of this area. Their present outcrops are confined to an area about 10 miles across, and they wedge out to the north, east, and west but are removed by erosion to the south. They are nowhere more than a few hundred feet thick and both the base and top are rather regular. They probably never occupied a large area and seem to have formed a low volcanic cone 10 miles or so across which rose less than 1,000 feet above the surrounding plateau.

The rocks in the northeastern area, including the Creede, Del Norte, Cochetopa, and Saguache quadrangles, are all of related light-colored quartz latites mostly in thick flows. They are distributed over an area about 60 miles in a north-south direction and spread over an irregular topography. The flows seem to be local and not regular, widely distributed flows such as are found in the Treasure Mountain, Alboroto, and Piedra rhyolites. There must have been a number of related vents. One group was probably in the southwestern part of the Del Norte quadrangle, another group near the town of Del Norte, a third near the head of La Garita Creek in the eastern part of the Creede quadrangle, a fourth in the area north of Carnero Creek, and others, no doubt, in the Cochetopa and Saguache quadrangles.

The formation must have once covered much of this northeastern area but it probably accumulated around the centers and filled in the gulches of the old topography, leaving some of the high mountains and ridges uncovered, and some uncovered areas between the local centers.

ALBOROTO RHYOLITE

DISTRIBUTION, THICKNESS, AND VOLUME

The Alboroto rhyolite is one of the most widely distributed of the volcanic formations of the San Juan Mountains. In both the width of distribution and the area occupied it is exceeded only by the Conejos quartz latite. It is distributed over an area nearly 100 miles in diameter. It extends in a north-south direction from the mountains north of the Uncompahgre quadrangle, southward for a short distance into the Summitville quadrangle; and in an east-west direction it extends from a few miles west of the Uncompahgre quadrangle, eastward to about the central part of the Del Norte quadrangle.

In the Montrose quadrangle it is found only as remnants capping mesas in the eastern part, and mostly in the extreme northeastern and southeastern parts, and it is similarly present only in the northeastern part of the Silverton quadrangle. In the Uncompahgre quadrangle it underlies great mesas and is the chief volcanic formation in the quadrangle. It extends, according to the Hayden survey, for 10 miles to the north of this quadrangle into the West Elk Mountains, where it also underlies great mesas. In the San Cristobal quadrangle to the south, it is widely distributed but is found chiefly in cliffs overlain by younger rocks.

To the east, in the Saguache and Cochetopa quadrangles, it underlies some large areas and is widely distributed. In addition to the areas mapped as Alboroto in these quadrangles it is present in the area mapped as undifferentiated volcanic rocks.

Southward, in the Creede quadrangle, there are a number of large bodies of this formation. The formation extends for only a short distance south into the Summitville and Pagosa Springs quadrangles. In the Del Norte quadrangle it is present only as remnants in a north-south strip through about the central part of the quadrangle (fig. 17).

The details of the distribution are shown on the geologic map (pl. 1).

The Alboroto rhyolite no doubt once covered much of the area over which its outcrops are now scattered. To the northwest it originally extended for an unknown distance, as its boundaries in this direction are erosional. To the east it passes under the gravels of the San Luis Valley, but it seems to be getting thinner in this direction and may not extend far to the east. To the southeast it pinches out, barely entering the Conejos quadrangle. To the south it has been removed by erosion, but in the southwestern and western part of the San Cristobal quadrangle it pinches out and probably never extended much beyond its present limits.

The thickness of the Alboroto rhyolite varies greatly and it reaches a maximum in the Creede quadrangle in the central part of the area in which the formation is distributed and seems to thin out irregularly in all directions. This change in thickness is shown in the sections of figure 18. The thickest section noted was on the west slope of San Luis Peak in the northwestern part of the Creede quadrangle where nearly 4,000 feet are exposed. This great thickness is of massive rock of a single kind and it may be a single flow. It is the Alboroto type of rhyolitic quartz latite but has much larger phenocrysts than usual. In La Garita Mountain about 3,000 feet are exposed. In Snowshoe Mountain in the western part of the Creede quadrangle, south of the Rio Grande, nearly as great a thicknes is exposed and here, too, the rock is massive, of a single kind, and may be in large part a single great flow. Texturally, it is much like the Alboroto type of rhyolitic latite, but it carries augite in addition to biotite and hornblende and differs appreciably from the other rhyolitic latites of the Alboroto. Under Mt. Hope, in the south-central part of the Creede quadrangle, about 3,000 feet of massive rock, much like that of the San Luis Peak area, are exposed. These three thickest bodies may owe their thickness to the fact that they are around vents from which the Alboroto rocks were extruded. Indeed, as shown in figure 18, the manner in which the formation thins out in all directions from this central area, the fact that the individual flows become thinner, and the fact that gravels, tuffs, and thin flows of rhyolite and other rocks make up a greater and greater part of the sections as the distance increases from this central area—all these indicate that the main sources for the Alboroto type of rhyolitic latite were in this area. However, no actual vents or intrusive stocks of Alboroto rocks have been found.

In the southeastern part of the San Cristobal quadrangle, the great flows of normal rhyolitic latite of the Alboroto are in places more than 1,000 feet thick but become rapidly thinner to the northwest and pinch out

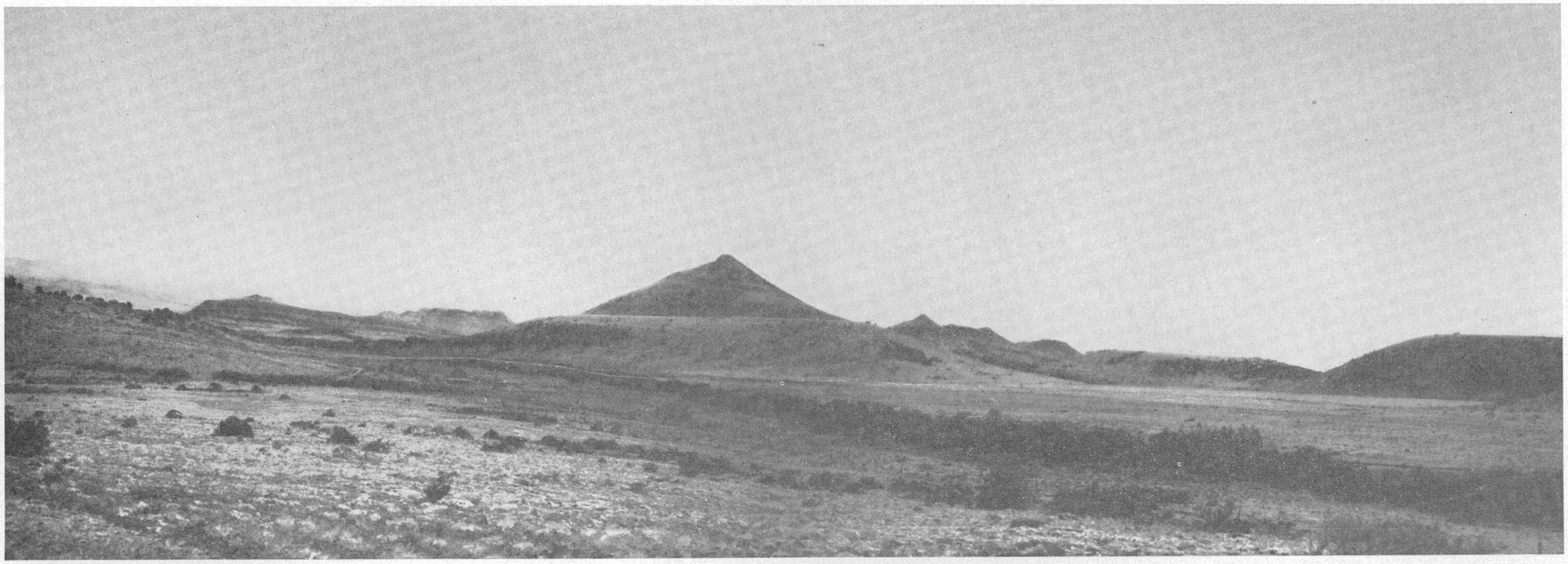

FIGURE 17.—Gently dipping lava flows and tuff beds, as seen looking down San Francisco Creek, Del Norte quadrangle. Dog Mountain, center, is capped by a remnant of latite and basalt of the Hinsdale formation; the upper steep slopes are Piedra rhyolite, the lower ones are Alboroto rhyolite. Conejos quartz latite underlies the flat foreground. The flows dip regularly toward the San Luis Valley.

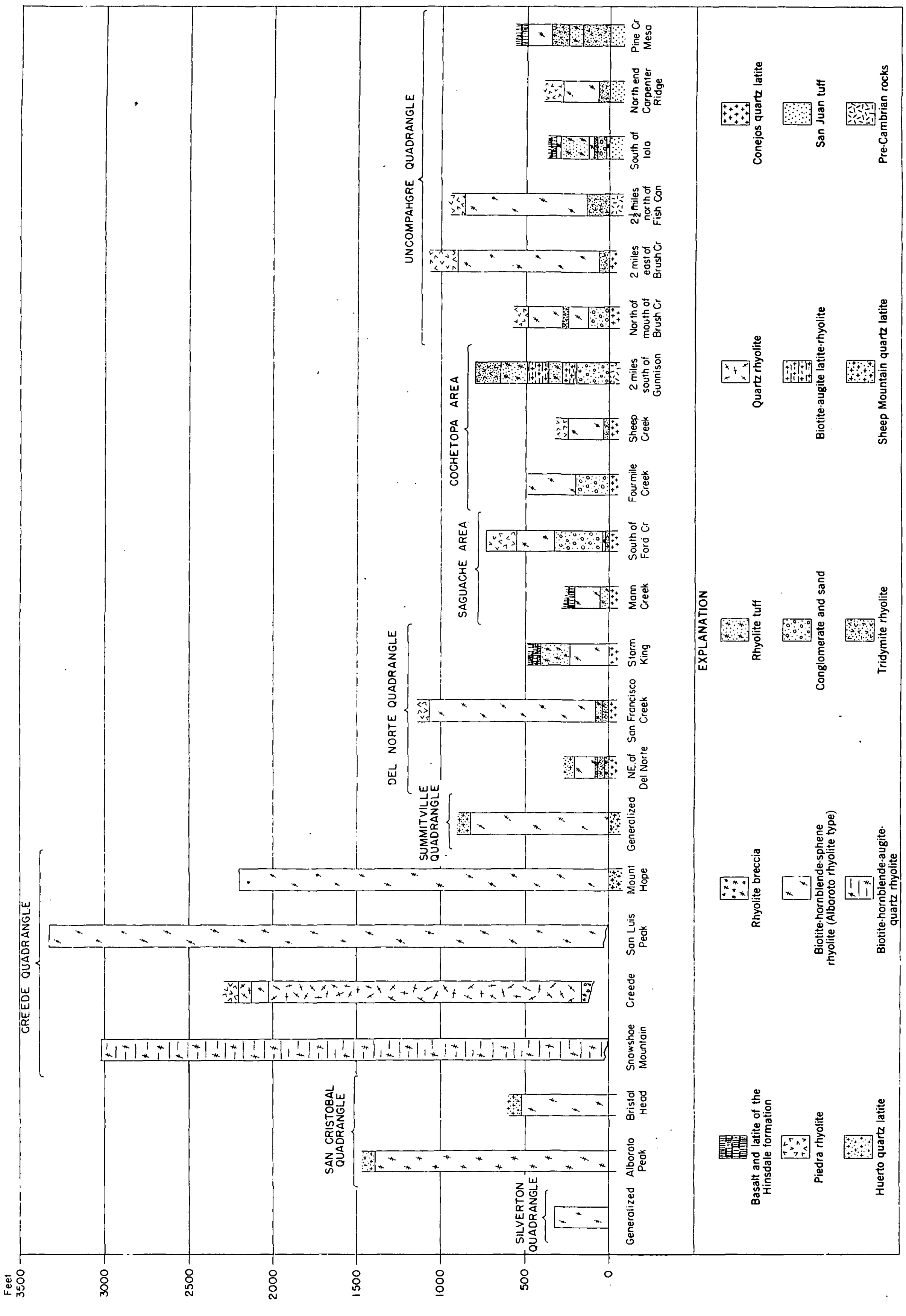

FIGURE 18.—Comparative sections of the Alboroto rhyolite. The sections are somewhat generalized.

just west of Weminuche Pass. South of Mt. Hope the formation also thins and in the Summitville quadrangle it is probably nowhere 1,000 feet thick. It also thins rapidly to the east and on the east flank of the mountains it is only a few hundred feet thick.

It also becomes thinner to the north. In the southern part of the Uncompahgre quadrangle it reaches nearly 1,000 feet in thickness, as it does also in the Saguache River basin to the east and just south of the town of Gunnison in the north-central part of the Saguache quadrangle. Farther north, in the northern part of the Uncompahgre quadrangle and to the north in the West Elk Mountains, it becomes a formation of only a few hundred feet in thickness and is made up of rhyolite in flows and tuff beds.

The Alboroto rhyolite appears to have at one time formed a broad dome, in detail somewhat irregular at the base, and about 110 miles across, with a thickness of several thousand feet in the central part but gradually thinning out away from the center. This dome covered an area of about 10,000 square miles and had a volume of about 1,100 cubic miles.

GENERAL CHARACTER

Nearly 80 percent of the Alboroto rhyolite consists of a uniform biotite-hornblende rhyolitic quartz latite, later in this paper described as the Alboroto type of rhyolitic latite (upper member); a few percent are a similar rock but with augite, as well as hornblende and biotite; about 20 percent is interbedded flows of tridymite rhyolite and tridymite rhyclitic latite and associated tuffs and gravel beds; and a few percent are quartz-bearing rhyolites. The Alboroto type of rhyolitic latite (upper member) makes up nearly all of the formation in the central, thick part of the dome in an area about 50 miles across, but to the north in the Montrose, Uncompahgre, Cochetopa, and Saguache quadrangles, and to the east in the Del Norte quadrangle, the rhyolitic flows and tuffs (lower member) come in at the base of the formation, at first as a thin member which thickens and to the north and in the canyon of the Gunnison River is 400 feet thick and makes up most of the formation. The two members will be described separately.

A number of sections of the Alboroto rhyolite are shown in figure 18. The sections give a good idea of the character of the formation in the different areas, but it should be emphasized that relatively few sections are shown in the great area near the central thick part of the dome where the formation is uniform, that the section at Snowshoe Mountain and that at Creede represent local cones, and that many sections are shown in the northern and eastern parts of the dome where the formation is thin but variable in character.

LOWER RHYOLITE MEMBER

The lower rhyolite member of the Alboroto rhyolite is found chiefly in the Montrose, Uncompahgre, Cochetopa, Saguache, and Del Norte quadrangles and the West Elk Mountains. In the southern part of the Uncompahgre quadrangle it is absent or rarely more than 100 feet thick, but to the north, near the margin of the dome, it increases in thickness and in the northern part of the quadrangle makes up nearly the whole of the formation. Four such cones have been recognized. One is in the northwestern part of the Creede quadrangle extending for a short distance into the San Cristobal quadrangle and centered near the town of Creede.

Its western limit is west of Shallow Creek, in the San Cristobal quadrangle; its eastern limit is near Wagonwheel Gap where it is exposed just west of the mouth of Goose Creek; south of the Rio Grande it was found only as a small outcrop west of Goose Creek; and to the north it passes under younger rocks south of the head of West Willow Creek, and northeast of Nelson Mountain in East Willow Creek. It seems to be thinning rapidly to the north where last exposed and was probably absent or was a thin formation beyond the last exposures. It forms all the Alboroto rhyolite in the drainage area of Shallow Creek except the cap of the ridge southwest of the creek, and all of the Alboroto to the northwest as far as Bull Dog Mountain; it also makes up all of the Alboroto of the Willow Creek drainage area, near Creede, as far north as Nelson Mountain, and the arm of Alboroto that lies east of Creede. A small isolated outcrop surrounded by Fisher quartz latite and Creede formation was found west of the mouth of Goose Creek.

The rocks of this cone show a thickness of more than 2,000 feet near Creede, where the base is not exposed; they cover an area about 14 miles across, or about 150 square miles, and have a volume of roughly 20 cubic miles.

This cone is made up very largely of quartz-rich rhyolite lavas in very thick flows with only a little tuff. No actual vent was found but the presence near Creede of a large number of irregular intrusive bodies of rhyolite probably of the same age as these flows, and the rapid thickening of the flows indicate a center near Creede. In the report by Emmons and Larsen (1923, p. 17–30) on the Creede special area the Alboroto group was divided into the Outlet Tunnel quartz latite, the Willow Creek rhyolite, and the Campbell Mountain rhyolite.

Another cone lies a few miles to the north, in the southwestern part of the Cochetopa quadrangle, in the basin of Spring Creek, near its forks and near the old mining camp of Bondholder. The base of this body is not exposed but it crops out in only a small area and was probably only a small cone. It is very similar to and probably closely related to the Creede cone.

A small cone a few miles farther north, partly in the Uncompahgre quadrangle and partly in the Cochetopa quadrangle, southeast of Cathedral between Spring and Los Pinos Creeks. It is crossed by the automobile roads. Thin flows of rhyolite are at the base of the Alboroto rhyolite in most places for some miles to the west and north. This cone is made up of thin flows of tridymite rhyolite and tridymite rhyolitic latite with much interlayered tuffs. The cone is about 1,500 feet high, occupies a small area, and has a small volume.

To the east, in the southwestern part of the Saguache quadrangle, centered south of the Saguache River, a few miles south of the mouth of Big Dry Gulch, there is a fourth cone, nearly as large as the one near Creede. It was about 10 miles across, must have been at least 1,500 feet high, occupied an area of about 75 square miles, and had a volume of nearly 10 cubic miles. It is made up chiefly of rhyolitic tuff, mostly of sandy or finer texture, but in part coarser. There are a few layers of dark quartz latite conglomerate. A few thin flows of cavernous tridymite rhyolite are present and, as they dip toward the river and form sloping mesas, they give the impression of making up a larger proportion of the formation than they really do.

The large body of Alboroto rhyolite in the eastern part of the Cochetopa quadrangle, chiefly in the basin of Razor Creek, has, in its lower part above Razor Creek, an irregular body, probably a part of a local volcano, made up chiefly of pink, felsitic rhyolite, with associated tuff, breccia, and volcanic glass.

The greater part of the lower member of Alboroto rhyolite is made up of regular, nearly flat tuff beds, gravels, and flows that underlie the Alboroto type of rhyolitic latite (upper member) regularly and overlie the pre-Alboroto rocks irregularly. These rocks are best developed in the Uncompahgre quadrangle and adjoining areas, especially to the north in West Elk Mountains, but are widespread at the base of the Alboroto throughout the drainage basins of the Gunnison River and Saguache Creek and are present along the western borders of the San Luis Valley.

In the southern part of the Uncompahgre quadrangle in the upper drainage area of Cebolla Creek, the horizon is represented chiefly by a flow, mostly less than 50 feet thick, of a cavernous rhyolite, with little tuff and local gravel. To the north the horizon thickens and is made up in considerable part of tuff, and around the canyon of the Gunnison River it is several hundred feet thick and is made up of alternating flows of tridymite rhyolite and cavernous rhyolite and tuff beds.

In the northeastern part of the Uncompahgre quadrangle the horizon is thin and is represented by flows of rhyolitic rocks, gravels, and tuff beds. Farther east, near Gunnison, gravel becomes conspicuous at the base of the formation and the upper part is made up of tuff and rhyolitic flows. The Alboroto type of latite is absent in this area and the upper part of this section may belong to the Piedra rhyolite. The section on the west slope of the mesa about 2 miles south of east of the town of Gunnison is representative of all the isolated mesas of Alboroto rocks in the northern half of the Cochetopa quadrangle, though the large irregular body cut by Razor Creek is made up mostly of the Alboroto type of latite, with some chaotic rhyolite and tuff at its base.

The lowest member of the Alboroto rhyolite in the Gunnison section is a conglomerate or breccia in which the pebbles are partly rounded and of variable size (as much as 8 inches in diameter.) It consists of granite, biotite schists, andesite, and many volcanic rocks. This layer is about 200 feet thick and may be more closely related to the extensive breccia occurrences north of the Gunnison River. Overlying this is a white rhyolitic latite near the Alboroto type, but with no hornblende, which breaks easily, with a moderately smooth fracture. This flow is overlain by 100 feet of tuff and by another flow or welded tuff of pinkish-gray rhyolitic latite near the Alboroto type, which is characterized by the presence of many fragments of pink pumice. Above this latite horizon is 150 feet of tuff breccia containing fragments of rhyolite, rhyolitic latite, schists, and dark quartz latites; following which there is a porous, pink rhyolitic welded tuff capping the knoll. This rock is cavernous, has a fluidal structure, contains a few scattered fragments, particularly near the base, and breaks easily. It contains a few subhedral phenocrysts of plagioclase, biotite, quartz, and occasionally orthoclase as long as 2 millimeters, in a submicroscopic groundmass rich in tridymite and characterized by many glassy and broken spherulitic fragments.

In the southeastern part of the Cochetopa quadrangle, the Alboroto body between Saguache River and California Gulch is made up mostly of gravel, with some flows of rhyolite and some tuff, and this material is at the base of the Alboroto in much of this area as far as the drainage basin of Fourmile Creek. In the section in the canyon of Saguache Creek above the mouth of Fourmile Creek the lower 50 feet of the Alboroto is a flow of rhyolite over which are several hundred feet of well-bedded sands and gravels made up of rhyolitic latite and dark quartz latite. In some layers the boulders are 6 feet across.

A better-exposed, but much thinner, section a few miles to the northeast, north of the upper part of Fourmile Gulch, is shown below. It probably contains more rhyolitic tuff than the average.

Alboroto quartz latite:
- Upper rhyolitic latite member:
  - Flow, or hard tuff.
- No exposures, sandy soil with scattered pebbles of dark quartz latites.
- Lower rhyolite member:
  - Light-colored, well-banded sands and pebbly sands with some lenses and thin layers of gravel, and some layers of mud. Pebbles well-rounded and rarely more than 6 inches across; a few more than a foot across. Fragments are of dark quartz latite and rhyolitic latite.
  - Light-colored beds of tuffs. Angular fragments of pumice as much as 1 foot across.
  - Soft sands with pebbles.

Conejos quartz latite:
- Hard, dark quartz latite breccia.

Similar sands and gravels, but with somewhat less-rounded pebbles, underlie the Alboroto type of rhyolitic latite (upper member) east and south of Cochetopa Pass and extend to the north as far as Spanish Creek. Such gravels are also found locally at the head of Wanamaker Creek in the northern part of the Creede quadrangle. Pebbly tuffs are at the base of the Alboroto at many places in the Uncompahgre, Montrose, and Silverton quadrangles, and in the northern part of the Cochetopa quadrangle.

In the Sheep Creek area northeast of Cochetopa Pass a thin, regular flow of cavernous rhyolite forms the base of the Alboroto rhyolite and is overlain by rhyolitic latite of the type area. This rhyolite was found in many places as far as Middle Creek. In the section south of the mouth of Ford Creek, immediately over the Sheep Mountain quartz latite, there are 30 feet of a white- to flesh-colored rhyolite with large irregular cavities and a few small inclusions. Over this rhyolite flow are 20 feet of white rhyolite tuff, above which there are no good exposures for more than 200 feet. However, the soil and the abundance of well-rounded pebbles of diverse character in the debris indicate that this part of the section is probably made up of rhyolitic tuffs with sands and gravel beds much like those at the base of the Alboroto to the west in the drainage basin of Fourmile Creek and elsewhere. The Alboroto type of rhyolitic latite (upper member) is over this gravel.

To the south this rhyolite-gravel layer at the base of the Alboroto rhyolite becomes thinner, at the head of Mann Creek it is represented by only 60 feet of tuff, and under Storm King Mountain, a few miles farther south in the Del Norte quadrangle, it is entirely absent. Along the eastern flank of the mountains in the Del Norte quadrangle the Alboroto is only about 200 to 300 feet thick, and in the section about 4 miles north of Del Norte at the base of the Alboroto there are 18 feet of sandy latite tuff, and over this 12 feet of welded tuff of plagioclase rhyolite with few phenocrysts and a glassy groundmass. Above this are 20 feet of sandy tuff of Alboroto type of rhyolitic latite with scattered fragments of dark quartz latite. This sandy tuff is overlain by a flow of rhyolitic latite of Alboroto type.

Near Del Norte, in the drainage basin of San Francisco Creek and extending to Sevenmile Plaza, the lowest member of the Alboroto rhyolite is a thin flow of cavernous rhyolite with a basal zone of black glass.

In the western part of the San Juan Mountains this lower rhyolite member is widely distributed.

This lower member, made up of flows of tridymite rhyolite, cavernous tridymite rhyolite, quartz rhyolite, and associated tuffs and gravels, originally underlay an area roughly estimated at about 4,000 square miles and had a volume of roughly 200 cubic miles.

THE UPPER RHYOLITIC LATITE MEMBER

The upper member of the Alboroto rhyolite is made up of a rhyolitic quartz latite of remarkably uniform character which will be called the Alboroto type of rhyolitic latite. This rock makes up nearly all of the upper part of the Alboroto dome in the San Cristobal, Creede, Summitville and Pagosa quadrangles and throughout this area many cliffs consist entirely of this latite, which is so uniform in character that in many places it seems to represent a single thick flow, or tuff bed.

In the canyon of the Rio Piedra more than 1,000 feet of this latite are exposed without glass horizons or other evidence of more than a single eruption, and on the west slope of San Luis Peak in the southwest corner of the Cochetopa quadrangle about 4,000 feet of this latite are exposed.

Elsewhere in this area several flows and tuff beds of almost identical rhyolite latite are present. Some of the sandy tuffs are so similar to the flows that it is difficult to distinguish between some of the indurated tuffs and some of the friable flows, especially when the rocks are somewhat decomposed. In the Pagosa Springs quadrangle, especially in the high mountains north and northwest of Eagle Mountain, there is a great thickness of angular, chaotic breccia made up of fragments of this latite and a similar breccia is present locally in the northwestern part of the Creede quadrangle in the drainage basin of East Willow Creek, northeast of Nelson Mountain.

To the north and east of the center of the Alboroto dome, in the Uncompahgre, Cochetopa, Saguache, and Del Norte quadrangles, this rhyolitic latite becomes thinner and near the Gunnison River it is relatively thin. In the eastern part of the Creede quadrangle great flows and thick tuff beds of this rock make up most of the section. In this great central area the only large bodies of Alboroto rhyolite that are not of this rhyolitic latite type are the rhyolite cone at the base of the formation near Creede, the pyroxene-bearing rhyolitic latite of Snowshoe Mountain, and a latite with large phenocrysts. The latter rocks were found in the upper drainage area of Cochetopa Creek and extend south to Mt. Hope and the Summitville quadrangle.

In the southeastern part of the Uncompahgre quadrangle and adjoining parts of the Cochetopa quadrangle, this latite makes most of the formation. In most of this area the base of the Alboroto is a rhyolitic flow with some tuff belonging to the lower horizon and over that there is a massive, cliff-forming flow of Alboroto type of latite 400 to 500 feet thick. This is overlain regularly by, and in places seems to grade into, a soft white latite, almost identical with the underlying massive latite except for color and hardness, and is probably a tuff several hundred feet thick.

North of Mill Creek, a little above its mouth, the base of the Alboroto rhyolite is a white tuff of the Alboroto type of rock; above this there is a thin flow of cavernous rhyolite, and above that the main layer of rhyolitic latite. In most of the Uncompahgre quadrangle the main part of the rhyolitic latite is a massive flow, and over it there is a few hundred feet of friable, white tuff which is very similar to the underlying flow. The massive rock forms cliffs, and the soft tuff over it underlies the broad benches and gentle slopes which are conspicuous topographic features north and west of the Cebolla in the Powderhorn drainage area and elsewhere. The several canyons of Cebolla Creek above Spring Creek are cut in this massive rhyolitic latite, as are the canyons of Rough Creek, Rock Creek, and Powderhorn Creek. The character of the topography formed by this rock is indicated by the names of Rough and Rock Creeks. The soft white tuff of this type also underlies many of the parks of the area, such as Rock Creek Park in the western part of the Cochetopa quadrangle.

To the north this member of the Alboroto rhyolite becomes thinner and near the Gunnison River it is very thin or lacking, as shown by the sections (fig. 18) near Iola, under Carpenter Ridge, on Pine Creek mesa, and south of Gunnison.

Farther east, in the east central part of the Cochetopa quadrangle, the large body of Alboroto, a few miles southeast of Razor Creek Dome, is made up chiefly of the typical rhyolitic latite, though there is some rhyolite and rhyolite tuff at the base in the drainage area of Razor Creek.

To the south and southeast, in the Cochetopa and Saguache quadrangles, there is more or less gravel, tuff, and rhyolite of the lowest member at the base of the Alboroto rhyolite but most of the rock is of the type rhyolitic latite. The lowest rhyolitic latite is thick in the Four Mile Creek area, for some miles to the south, and north as far as Spanish Creek. Farther north and east it is thin. There is a high volcano of the lower rhyolite member near Big Spring Gulch extending as far as Ford Creek. To the south in Saw Log Creek the formation is made up almost entirely of the type rhyolitic latite.

Farther south in the Del Norte quadrangle, this rhyolitic latite is only from 100 to 200 feet thick and is both underlain and overlain by rhyolitic rocks. Those overlying it are believed to belong to the Piedra rhyolite.

In the western part of the San Juan Mountains, in the northern part of the Silverton and adjoining parts of the Montrose quadrangles, similar rhyolitic latite, associated with rhyolitic flows and tuffs, is present. It is also present over a rhyolite in the isolated body of Alboroto east of Lake San Cristobal in the San Cristobal quadrangle.

The thick mass of rhyolitic latite of the Snowshoe Mountain area south of the Rio Grande near the borders of the Creede and San Cristobal quadrangles, is made up chiefly of a massive rock much like the typical latite of the Alboroto but carrying augite, as well as hornblende. A part of this body just north of Lime Creek is made up of angular chaotic breccia whose fragments are like the massive rock of the body. This rock forms Snowshoe Mountain (about 3,500 feet high), is uniform in character, and in most sections shows only one flow. However, it is confined to this area and probably piled up around a local volcano.

The rhyolitic latite of the Alboroto rhyolite must have underlain an area of about 8,000 square miles and had a volume of about 900 cubic miles, which is about 75 percent of the whole Alboroto rhyolite.

In Alder Creek at the base of the Alboroto rhyolite there are 150 to 200 feet of white tuff with characteristically large masses of pumice fragments, besides andesite and latite and broken crystals of quartz, biotite, feldspar, and some hornblende. Similar beds were found on the south side of the river east of Willow Creek, and in at least one place on the ridge extending north from Del Norte Peak. In Park Creek south of Cattle Mountain finer and more homogeneous tuff, locally highly carbonaceous is at the base of the Alboroto.

In the northern part of the Lake City quadrangle the Alboroto rocks are like those to the north in the Uncompahgre quadrangle, but in Uncompahgre Peak and for some miles to the west and southwest, the typical rhyolitic latite of the Alboroto makes up less of the formation. Cavernous rhyolites are present, as are some augite-hornblende-biotite rhyolitic latites and considerable dark quartz latite. The last seem to be mostly in the upper part of the section and is interlayered with rhyolite and rhyolitic latite. Some of the rocks mapped as Alboroto of this area may belong to the Huerto quartz latite, Piedra rhyolite, or other divisions of the Potosi volcanic series. The quartz latites are tabular feldspar-pyroxene-quartz latite, and hornblende-pyroxene-quartz latites. Some of the rocks are intermediate in composition between these two.

A biotite-augite rhyolitic quartz latite caps Crystal Peak and the ridge to the northwest and is found in Uncompahgre Peak. It looks much like some of the Alboroto type of rhyolitic latite that carries more and larger phenocrysts. More than a third of it consists of broken crystals of andesine-labradorite, and some of biotite, augite, orthoclase, and quartz, in a glassy to finaly spherulitic groundmass.

In the southeastern part of the Ouray quadrangle the Alboroto is mostly rhyolitic latite grading to quartz latites. The thick body at Wetterhorn, which may be intrusive, is a dark-gray quartz latite with many phenocrysts of feldspar and biotite, few of which exceed 4 millimeters across. Phenocrysts of quartz and augite are in small amounts. This rock is less siliceous than most of the Alboroto rocks.

DARK QUARTZ LATITES

Dark quartz latites are not common in the Alboroto rhyolite. Henderson Mountain, north of Saguache Creek and south of Jacks Creek in the western part of the Saguache quadrangle, is capped by a flow, about 100 feet thick, of a platy pyroxene-quartz latite that has not been mapped separately from the Alboroto. Dark quartz latites are also present in the Alboroto of Uncompahgre Peak and elsewhere.

WEATHERING, TOPOGRAPHY, AND SCENERY

For the most part the Alboroto rhyolite is in flows or tuff beds of great thickness and wide distribution. The rocks are usually massive and have little fluidal structure. They break down much like a granite: many of them form great cliffs that from a distance resemble canyons in granite. In the drainage of the Saguache River and in the slopes just west of the San Luis Valley the latite tuff of the Alboroto rhyolite breaks down with picturesque rounded boulders similar to the boulders of disintegration common in granite rocks. The boulders commonly have the form of an old-style rounded-top beehive. This type of rock was called the beehive type of latite in the field. When there is little relief these boulders are several feet high and are separated by relatively level soil so that a horse can be ridden in and out among the boulders. Where the relief is greater and the erosion more rapid the soil is removed and the outcrops resemble huge boulders with occasional large monoliths. This is especially well shown in the drainage areas of Four Mile, Spanish, and Luders Creeks in the Saguache quadrangle, and north of the Rio Grande in the Del Norte quadrangle.

In many places, notably in the San Cristobal quadrangle and near San Luis Peak in the Cochetopa and Creede quadrangles, where the rhyolitic latite flows of the Alboroto rhyolite are of great thickness, notable canyons are cut in them.

Many of the high mountains of the area are made up of this rock and Mount Hope, San Luis Peak, and Snowshoe Mountain stand above the younger rocks much like the granite cores of many mountains. Views of the Alboroto rhyolite are shown in figures 19–22.

SOURCE OF THE MATERIAL IN ASSOCIATED INTRUSIVE ROCKS

No important intrusive phase of Alboroto rocks and no volcanic neck or vent of such rocks has been found. However, from a study of the general character, form, thickness, and distribution of the formation, much can be learned of its source and of the chief centers from which the material was erupted. From the character and distribution of the rock types it is clear that the tridymite rhyolites of the lower horizons had a different source from the great flows and tuff beds of the Alboroto type of rhyolitic latite and that the latter must have come chiefly from vents near the center of the dome, probably in the Creede and San Cristobal quadrangles. The tridymite rhyolite must have come chiefly from centers near the margin of the dome and in considerable part from vents north and east of the area included in this study.

Lower rhyolite member

The lower rhyolite member of the Alboroto rhyolite represents two kinds of eruption, as in part it accumulated around local, relatively steep-sided cones, and in part it accumulated in nearly flat widespread flows and tuff beds as a broad, low dome or group of domes. These flat beds are chiefly in the northern area, and the fact that they thicken to the north of the Uncompahgre quadrangle indicates a chief source to the north, possibly in the West Elk Mountains. This dome must have been more than 50 miles across and only a few hundred feet in thickness at its thickest part. Other centers must have existed on the east and west flanks of the main Alboroto dome, and some of the widespread flat flows probably came from the local cones.

Flows of tridymite rhyolite of uniform, character make up nearly half the dome. These flows are rarely more than 50 feet thick, regular in thickness, regularly interbedded with tuffs, and widespread. This indicates that each flow spread over a relatively smooth, nearly

FIGURE 19.—Characteristic cliffs of Alboroto rhyolite, with flat benches at top overlain by tuff and flows of Alboroto. The view is southward up the South Fork of the Rio Grande from a point 1 mile above the mouth of Beaver Creek, south of the center of the Creede quadrangle. Lettuce fields in the foreground. Photograph by H. F. Hume, Del Norte, Colo. Courtesy of Del Norte Studios.

FIGURE 20.—Characteristic weathering of tuff of the Alboroto rhyolite. Cliffs are on the east side of Blue Creek near the north border of the Lake City quadrangle.

flat surface, that considerable lava was erupted at one impulse, that the lavas were fluid, and that they retained their fluidity long enough to spread out as thin sheets which extended many miles from the vents.

The tuffs are made up largely of fragments of glass, either pumice or the walls of gas bubbles, and only in small part of fragmental material like the flows. They are mostly of fine sandy texture, are poorly bedded, and the beds are widespread. In many places they are associated and interbedded with gravels and sands, showing some distribution by water. Their character indicates that they were formed by the comminution by explosions of liquid lava in the crater, or at least from local accumulation around the craters.

The rhyolites of the lower horizon on the east flank of the mountains represent the border zone of what is probably a much more extensive development under the San Luis Valley to the east.

The local cones near Big Dry Gulch and at the head of Los Pinos Creek are made up of material much like that of the broad domes, but the flows came over a steep surface and flowed a much shorter distance. They were much like the flows of the broad domes but a smaller amount of lavas was erupted at an impulse.

The cone near Creede and that near Bondholder in Spring Creek are different in that they are made up almost entirely of lavas in thick flows of moderately wide distribution. Some of the lava extrusions must have been large, but the lava must have been much more viscous than the tridymite rhyolite lavas because they piled up as thick bodies which did not spread much.

Near Creede are a number of dikes and rather flat-lying less regular bodies of a rhyolite porphyry that cut these rhyolites, are older than the Piedra rhyolite, and are believed to be of Alboroto age. They have a chemical composition much like that of the associated rhyolites. These rocks have a dull, chalky luster, and are nearly white to light vinaceous. They are commonly somewhat porous and much of the rock has a very fine fluidal banding. The rock is characterized by a few thick tablets of sanidine, nearly a centimeter across, in an aphanitic groundmass. Dark minerals are almost entirely lacking. The body just south of

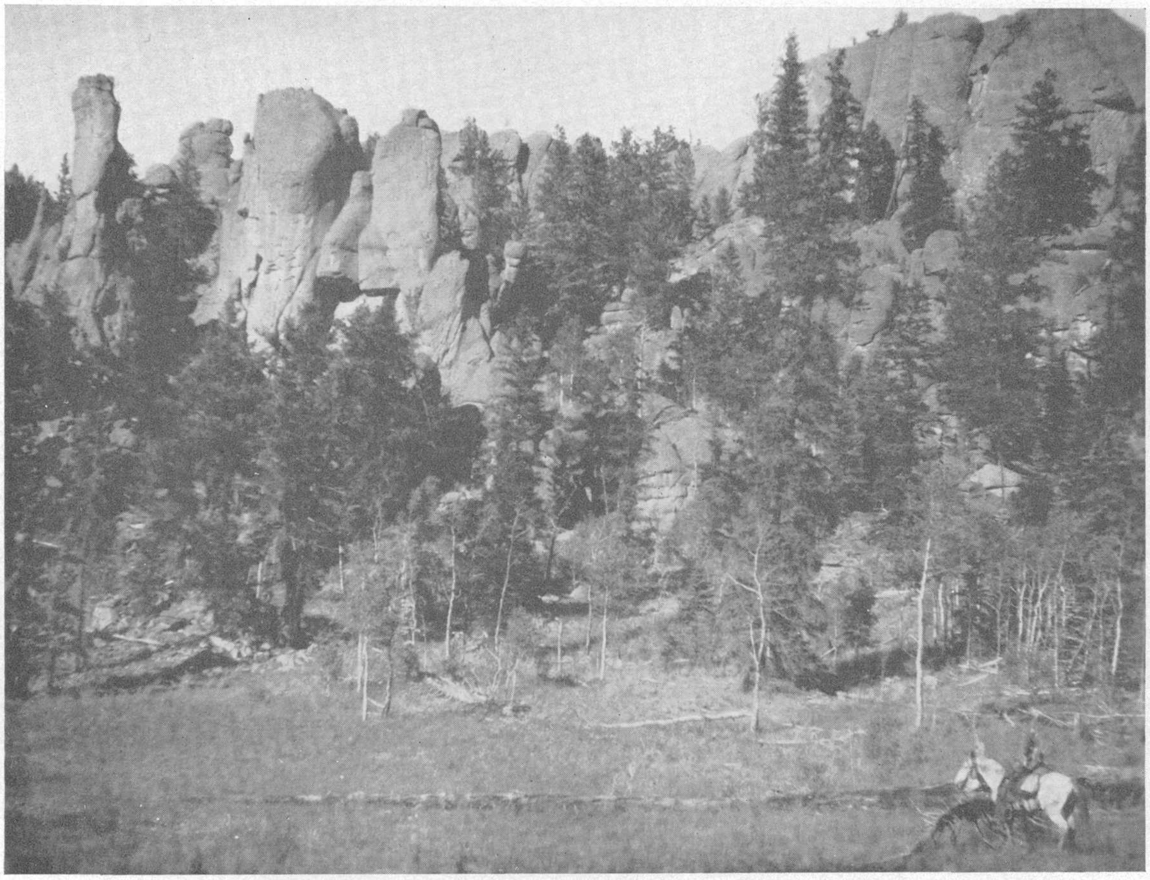

FIGURE 21.—Weathering of tuff of the Alboroto rhyolite along a road near Fourmile Creek, Cochetopa quadrangle.

FIGURE 22.—Beehive type of weathering of Alboroto rhyolite in the basin of Antelope Creek in the western part of Cochetopa quadrangle.

Weaver has a somewhat brecciated appearance and has a few phenocrysts of quartz, biotite, and a completely altered feldspar, probably plagioclase, in addition to the orthoclase.

Besides the orthoclase phenocrysts some resorbed biotite and accessory apatite, zircon, and magnetite are present. The groundmass is irregular in texture. It carries very abundant grains of quartz, of which the largest are a few tenths of a millimeter in cross section, and a few grains of orthoclase; these are imbedded in, and not sharply distinct from, a very fine matrix of quartz and orthoclase. A more detailed description is given by Emmons and Larsen (1923, p. 74–75).

Upper rhyolitic latite member

The upper rhyolitic latite member of the Alboroto rhyolite is nearly 100 miles across and attains a thickness of 4,000 feet. It consists of very thick widespread lava flows (?) and thick beds of sandy tuffs made up of material about like the flows, and a very little chaotic breccia. No actual centers of eruption were found, though the thick breccia very locally developed north of Creede, southwest of Snowshoe Mountain in the western part of the Creede quadrangle, and near Eagle Mountain in the Pagosa Springs quadrangle are believed to be very near vents. However, the fact that both the individual flows and the member as a whole are thickest in the Creede quadrangle indicates a general center, probably with several vents, in that area. The very thick flows near San Luis Peak and also near Mt. Hope indicate vents near those places. The local thick body of Snowshoe Mountain which is of a uniform rock type different from the rest, clearly indicates a vent for this type in the Snowshoe Mountain area.

Tremendous volumes of lava must have been erupted at one time—probably 100 cubic miles or more in some cases. The lavas probably had a moderate fluidity for some flows seem to have been widespread though very thick, but they were probably not so fluid as the tridymite rhyolite lavas. An uncertain part of the material originally called flows may represent hard, welded tuffs.

HUERTO QUARTZ LATITE

NAME AND DEFINITION

The name Huerto formation was furnished by the authors to Patton (1917, p. 20) for that group of quartz latites (called andesitic rocks), belonging to the Potosi volcanic series, and lying between the Alboroto and the Piedra formations. The name was again quoted by Emmons and Larsen (1923, p. 12) and by Knowlton (1923, p. 184).

Since these reports were written, the formation has been more completely studied and, as it has been found to be made up almost entirely of dark quartz latites, the name Huerto quartz latite is proposed in place of Huerto formation. The Huerto quartz latite is therefore defined as that body of dark quartz latites that lies between the Alboroto and the Piedra rhyolites. It overlies the Alboroto rocks regularly and is overlain irregularly by the Piedra. It is especially well developed in the San Cristobal quadrangle and it is named from its occurrence on Huerto Peak, west of Huerto Creek, in the southern part of that quadrangle.

DISTRIBUTION AND SIZE

The Huerto quartz latite has been mapped from the southern part of the Uncompahgre quadrangle, south and southeast, to the north-central part of the Summitville quadrangle, a distance of about 50 miles. In all it underlies an area of about 200 square miles.

There seem to have been three main broad volcanic domes of Huerto age, all with gentle slopes and all chiefly in the San Cristobal quardangle. The largest was centered in the Squaw Mesa area south of the Rio Grande, and must have had a height of more than 2,500 feet and a diameter at its base, representing the maximum extent of its flows, of nearly 40 miles. It occupied an area of about 1,000 square miles and had a volume of about 150 cubic miles. It is made up almost entirely of dark pyroxene-quartz latites, and most of the eruptions are flows. The volcano of the Bristol Head area was much smaller and attained a height of more than 1,700 feet and a diameter of only a few miles. It occupied an area of approximately 75 square miles and had a volume of only 10 cubic miles. Its center could not have been far from the place on the western slopes of Bristol Head where the maximum thickness is now exposed. The materials ejected by this volcano were in considerable part pyroclastic and the rocks were much like those of the Squaw Mesa area, but some were hornblendic quartz latite. Material from this volcano and from the Squaw Mesa volcano probably coalesced. The third volcano must have centered east of Lake San Cristobal and was of about the same size as the one of the Bristol Head area. The chief eruptions of this volcano were light-colored hornblende-quartz latites and rhyolites. Other volcanoes of Huerto age may have existed but they are either covered by the Piedra rhyolite or completely removed by erosion.

The Huerto rocks were mostly flows, with considerable pyroclastic material, especially in the Bristol Head area, and along the borders of the volcanoes is some material that was carried by water.

GENERAL CHARACTER

The Huerto quartz latite of Squaw Mesa is made up of dark quartz latites and it shows conspicuous somber outcrops. It is commonly made up of a succession of thin flows—rarely more than 100 feet thick—and layers of breccia. The flows and breccia are in nearly equal amounts, but under Bristol Head the breccia makes up the greater part of the material. In general the breccia is made up of coarse, angular fragments of rocks similar to the flows, and there is little fine material and little evidence of bedding or sorting; some probably represents material brecciated during flow. The thick body of breccia under Bristol Head is made up of a greater variety of rocks, it contains some fine material, the fragments show some evidence of rounding, there is some sorting and bedding, and locally there are thin-bedded tuffs. The body in the basin of Trout Creek also contains considerable fine-grained tuff-breccia, but not so much as the Bristol Head section. This tuff probably represents an upper layer eroded from the areas to the west.

Most of the Huerto quartz latite in the Creede and Summitville quadrangles is chaotic tuff-breccia in which angular fragments of all sizes as much as a foot or more in diameter occur. Only locally is there a suggestion of bedding or sorting. In most places the fragments are equal to or more abundant than the softer matrix. Here and there are thin intercalated flows and lenses of flow-breccia which thin out laterally in short distances. East of South Fork basin a flow of pyroxene-quartz latite from 100 to 300 feet thick forms the lowest member of the formation. The Huerto east of Lake San Cristobal is mostly in thick flows.

The rocks of the Huerto are predominantly dark pyroxene-quartz latites not far from basalts, but lighter colored hornblendic quartz latites are present under Bristol Head and they make up most of the body that is east of Lake San Cristobal.

DESCRIPTION

The greater part of both the flows and the breccia south of the Rio Grande are dark pyroxene-quartz latites, chiefly of two kinds with some of intermediate character. Both kinds have much the same chemical and mineralogical composition, and they differ chiefly in texture. Neither of these types is characteristic of any particular area or horizon but they are interbedded and closely associated. Perhaps the most common rock is an olivine-bearing tabular feldspar-pyroxene-quartz latite. The other type, which is nearly as common, has small inconspicuous feldspar crystals and commonly has large augites. Rock of intermediate character are less abundant.

The tabular feldspar-pyroxene-quartz latite is present in all the large bodies of the Huerto quartz latite. A flow near the base of the Huerto northeast of Lake Santa Maria is of this type but contains more quartz and orthoclase than the rocks of the Huerto Peak mass. Similar rocks make up the lower part of the Huerto east of Lake San Cristobal. Quartz latites with hornblende and pyroxene, or with hornblende alone, are subordinate in the southern area, but they make up most of the body east of Lake San Cristobal and are found in the Bristol Head area, both in the flows and the breccia, where they are subordinate to the pyroxene rocks. Small dikes and sills of the hornblendic rocks were found at a number of places. Small flows of rhyolitic rock were found in Clear Creek Canyon southeast of Lakemans Fish Pond in the lower slopes of Trout Creek, just above the forks and east of Lake San Cristobal.

Overlying the pyroxene-quartz latites and making up the greater part of the mass east of Lake San Cristobal is a group of hornblende-quartz latites. These rocks are dense except for a few large gas cavities and some porous streaks, and are medium to dark gray, rarely purplish or red-brown. They carry a few white plagioclase laths a millimeter long, some hornblende and biotite, and rare hypersthene and augite, in an aphanitic groundmass.

The upper parts of the Huerto quartz latite of this area east of Lake San Cristobal are somewhat similar to those described in the preceding paragraph but they carry more and larger feldspar phenocrysts—as much as a centimeter across—and are much like the rocks of the Fisher quartz latite. The rocks at the crest of the southern part of the ridge have augite as the chief dark mineral, some resorbed biotite, and commonly lack hornblende and hypersthene. The rocks at the crest in the northern part of the ridge are hornblende-pyroxene-quartz latites, similar to those immediately overlying the tabular feldspar-pyroxene-quartz latite.

ASSOCIATED INTRUSIVE ROCKS

The Huerto rocks are found in three domelike bodies. In each of the domes some small dikes but no large body of intrusive rocks were found. In the San Cristobal quadrangle south of the Rio Grande in the drainage of Squaw and Jumper creeks and adjoining areas, several small dikes of pyroxene-quartz latite similar to the flows of the Huerto-quartz latite cut the Alboroto rhyolite and in places the Huerto quartz latite. Many dikes cut the Huerto near the head of Woodfern Creek. Similar small dikes were found to the east in the western part of the Creede quadrangle near Wagonwheel Gap in Soda Creek, where they cut the Alboroto, and still farther east in the southeastern part of the Creede quadrangle, east of Ribbon Mesa, where they cut Treasure Mountain and Alboroto rocks.

PIEDRA RHYOLITE

DISTRIBUTION AND THICKNESS

The Piedra rhyolite is not so widely distributed nor does it underlie so large an area as the Treasure Moun-

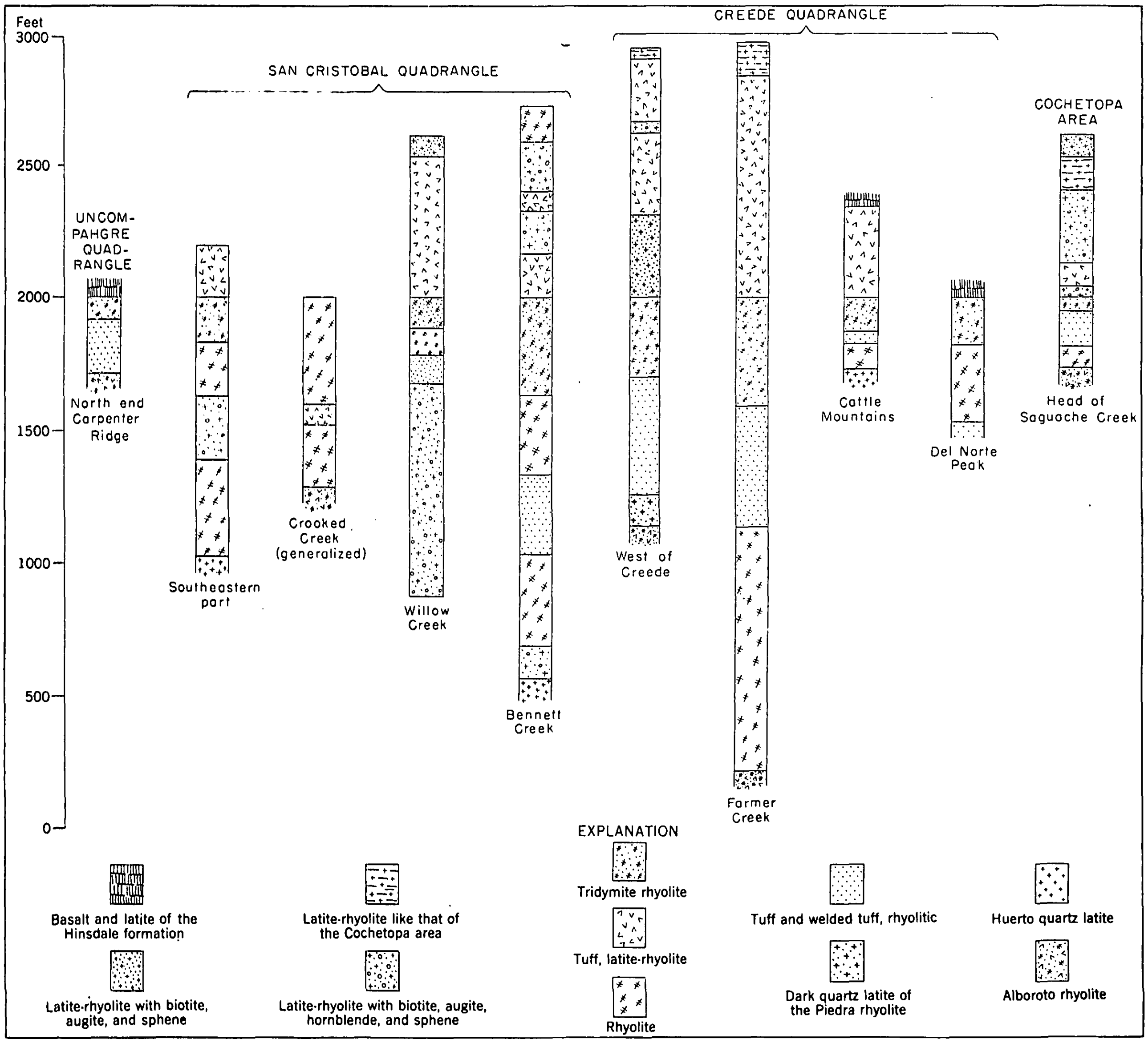

FIGURE 23.—Comparative sections of the Piedra rhyolite. The sections are somewhat generalized.

tain or Alboroto rhyolites, or as the Conejos quartz latite, and it is confined to the central part of the area occupied by the Potosi rocks. It is present chiefly in the San Cristobal and Creede quadrangles but extends to the north into the Uncompahgre and Cochetopa quadrangles, and to the southeast for a short distance into the Pagosa Springs and Summitville quadrangles. It is thus confined to an area that is rudely circular in outline and about 70 miles in diameter whose center is near the west border of the Creede quadrangle somewhat north of the center of that quadrangle and a few miles west of the town of Creede. The details of the distribution are shown on the geologic map (pl. 1).

Its thickness is variable, because it was deposited as a lenslike body. It buried a surface of considerable relief, and its upper surface is everywhere more or less modified by erosion. In the central part of the area it is commonly more than 2,000 feet thick and it locally reaches nearly 3,000 feet, but it becomes thinner toward the margins of the area it occupies. As the formation as a whole becomes thinner toward the margins, the individual members become thinner and tuff and thin flows make up more of the sections, as shown in the cross sections in figure 23. This is less obvious to the west where erosion has been greater than to the east, north, and south.

The thinning out of the formation as a whole and of its constituent members in all directions from the center, as well as the present roughly circular limit of distribution, indicate that the formation never extended

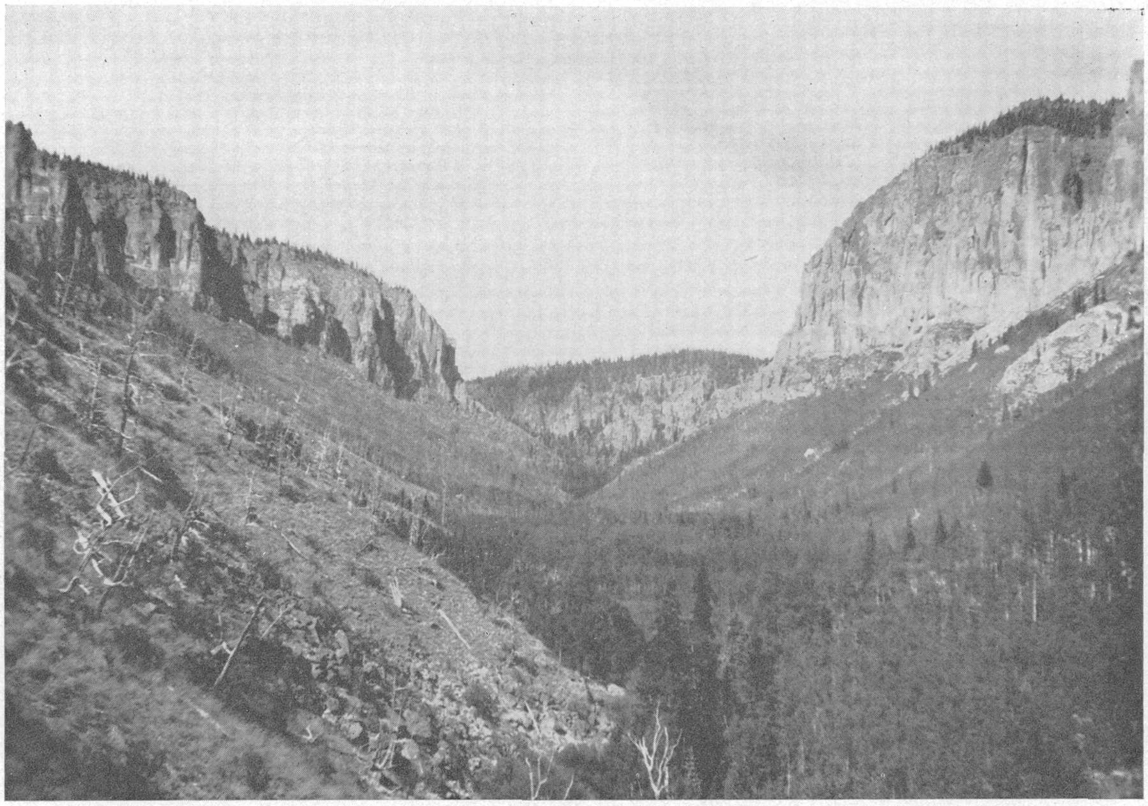

FIGURE 24.—Typical outcrops of Piedra rhyolite in West Bellows Creek, as seen from north of bench mark 11,570, Creede quadrangle. The bench above cliff is formed by the main tuff layer of the Piedra.

far beyond its present limits and that it was originally a great dome with very gentle slopes, about 70 miles across and 2,500 feet thick in its central part. It covered an area of about 5,000 square miles and had a volume of about 600 cubic miles.

GENERAL CHARACTER AND SUBDIVISIONS

The Piedra rhyolite is made up of four distinct members whose succession is similar throughout the area occupied by the formation. As these extrusions were spread over a topography of mountains and canyons, the lower members partly filled the canyons; hence, the members are not everywhere present. The chief rocks of all four members are rhyolites or latites very near the rhyolites.

The lowest member is made up chiefly of flows of the cavernous rhyolite, low in plagioclase content, whose thickness, because of the irregularity at the base, is highly variable and locally exceeds 1,000 feet. Some tuffs are associated with the rhyolite, some rhyolitic latites, and some dark quartz latites.

Overlying the lower rhyolite member are several flows of tridymite rhyolitic latite. These flows are widespread and rather uniform in character and thickness. They are reddish-brown rocks characterized by conspicuous fluidal lenses of porous lighter colored material. They have conspicuous phenocrysts of plagioclase, orthoclase, biotite, and augite. This member is more resistant than the underlying and overlying rocks and forms prominent cliffs and mesas. The rhyolitic tridymite latite is rarely more than 400 feet thick.

Regularly overlying the rhyolitic tridymite latite member is a layer made up chiefly of rhyolitic latite tuffs but with some flows of similar rock, some welded tuffs, and local lenses of dark quartz latites. This tuff is commonly from 300 to 500 feet thick.

Regularly overlying the tuff and grading into it is a group of thin flows, with interbedded tuff, of rhyolitic latites that carry phenocrysts of plagioclase, biotite, hornblende, and some augite, quartz, sanidine, and sphene. They underlie the high mesas and are commonly less than 600 feet thick.

The outcrops (figs. 24–26) of the different members of the Piedra rhyolite are typical. The lower rhyolites form irregular slopes, the tridymite rhyolitic latite forms cliffs and a mesa, the tuff underlies smooth slopes, and the upper rhyolitic latites form an upper series of cliffs and mesas.

THE LOWER RHYOLITE MEMBER

In the central part of the Piedra mass in the San Cristobal and Creede quadrangles, the lower rhyolite member of the Piedra rhyolite is of irregular thickness because it was spread over a mountainous surface, and in many places it is more than 1,000 feet thick. To the north and east, nearer the margin of the Piedra mass, the base of this rhyolite is more regular and the rhyolites are much thinner. In the thick part of this member it is made up predominately of thick flows of the cavernous rhyolite. Tuffs and breccias in thick beds overlie or are interbedded with the rhyolite, and local lenses of dark quartz latites, chiefly breccias, are associated with the rhyolite tuffs. In the San Cristobal quadrangle flows of a tridymite rhyolitic latite, much like the rocks of the upper unit of the Piedra, are at the base of the Piedra or between flows of rhyolite.

Near the borders of the Piedra mass this lower member is made up chiefly of tuffs, with some thin flows and hard welded tuffs. In the extreme southern part of the Del Norte quadrangle gravels of dark quartz latites are interbedded with rhyolitic flows and tuffs.

The lowest observed rocks of the Piedra rhyolite are a group of rhyolites and rhyolite breccias, found only near the foot of the escarpment in the basin of Farmers Creek where they have a maximum thickness of about 200 feet. The most usual type of these rocks is a pink or gray brecciated rhyolite in which fragments of rhyolite, glass, and pumice are most abundant and pebbles of dark quartz latites are few. The weathered outcrops frequently have a cavernous or vesicular character resulting in large measure from the weathering out of fragments of pumice and other material.

Of greater importance is the overlying reddish rhyolite so wonderfully developed in the Creede mining district and known in the Creede report as the Mammoth Mountain rhyolite (Emmons and Larsen, 1923, p. 40–44). Northeast of Creede this flow is about 1,000 feet thick, but it varies greatly in thickness and thins out rapidly to the east. In the cliffs east of Farmers Creek it is only a few hundred feet thick. It was found only north of the Rio Grande and east of Willow Creek and seems to have filled in a pre-Piedra valley. The rock is characteristically reddish brown, of dull luster and has an uneven or hackly fracture. It is a flow breccia or tuff and has a mottled appearance much emphasized by weathering. The rock contains about 10 percent of phenocrysts; glassy orthoclase as much as 2 mm in cross section. It is in excess of porcelain-white plagioclase, and quartz and biotite are less abundant. The groundmass is aphanitic, dense, and shows a delicate, indistinct fluidal texture. The fragments consist of rhyolite similar to the host, and of foreign material, chiefly rhyolitic latite.

South of the Rio Grande the base of the Piedra rhyolite is marked by cavernous rhyolite ranging from gray to pink. In the Creede quadrangle it is well exposed on the slopes of Del Norte Peak, Beaver Mountain, Cattle Mountain, on both slopes of Park Creek and elsewhere. It resembles the rhyolite just described in composition and, to a somewhat less degree, in texture. In outcrop it commonly, although not always, exhibits irregularly shaped and frequently

FIGURE 25.—A regular flow of Piedra rhyolite overlying thick beds of rhyolite tuff at the head of Bennett Creek, northeastern part of the San Cristobal quadrangle.

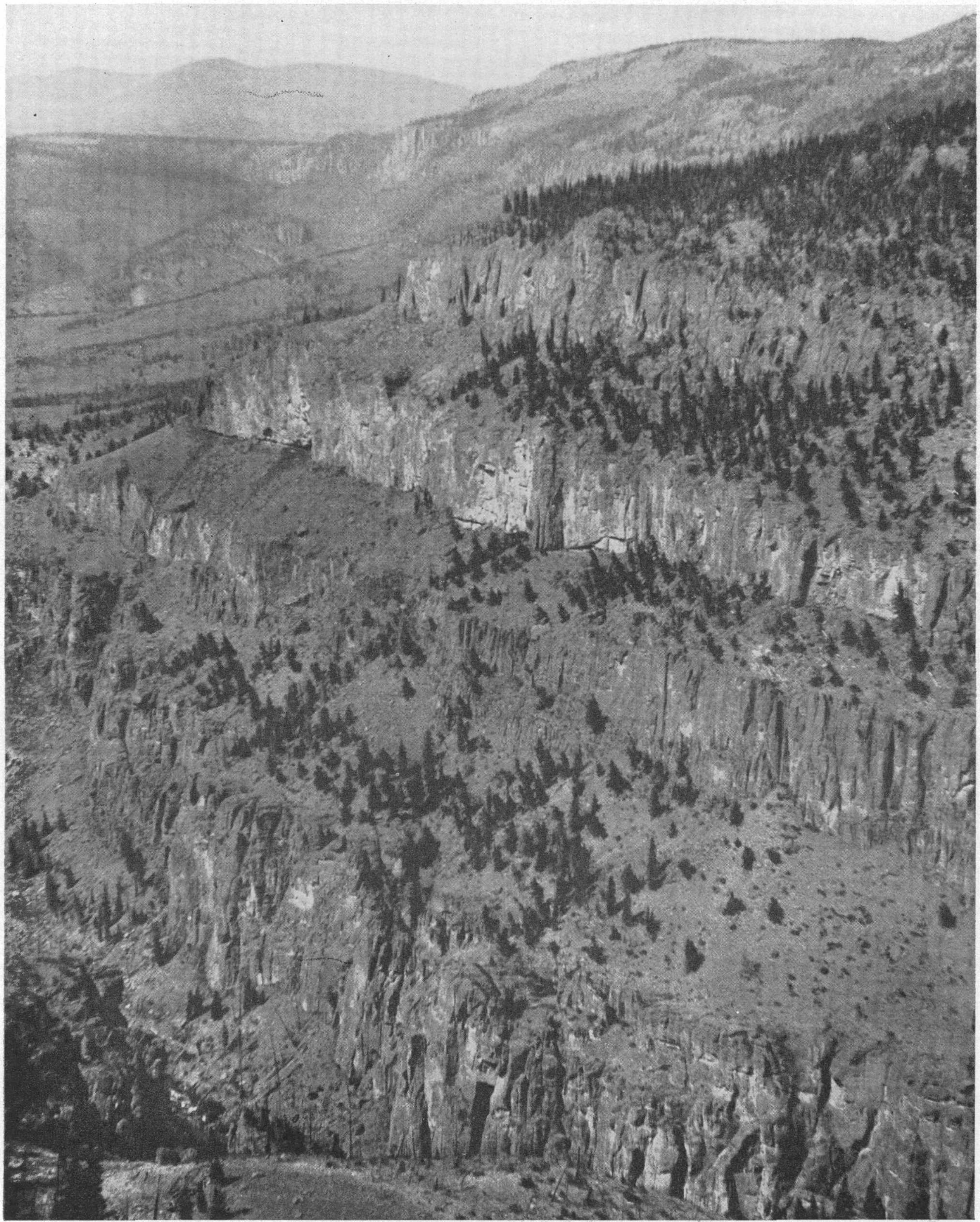

FIGURE 26.—Outcrops showing regular layering of Piedra rhyolite in cliffs in West Bellows Creek, as seen from south rim of East Bellows Creek, Creede quadrangle.

lenticular cavities which are as long as several inches. In this respect and in its somewhat less mottled appearance, the rock differs from the Mammoth Mountain type. The rhyolite usually possesses a distinct fluidal structure. The base of the flow is usually marked by a zone of glass, and small lenses, an inch or more long, of black glass in fluidal arrangement are common throughout the body.

A somewhat similar cavernous rhyolite with phenocrysts of orthoclase, plagioclase, quartz, biotite, and augite, is locally present at the base of the Piedra rhyolite in the Saguache Park area in the southern part of the Cochetopa quadrangle, and is nowhere more than 100 feet in thickness. It is overlain by about 100 feet of poorly exposed tuff which carries a few pebbles of rhyolitic latite and dark quartz latite.

In the southwestern part of the Creede quadrangle on the ridge between West San Juan and Beaver creeks, similar rhyolites at the base of the Piedra rhyolite are locally nearly 1,000 feet thick. In the San Cristobal quadrangle, these flows cover much of the high country about the Continental Divide from the vicinity of Red Mountain to the northwest as far as the Huerto Creek fault, including the remnants of Piedra to the south and east. Locally, at Piedra Peak and a few places to the west, remnants of rhyolitic latites form most of the northern part of the ridge. The Piedra areas on both sides of Texas Creek, with the exception of the rounded area south of Ruby Lake, are made up of the cavernous rhyolites. Farther west the flows overlying the Huerto quartz latite, both east and west of Weminuche Pass and the remnants west of Ute Creek, are of this type. North of the Rio Grande in the eastern part of the San Cristobal quadrangle on the ridge to the west and south of Lake Santa Maria, a flow of similar rhyolite filled in the irregularities in the underlying Huerto and is of variable thickness at the base of the Piedra, in places pinching out altogether. This is well shown north of the Rio Grande and again south of Lake Santa Maria. There was probably some erosion between the rhyolite and the overlying rhyolitic latite because just northeast of Lakemans Fishponds and for some distance to the northwest the irregularity at both the base and top of this rhyolite flow is well shown and the rhyolite underwent a considerable amount of erosion before the deposition of the overlying tuffs and flows. South of this beneath Bristol Head the rhyolite is not present but on the eastern border of the quadrangle northwest of the Rio Grande these rhyolites reappear, and to the east of this they thicken very rapidly and extend for several miles. To the northwest the rhyolites become somewhat more abundant and are found nearly everywhere at the base of the Piedra in the drainage areas of Clear and Crooked Creeks. In the Cebolla basin the flows are of the same character.

In the southeastern part of the San Cristobal quadrangle there is commonly at the base of this rhyolite a considerable thickness of a red to reddish-brown flow breccia. The included fragments are generally less than an inch across, are evenly distributed, and are made up of different rocks—rhyolite, rhyolitic latite, and darker rocks. In places near Red Mountain the fragments become larger and are so abundant that the rock superficially resembles a mafic breccia. A considerable part of the fragments are of dark quartz latite picked up from the Huerto quartz latite, and of quartz monzonite porphyries, quartzites, and other rocks carried up from below. The matrix of this flow breccia is commonly red or reddish-brown; it is porous to fairly dense and has an earthy luster. It contains a few phenocrysts of white andesine and biotite in an aphanatic to glassy groundmass. Higher up, the rhyolite is pink and carries few inclusions. It is a platy fluidal rock with very few crystals of feldspar and biotite. Cavities an inch or more across and forming the centers of large spherulites are common, and in some of the rock they are lined with quartz crystals and less commonly with tridymite.

In the drainage areas of Clear and Crooked Creeks there are also present thin flows of a porous, pink rhyolite with rather more phenocrysts of sanidine than in the rock just described, and abundant tridymite. Banding is sometimes present and the rocks then resemble the rhyolites of the Alboroto rhyolite near Creede.

For some miles west of Creede, as far west as Shallow Creek, these massive flows of rhyolite are not present at the base of the Piedra rhyolite and their place is taken by a hornblende rhyolitic latite and rhyolite in tuff beds and thin flows. At the head of Shallow Creek the massive rhyolite is overlain by an irregular to lens-like body, as much as several hundred feet thick, of flows and breccia beds of hornblende-rich rhyolitic latite, with some dark quartz latites and rare rhyolite. Farther east, this rhyolitic latite is at the base of the Piedra. This horizon was described as the hornblende-quartz latite in the Creede report (Emmons and Larsen, 1923, p. 36–38).

This rhyolitic latite shows a great range in color but much is drab. Most of the fresh rocks are dense, and nearly all show a more or less distinct fluidal structure. At the bases of some of the flows there are a few feet of black obisdian carrying the usual phenocrysts. The rocks are chiefly rhyolitic latites nearer the dark quartz latites than the normal rhyolitic latites of the Piedra. Some are darker quartz latites.

Overlying the cavernous rhyolite of the Piedra on the ridge east of Ute Creek, both north and south of Rio Grande Pyramid there is a dark quartz latite tuff-breccia which is locally 600 feet thick. The base of this member is regular, lies at an altitude of 12,900 feet south of Rio Grande, and gradually becomes lower to the north and east and is at an altitude of 12,100 feet at the northern end of the ridge. The material is fairly well bedded but is not sorted. The fragments, many of which are several feet across, show no evidence of rounding. The outcrops are light colored and the breccia is soft and poorly cemented. The fragments are all of a single kind of hornblende-pyroxene-quartz latite. The lack of rounding of the fragments and the uniformity of the material indicate pyroclastic material from a local vent nearby. No similar tuff-breccias have been found in the adjoining area, and the rocks resemble some of the hornblende rhyolite-latites in the Shallow Creek area near the same horizon of the Piedra, morely closely than they do the rocks of the Fisher quartz latite. This similarity, together with the regularity at the base of the breccia, make their inclusions in the Piedra rhyolite seem reasonable. The rocks of this breccia are rather light-colored hornblende-pyroxene-quartz latites. They are red-brown to light gray, rather dense, and show abundant white crystals, rarely more than a millimeter across, of feldspar with black prisms of hornblende in an indistinct groundmass.

Overlying the hornblende rhyolite-latite in Shallow Creek and east as far as Creede there is a variable thickness of rhyolite tuff and flow breccia, characterized by a porous texture and abundant fragments of pumice. It was called the Windy Gulch rhyolite breccia in the Creede report (Emmons and Larsen, 1923, p. 38–40). A similar tuff and flow breccia overlies an irregular surface of the rhyolites east of the north end of Lake Santa Maria in Rough and Mineral Creeks in the northern part of the San Cristobal quadrangle and adjoining parts of the Uncompahgre quadrangle, and in Saguache Park in the southern part of the Cochetopa quadrangle. This rhyolite breccia is commonly from 100 to 200 feet thick, although locally it is much thicker. This rock is commonly pale red brown, less commonly it has one of the lighter tints of gray; the altered rock is white or gray. The luster is always chalky dull. The rock is made up in considerable part of irregular, ragged fragments of pumice rarely more than a few centimeters across, having a fibrous appearance, due to the fine elongated pores. These fragments are of somewhat lighter color than the body of the rock; locally they are replaced by a green claylike material or by drusy quartz. They weather out, leaving many rough cavities of different sizes. In addition there are fewer fragments, commonly not more than 1 centimeter across but rarely more than 10 centimeters, of a variety of foreign rocks; these are generally much altered and consist chiefly of the underlying rhyolites and hornblende-rhyolite-latite, but a few are of other rhyolitic and quartz latitic rocks. The matrix is always less porous than the pumice fragments, and in some of the rock it is fairly dense. It carries a few 1-millimeter crystals of glassy orthoclase and a very few crystals of biotite. Much of the rock is believed to be a welded tuff, although a part may represent a "mud flow" or tuff. The fragments, which make up a large part of the rock, are similar to the matrix except for their greater porosity. These welded tuffs may represent material that was thrown from a crater, settled around the vent while still soft, became welded together, and flowed much as any viscous lava. The thin sections of the rock show a few crystals of orthoclase and a very few crystals of plagioclase, biotite, magnetite, apatite, and zircon, in a highly porous, submicroscopic to glassy groundmass.

On the upper slopes east of Phoenix Park, a few miles north of Creede, about 200 feet of rhyolite tuff with one or more flows near the base rather regularly overlie the rhyolite breccia and underlie the tridymite rhyolitic latite. It therefore occupies about the same position in the section as the rhyolite tuffs described in the preceding paragraph. This is the rhyolite tuff of the Creede report (Emmons and Larsen, 1923, p. 44–45). The tuff is nearly white to pale drab and has in large part a sandy texture. It carries abundant glassy crystals of feldspar, black biotite several millimeters across, and a few small fragments of a rock which contains abundant phenocrysts in a pumiceous matrix. Larger pebbles of similar rock and of a variety of other rocks are locally present. A part of the material is a rhyolitic latite tuff made up largely of broken crystals of plagioclase, with considerable orthoclase, some quartz, biotite, green hornblende, and augite in a very fine glassy matrix. It closely resembles the quartz latite tuff under Nelson Mountain. The flows and welded tuffs are rarely more than 25 feet thick, and where two are present they are separated by a small amount of tuff. The rocks of the flow and welded tuff are rather porous light red-brown rhyolite flow-breccia with many small fragments of pumice and rhyolite and a few of a fine-textured granitic rock. It carries scattered glassy crystals of orthoclase, white andesine, and black biotite. The groundmass is largely glass, with many trichites of red hematite and some ropy streaks that are largely crystalline.

Rhyolite tuffs with associated rhyolite flows or welded tuffs, mostly thin, make up nearly the whole of the Piedra rhyolite in the Uncompahgre, Cochetopa, Saguache, and Del Norte quadrangles, They probably belong to the lower rhyolite horizon, though they may include other parts of the Piedra. These tuffs with rhyolite flows, are especially thick in the basin of Spring Creek in the southwestern part of the Cochetopa quadrangle and adjoining parts of the Uncompahgre quadrangle, where they reach a thickness of 1,000 feet. In this area part of the tuff is a chaotic breccia made up of angular fragments of rhyolite, mostly white and glassy, as much as 6 inches across, and part is finer grained and made up of pumice fragments and the broken walls of gas cavities. The material shows little bedding. Several thin flows and welded tuffs of rhyolite, mostly less than 25 feet thick are present in nearly every thick section, but they are seldom widespread. Sections only a mile or so apart may be very different. These flows are chiefly of red-brown cavernous rhyolite. Some of the flows are fluidal and platy and carry porous lenses or streaks rich in tridymite. One thick widespread flow is a dense, nearly white tridymite rhyolite with few phenocrysts. Some small flows of black or lighter-colored glass with few or no phenocrysts are present. These rhyolite tuffs, breccias, and flows are thick to the southwest in the San Cristobal and Uncompahgre quadrangles at the heads of Mineral and Rough Creeks, where they are much altered, but to the north and east they are thinner and more regular. It seems probable that the source for this material was in this general area.

Small local bodies of dark rocks are associated with the tuffs in the southern part of the Uncompahgre quadrangle. On the east slopes of Rough Creek near the quadrangle line is an outcrop of latite with phenocrysts up to 1 centimeter across of plagioclase, biotite, and hornblende in a groundmass with much tridymite. In upper Mineral Creek, as well as near the mouth of Spring Creek, there are some dark rocks.

Another thick body of rhyolitic tuff underlies the area around Cochetopa Dome in the central part of the Cochetopa quadrangle. In this area several hundred feet of rhyolitic tuffs, in part thin bedded, and clearly water laid, are exposed and form the gentle slopes on both sides of West Pass and Archuleta Creeks. The lower layers of this tuff are fine textured and thin bedded, but the upper layers carry more large fragments, chiefly of rhyolite, but some of dark quartz latite. The fragments of rhyolite are mostly angular and those of the dark rocks tend to be well-rounded. These beds are clearly water laid, probably mostly by streams but in part in ponds.

Over the tuff there is the thick flow of a light-colored rhyolite that has few phenocrysts and forms Cochetopa Dome.

In the southern part of the Uncompahgre quadrangle in the upper drainage of Cebolla Creek, these rhyolitic tuffs and flows of the Piedra rhyolite overlie an irregular surface of Alboroto rhyolite and older rocks, but to the north similar tuffs that can be connected with but few breaks overlie the Alboroto regularly and are much thinner. Near the Gunnison River these rhyolites are much like the rhyolites at the base of the Alboroto. They were at first thought to belong to the Alboroto, but their correlation with the Piedra seems more probable because, although they are petrographically similar to both the lower member of the Alboroto and the tuff member of the Piedra to the north, they seem to connect stratigraphically with the Piedra. However, where rhyolites of the Alboroto and Piedra of like character come together in this way it is difficult to distinguish between them. In the Uncompahgre quadrangle these upper rhyolites have been included in the Piedra though the contact was not followed out in detail. Near the town of Gunnison the Alboroto is made up entirely of rhyolite and if any of the Piedra rhyolite is present it has been included in the Alboroto. These tuffs of the Piedra may extend to the north into the West Elk Mountains and make up the Piedra of the Saguache quadrangle and of the Del Norte quadrangle to the south. The tuffs of most of the material are nearly white, pale pinkish, or cream colored, are thick-bedded, and made up mostly of small fragments of glass, pumice, and the broken walls of gas cavities, and carry a few crystals of feldspar and biotite.

A few thin massive beds of welded tuff consist of about 15 percent of phenocrysts 1 or 2 mm in cross section, of sanidine, oligoclase or andesine, biotite, and, in places, hornblende or augite. Except for the glassy horizons at the base of these, the groundmass is holocrystalline but very fine grained to submicroscopic, and contains much tridymite. The flow 20 feet thick under the Hinsdale on the north end of Carpenter Ridge in the northern part of the Uncompahgre quadrangle is a tridymite rhyolite that carries biotite, brown hornblende, and augite. Immediately under this is a flow of cavernous tridymite rhyolite that carries only biotite.

The widespread flow at the base of the Piedra rhyolite in the Sheep Creek area in the extreme western part of the Saguache quadrangle and adjoining part of the Cochetopa quadrangle is a red-brown cavernous tridymite rhyolite of the usual type, except that it carries some hypersthene as well as biotite. Hypersthene is very rare in the rhyolitic rocks of the San Juan Mountains.

The rock capping Henderson Mountain, east of Sheep Creek in the Saguache quadrangle, is a banded, fluidal, light-colored quartz latite with porous layers. It carries a few phenocrysts of andesine, some of biotite and hornblende, both much resorbed, and a few of augite, in a groundmass that is made up of felted, shredded feldspar and altered dark minerals. Cristobalite is abundant, partly in spherulites, in the porous parts of the rock.

Rhyolitic tuff and associated flows are present locally over the great latite flows of the Alboroto rhyolite on the east flank of San Luis Valley and in the Saguache River drainage area and they were no doubt at one time much more widely distributed. A section of this member from the steep slopes south of the mouth of Ford Creek is shown in figure 23. Immediately over the latite of the Alboroto there are 200 feet of rhyolitic tuff, forming gentle slopes and poor exposures. Above this tuff are 100 feet of dense pink rhyolite or welded tuff which has a few phenocrysts of orthoclase, oligoclase, and biotite. It is in turn overlain by the latite and basalt of the Hinsdale formation. Under Storm King Peak in the northwestern part of the Del Norte quadrangle about 200 feet of tuff separates the rhyolite-latite of the Alboroto and the basalt of the Hinsdale.

In the southern part of the Del Norte quadrangle north of Rock Creek, at the base of the Piedra rhyolite is a considerable thickness (as great as 100 feet) of dark, well-bedded and sorted quartz latite gravel, with interlayered sand. The fragments are of a dark, fine-grained basaltic-looking rock, are as much as a foot across, and are well rounded. This gravel is overlain by a flow of welded tuff of tridymite rhyolite about 25 feet thick; above this is a little more gravel similar to the lower gravel; and over that is more rhyolite tuff.

THE TRIDYMITE RYHOLITIC LATITE MEMBER

In the central, thick part of the Piedra mass a group of rather uniform flows of rhyolitic latite, characterized by abundant tridymite, overlies a fairly smooth surface of the lower rhyolite horizon of the Piedra rhyolite. This group of flows is rarely more than 400 feet thick, and it has been found in an area nearly 50 miles across. These flows are more resistent to erosion than the underlying rhyolite tuff and the overlying rhyolitic latite tuff and characteristically crop out in prominent cliffs and underlie broad benches, such as that in the Creede quadrangle north of the Rio Grande, of which Wasson and Blue Creek Parks are a part. The rocks of this member are pinkish red and most of them contain irregular, lenslike, fluidal bands, a few millimeters thick, that are nearly white, porous, relatively coarsely crystalline, and rich in tridymite. The rocks carry about 30 percent of phenocrysts, a few millimeters long, of sanidine, andesine, and biotite in an aphanitic, rhyolitic mass that is rich in tridymite. In places, the lower flows lack the porous lenses, have more phenocrysts, and contain some quartz, augite, and hornblende. East of Creede and elsewhere the base of this member is biotite-augite-tridymite rhyolitic latite. It overlies the rhyolites and is a widespread series of flows, similar in composition, and to a less extent in texture, to the overlying tridymite rhyolitic latite and clearly related to it structurally. These flows are locally more than 500 feet thick in the Farmers Creek area and were found along the steep slopes north of the Rio Grande, and in considerable thickness in the South Fork of Saguache Creek, and they rim the canyon near the mouth of North Fork of Saguache Creek and extends up Horse Canyon. They are also present to the northwest in the drainage area of Cochetopa Creek, west of the head of Horse Canyon. In the southern part of the Creede quadrangle, they are less widespread, probably because they have been largely removed by erosion, but they are present east of the South Fork of the Rio Grande, and under Metroz and Trout Mountains. In the San Cristobal quadrangle very similar rock is locally developed beneath the tridymite rhyolitic latite flows under Bristol Head, north of Fir Creek. Similar flows are present west of Antelope Springs and extend northwest into the drainage area of Clear Creek and on to the high bench north of Porcupine Gulch. The Piedra mass south of the Rio Grande and north of the Spring Creek fault is of the same character; so is that between Trout Creek and South River in the Creede quadrangle, where there are several flows which overlie the lower rhyolite member of the Piedra at the head of the streams. Farther north, however, they immediately overlie older rocks. In most of the San Cristobal quadrangle this rhyolitic latite overlies rhyolite of the Piedra but locally it is at the base of the Piedra.

This rhyolitic latite has the same color as the overlying tridymite rhyolite, but is to be distinguished from that rock by the absence of the lighter-colored lenses and streaks of tridymite and orthoclase, its larger phenocrysts, and its uneven fracture. In a few places, as in West Bellows Creek, there is an associated flow of grayer rock having a composition between a rhyolitic latite and quartz latite. The lower flow contains inclusions of dark quartz latite.

Overlying the rhyolitic latite just described in the Farmers Creek section east of Creede is the rock called the tridymite latite in the Creede report (Emmons and Larsen, 1923, p. 45–50), but which is called in this paper a tridymite rhyolitic latite. It is the most uniform and distinctly characterized member of the Piedra rhyolite. This rock underlies the great bench north of the Rio Grande of which Wasson and Blue Creek parks are parts, and extends north under the high divide into the Saguache basin, but it does not appear to extend as far as Saguache Park. This same group of flows is the cliff-forming member under Bulldog Mountain northwest of Creede, and it forms a band, characterized by cliffs and an overlying mesa, westward to Bristol Head and from there northwest as far as the head of Cebolla Creek. The top of these flows forms the bench at an altitude of 11,500 feet under and north of Bristol Head. Farther west a similar rock underlies the rhyolite of the Hinsdale formation about 3 miles east of south of Heart Lake and makes the three isolated areas of Piedra about the head of Lost Trail Creek. In all this area west of Creede the tridymite rhyolitic latite directly overlies the lower rhyolite member.

The tridymite rhyolitic latite member of the Piedra formation is in regular thick flows and is commonly several hundred feet thick. In most places it is underlain by softer or less regularly layered rocks and is overlain in most places by soft tuffs. It therefore forms one of the most prominent and nearly continuous group of cliffs in the Piedra rocks and its upper surface underlies many large benches and parks.

In color this rhyolitic latite member is dark red-brown. It is characteristically banded and platy, with bands as much as a centimeter across. The main part is rather dense, but irregular streaks and lenses of a paler tint are decidedly porous. These are rather regularly spaced a few centimeters apart and make up a considerable part of the rock. The rock shows abundant phenocrysts of white plagioclase, glassy sanidine, and black biotite, as much as 2 millimeters across. The pores are characteristically lined with minute drusy crystals of tridymite.

Associated with and at the top of the tridymite rhyolitic latite is a coarser, more felsitic rhyolitic latite, which is further distinguished by its light-pink groundmass, its copper-colored biotite, and the glassy sanidine phenocrysts.

The tridymite rhyolitic latite member was not recognized in the Cochetopa or Uncompahgre quadrangles, except in the extreme southern parts, nor in the Del Norte or Saguache quadrangles. However, some of the thin flows of tridymite rhyolite may represent this horizon, for they do not differ greatly from it.

LOCAL DARK QUARTZ LATITE AT BASE OF TUFF

On Bulldog Mountain and the ridge to the north a few miles northwest of Creede, the tridymite rhyolitic latite member of the Piedra rhyolite is overlain regularly by a lenslike body of dark quartz latite which is about 500 feet thick north of Bulldog Mountain, but is entirely absent a mile or so to the east and is absent or very thin a mile to the west. Farther west, this quartz latite is present locally in the upper basin of Rough Creek and above the tridymite rhyolitic latite southeast of Bristol Head. The base of the quartz latite is fairly regular but the upper surface is irregular. This is the andesite of the Creede report (Emmons and Larsen, 1923, p. 51–54).

The mass of the Bulldog Mountain areas is made up of a considerable number of thin flows and a somewhat smaller amount of intercalated breccia. The rocks differ considerably and include light-colored biotite-augite,quartz latites, biotite-hornblende-quartz latites, augite-quartz latites, and dark olivine-quartz latites. Normal basalts have not been recognized. The rocks are largely near quaker drab or mouse-gray. The greater parts of these rocks are fine textured and carry very few crystals that can be seen without a careful inspection with a hand lens. They are, as a rule, conspicuously vesicular or amygdaloidal. In many places the vesicles are much flattened by flow, a process that gave the rocks a platy, fluidal texture. Megascopically they were thought to be basalts. The lowest flow in the drainage basin of Windy Gulch is dark reddish brown and rather dense. It carries scattered crystals a few millimeters across, of white plagioclase and brownish-black biotite and hornblende in a felsitic groundmass. In the basin of West Willow Creek are several small exposures of a dense, deep mouse-gray rock which carries abundant tabular crystals of glassy, striated plagioclase, as much as 5 mm long, and some augite, in an aphanitic groundmass. The lowest flow in Windy Gulch is a quartz latite that carries rather abundant phenocrysts of plagioclase and less of hornblende and biotite. The rock that crops out just below the mouth of Deerhorn Creek on the east approach of the bridge across West Willow Creek and in the two prospects to the west is a biotite-pyroxene-quartz latite. The dark rocks surrounding Bristol Head are in part breccia made up of somewhat rounded fragments of pyroxene-quartz latite, hornblende-pyroxene-quartz latites, and light-colored quartz latite, and in part flows of dark quartz latite.

The small body of dark breccia in the basin at the head of Rough Creek in the northeastern part of the San Cristobal quadrangle is believed to belong to the Piedra rhyolite although its exact character and relations are uncertain, owing to poor exposures and extensive alteration of the rocks of this area. It is clearly beneath some of the Piedra flows but its base is not exposed. The material is a breccia made up of fairly well rounded fragments of dark-gray tabular feldspar-pyroxene-quartz latite imbedded in a matrix of volcanic sand and limonite.

THE TUFF MEMBER

Overlying the tridymite rhyolitic latite or the dark quartz latite of the Piedra rhyolite where the latter is present, is a body of rhyolitic latite tuff, with subordinate local flows and welded tuffs of rhyolite. It is commonly 300 to 500 feet thick. In the Creede report

(Emmons and Larsen, 1923, p. 54–57) it was called the quartz latite tuff.

It is present at roughly the same altitude in Willow Creek basin above Creede, under the mesa of Nelson Mountain, around the heads of Rat and Miners Creeks, under the high mesa north of Bristol Head, and as far north as Painted Peak. Similar tuffs occur at the head of Buck Creek and in Rough and Mineral Creeks. It has been removed by erosion to the west and southwest, but east of Creede it extends for many miles and is well developed above the tridymite rhyolitic latite member north of the Rio Grande. Erosion in these tuffs has given rise to the remarkable forms of Wheeler National Monument. In the Saguache quadrangle these tuffs are widely distributed but they are of variable thickness in the Saguache Park area. Under the long ridge between the North Fork of Saguache River and the Horse Canyon basin these tuffs are several hundred feet in thickness; whereas, to the east of Cochetopa Creek they either do not occur or are covered by the higher mesa making flows.

The greater part of this tuff is sandy, with scattered pebbles which are rarely more than a few inches across; a part is fine grained, and almost none is conglomeratic. The coarser material is thick bedded, but some of the finer material has well-developed closely-spaced laminations.

The maximum development of this tuff member of Piedra rhyolite is in Wheeler National Monument where the section, from top to bottom, is as follows:

	Feet
Soft-white or light-pink homogeneous rhyolitic latite tuff, with few fragments, making castellated and columnar forms	400
Gray indurated tuff, with many angular fragments, of rhyolitic latite and dark quartz latite as much as 3 inches in diameter	150
Plagioclase-quartz-biotite-hornblende rhyolitic latite flow	30
Pink latite tuff-breccia, with many pumice fragments	100
Gray porous pumiceous latitic tuff	300
Total	980

On the ridge between Deerhorn and West Willow Creeks the tuffs carry a larger amount of flow rock, the tuff-breccia is more chaotic than elsewhere, and the rocks are poor in plagioclase. They probably represent a lower, local deposit in a valley, around a local vent. In this area the base is a thinly laminated tuff not more than 100 feet thick. This is overlain by an irregular flow of rhyolitic latite, locally several hundred feet thick, and this in turn is overlain by a chaotic aggregate of thin flows and tuff-breccia. On the west slope of the ridge the lower part of this aggregate is a glassy flow about 50 feet or more in thickness, with a highly irregular base. The extreme northern part of the body is in part tuff, but contains a considerable amount of massive rock in small irregular bodies. The central part of the body under and north of the 11,406-foot peak is in large part white tuff and latite breccia, with subordinate massive rock. South of this peak and beginning near its top there is a fan-shaped body of massive rock, with the handle of the fan forming the narrow ridge just below the peak and its broad part on the ridge to the south, where it directly overlies the rhyolite. This fan-shaped body is a steeply dipping flow which overlies successively the tuff and the rhyolite. Its outline is indicated on the geologic map of Creede and vicinity (Emmons and Larsen, 1923, pl. 3).

The tuff member is commonly nearly white, with a drab or buff cast. In the Creede area the finer material is made up of fragments of glass and some broken crystals of quartz, feldspar, and biotite. The sandy part contains a large number of 1-mm crystals in a finer matrix of glass fragments and some larger fragments of felsitic rock. The crystals are quartz, sanidine, plagioclase, biotite, hornblende, rare augite, and the usual accessory minerals. In quantity, size, and mineral character these crystals closely resemble those of the overlying flows, to which the tuff as a whole has a close similarity. The larger fragments, which make up the main part of the tuff on the ridge west of Deerhorn Creek, are chiefly pumice; locally fragments of thin, platy fluidal rhyolite are abundant, and fragments of other rhyolites and of black glass are present. Dark quartz latites are rare. Under Bristol Head the tuffs contain less plagioclase and have many fragments of pumice.

Massive flows make up a small part of the material; their form and extent are shown approximately on the Creede and vicinity geologic map (Emmons and Larsen, 1923, pl. 3). A prominent flow occurs on the slopes east of Nelson Mountain. It is about 100 feet thick and of a dense, quaker-drab rhyolitic latite much like the rock of the flows overlying the tuff layer but with fewer phenocrysts and a fine-textured groundmass. The rock of the flow west of the Amethyst mine has abundant kaolinized plagioclase, some sanidine, considerable pale-brown biotite, some embayed quartz, and accessory apatite, zircon, and magnetite. The groundmass is a glass with incipient crystallization. Rather abundant gas cavities carry drusy crystals of orthoclase, quartz, and tridymite.

A flow forms the slopes on both sides of West Willow Creek above the mouth of Deerhorn Creek. The rock is light drab or a related color and contains phenocrysts of andesine, quartz, sanidine, biotite, and sphene, in a spherulitic groundmass. This rock is easily weathered and disintegrates into small hackly fragments. Outcrops are poor, and most of them are made up of the disintegrated rock. The slopes are commonly smooth, rather steep, and show the disintegrated rock in place very near the surface.

The massive rock associated with the tuff that overlies this rhyolitic latite west of Deerhorn Creek is in large part a black or dark-gray glass; rarely it is nearly white. It carries rather abundant inconspicuous crystals of glassy, striated andesine as much as 5 millimeters across, some biotite, orthoclase, quartz, and sphene. Many of the rocks have also green hornblende and augite. The groundmass of the glassy rocks shows incipient crystallization, chiefly along the cracks. In some specimens abundant red rounded botryoidal spherulites several millimeters across are imbedded in a greenish glass. These flows have not been separated from the associated tuff on the geologic map.

The rock of the mapped fan-shaped flow south of the 11,406-foot peak west of Nelson Mountain (Emmons and Larsen, 1923, pl. 3) is dark purple drab and resembles some of the dense, fine-textured rhyolitic latites of the Piedra rhyolite.

At the base of these tuffs in the Saguache Park area there is a rhyolite breccia containing angular fragments of latites and rhyolites as much as half an inch in diameter. At the mouth of the North Fork of the Saguache the latter is cavernous and markedly fluidal, although in other localities it is more or less tuffaceous. Here it is a dirty yellowish brown, although elsewhere it is nearly white. A thin section from this locality showed broken, subhedral crystals, as much as 1 millimeter across, of soda plagioclase, sanidine, microcline, quartz, hornblende, and augite, in addition to fragments of the rocks mentioned. Manifestly some of these minerals are foreign to the rhyolite and have been picked up during the process of eruption. The groundmass is chiefly glass colored by ferritic particles. It contains a few microlites of feldspar. In places near the base this rhyolite contains many lenses of black glass, in places several inches across.

This main part of the tuff member is but little consolidated, relatively soft, and is much less resistant than the underlying or overlying rocks. The overlying rhyolitic latites in particular are thick, cliff-forming flows, and the soft tuff gives way under their load, thus giving rise to the landslides which so commonly cover the tuff. In general the tuff forms comparatively gentle slopes with few outcrops, and there is commonly a more or less well-developed bench near its base.

These castellated forms cut in the white tuffs are remarkably well developed in the Wheeler National Monument, about 8 miles west of Creede.

Associated with these tuffs, and in places, at least, overlying them, are flows of a light-colored hornblende-quartz latite. These flows cap Bristol Head and occur at many places at the head of Shallow Creek and west of Mineral Creek. The rock is red and is characterized by conspicuous crystals of hornblende and feldspar, as much as several millimeters across. A microscopic analysis shows that it carries abundant phenocrysts which in order of abundance are labradorite, brown or, less often, greenish-brown hornblende, biotite, augite, and occasionally hypersthene. The groundmass contains many small laths of andesine in a glassy to patchy granophyric base. Sphene, apatite and ilmenite are accessory. In the rock capping Bristol Head the hornblende is less conspicuous than the pyroxene. These rocks resemble the Fisher quartz latite and they may represent remnants of that formation. They have not been separated from the Piedra on the geologic map.

THE RHYOLITIC LATITE MEMBER

Overlying the tuff member of the Piedra rhyolite is a group of closely related flows of ryholitic latite with subordinate tuff in the lower part. These flows are similar in composition to the underlying tuff. They somewhat resemble the Alboroto type of rhyolitic latite, except for the presence of augite in them. They are still nearer the rhyolitic latite of the Alboroto that forms Horseshoe Mountain, south of the Rio Grande in the western part of the Creede quadrangle. These flows were once widely distributed at the top of the Piedra but they are now preserved only as remnants chiefly underlying the high mesas north of the Rio Grande.

In the San Cristobal quadrangle they have been found in the northern part in the heads of Cebolla, Miners, and Rough Creeks, and on the high mesa north of Bristol Head. They extend east into the Creede quadrangle as far as Nelson Mountain.

Under Nelson Mountain there are about 600 feet of these flows. The lower 400 feet is made up of thin flows, with some interlayered tuff, called the Rat Creek quartz latite in the Creede report (Emmons and Larsen, 1923, p. 57–59), and the upper 200 feet is a single great cliff- and mesa-forming flow of wide extent and was called the Nelson Mountain quartz latite (Emmons and Larsen, 1923, p. 59–60). These flows extend west and northwest into the San Cristobal quadrangle and underlie the mesas north of Bristol Head, though they are much thinner there. In color the rocks are pale drab or reddish brown. They are rather dense and have fairly well-developed flow structure shown by horizontal planes of fracture but not by conspicuous banding.

Associated with these flows and immediately under them at the head of Cebolla Creek and at the head of

Miners Creek are several flows of biotite ryholitic latite, rhyolite flow breccias, and a hornblende-augite rhyolitic latite similar to the flows of Nelson Mountain. Similar flows overlie a tuff horizon at the head of Big Buck Creek.

In the drainage area of Mineral Creek there is a thick flow of rhyolitic latite beneath the Fisher quartz latite which weathers rather easily and does not commonly give good exposures. The rock is pink or pale green and is rather dense. In places it shows fine wavy flow lines; in others it is spotted with large white spherulites. The microscopic analysis shows that about one-third of the rock is made up of phenocrysts of andesine-labradorite feldspar and biotite. The groundmass commonly consists of a fine spongelike micrographic intergrowth. Large spherulites are occasionally imbedded in this. This flow is again exposed in the basin of Rough Creek. In both places it overlies a horizon of tuff and associated flows, and in both places there is some biotite rhyolitic latite of normal character above it. There is much alteration in both.

The widespread flow (Cochetopa rhyolite-latite) that makes up most of this rhyolitic latite member in the Creede quadrangle east of Creede, and of the Cochetopa quadrangle is distinguished by its thin sheeting and by its dirty drab to lavender color, locally streaked with pink lenses and set with conspicuous phenocrysts of feldspar, biotite, and quartz. It breaks with an uneven surface.

In the Saguache Park area the latite described in the preceding paragraph is overlain by a white biotite rhyolitic latite that is porous, rather soft, and does not yield good outcrops. It contains few or no sanidine phenocrysts. It apparently has only local distribution, although its susceptibility to erosion suggests that it may have been poured out over a much wider area.

Along the west side of the Saguache River above the North Fork white, porous rhyolitic latite (welded tuff), which is nearly 300 feet thick, directly overlies the tuff member. This rock spalls easily and is usually characterized by small fragments of light-brown pumice, together with conspicuous phenocrysts of orthoclase, quartz, and biotite. This rhyolite makes up many of the fantastic forms, including Chimney Rock, along the ridge north of the North Fork of the Saguache. Similar rock was found on the Continental Divide at the head of a northern fork of Horse Canyon, apparently resting on dark quartz latite, and may indicate an overlap of the upper part of the section over the lower. It was not found in the Farmers Creek area. It also resembles a type of rhyolitic latite which is abundant in Los Pinos Creek. It resembles and probably corresponds approximately to the rhyolitic latite at the top of the Piedra section in the Creede area.

ASSOCIATED INTRUSIVE ROCKS AND CENTERS OF ERUPTIONS

Piedra rocks are less widely distributed than most of the other formations of the Potosi volcanic series and they form one great dome. The sections across the dome, however, show some variety in the rocks. The lowest layer is of rhyolite, over this there is locally dark quartz latite, then tridymite rhyolitic latite, then local dark rocks, followed by rhyolitic quartz latite tuff, and finally rhyolitic quartz latite flows.

The central part of the Piedra dome is near the town of Creede. The chief evidence for a vent in this general area was found in the drainage areas of Mineral and Spring Creeks, northwest of Creede, in the northeastern part of the San Cristobal quadrangle and adjoining parts of the Uncompahgre and Cochetopa quadrangles. There the tuff is unusually chaotic and contains many irregular thin flows of glassy rocks such as would be found only near their source. Somewhat similar tuff with glassy flows was found a few miles north of Creede on the ridge between West Willow and Deerhorn Creeks.

A few small dikes of Piedra age that resemble the rhyolites of the Piedra were found in the basin of Huerto Creek in the southeastern part of the San Cristobal quadrangle and another was found in Fir Creek basin in the eastern part of the San Cristobal quadrangle north of the Rio Grande.

The two dark layers near Creede are thick lenses of small horizontal extent, and they must both have been erupted from vents a few miles west of Creede. No large intrusive bodies were found in this area, but the irregular relations of the dark rocks in the drainage area of Miners Creek may be due to proximity to the vent.

West of the central part of the San Cristobal quadrangle, about 2 miles northeast of Rio Grande Pyramid is a large dike of quartz latite nearly a mile long and as much as 500 feet across. It cuts the Piedra rhyolite and the overlying quartz latite breccia that was included in the Potosi volcanic series. The intrusive rock is very similar to the fragments of the breccia and probably marks an intrusive phase of the dark effusive rocks. It may represent the vent for this breccia. The rock is light greenish-gray, dense, and shows conspicuous 2-millimeter long, glistening black prisms of hornblende and some crystals of white andesine-labradorite in an aphanitic groundmass. It contains about 40 percent of phenocrysts of which andesine-labradorite in stout crystals is chief, green hornblende much less abundant, augite and hypersthene still less so, and magnetite is in small amount. The groundmass is fine grained and rhyolitic in composition. The rock is fresh except for the hypersthene, which is almost completely altered to bastite.

DETAILED PETROGRAPHY OF THE POTOSI VOLCANIC SERIES

The rocks of the six divisions of the Potosi volcanic series have much in common and they will be described together in order to avoid repetition and to emphasize their similarities and differences.

As shown in the section on variation diagrams (pages 269 et seq.) the rocks of the Potosi volcanic series fall near a single set of variation curves and there is no appreciable difference among the variation curves of the different subdivisions of the Potosi. The variation in the composition is so systematic that if SiO_2 or even total iron as FeO, MgO, CaO, or K_2O is known, a fairly good estimate of the chemical composition can be made. The state of oxidation of the iron, the water content, and the proportion of soda and potash in the rocks very rich in SiO_2 and alkalies all will be uncertain. The rocks therefore belong to a single chemical group with one independent variable and if the position of a rock on the variation diagram is known, its chemical composition is approximately known. Moreover, in mineral composition and texture, the rocks of all the subdivisions of the Potosi are much alike although some peculiarities of mineral composition are characteristic of some of the latites of the different subdivisions.

The rocks range from quartz latites near quartz basalts to rhyolites; a very few of them are basalts. Rocks of every composition from quartz basalt to rhyolites are present (see fig. 57, page 286), but rocks of the quartz latite members are chiefly dark quartz latites near the andesites; whereas those of the rhyolitic members are chiefly near the boundary of the quartz latites and rhyolites. Intermediate quartz latites are present only as small local bodies, chiefly in the quartz latite members but also in the rhyolitic members. Graphs showing the approximate distribution of rocks between basalt and rhyolite for the six subdivisions of the Potosi and for all the rocks of the Potosi are shown in figure 57. The curve for all the Potosi rocks shows two broad maxima separated by a very low minimum.

Alkalic feldspar and free silica are the chief constituents of the groundmasses of nearly all the rocks, except the silica-poor rocks. In the rhyolites and rhyolitic quartz latites the groundmasses are chiefly very finely crystalline, are usually spherulitic, and the free silica is in the form of tridymite or cristobalite, or rarely quartz, but in the less silicious quartz latites the groundmass is commonly a spongelike or granophyric intergrowth of quartz and alkalic feldspar with more or less plagioclase and dark minerals.

DARK BASALTIC ROCKS

Dark basaltic rocks, chiefly pyroxene-quartz latites, form a very small proportion of the Potosi volcanic series and they nowhere form large or widespread bodies. They have been found in all three of the quartz latite formations of the Potosi and in the dark lenses of the Piedra and Treasure Mountain rhyolites. They are not confined to any position in any of the formations but seem to be common near the base of the Conejos quartz latite.

These rocks are nearly black, have a small to moderate proportion of small phenocrysts, a fine-grained groundmass, and a texture and habit that are distinctly basaltic. They range from vesicular to dense, and often form flow breccias or clastic beds. They contain phenocrysts of labradorite, augite, varying amounts of iddingsite secondary after olivine, magnetite, and in some rocks hornblende, partly resorbed. The groundmass is fine grained, holocrystalline to partly glassy, and is made up chiefly of plagioclase, with some orthoclase, augite, olivine, magnetite, and glass. A few of the rocks contain determinable quartz, hypersthene, or biotite. The plagioclase phenocrysts are commonly strongly zoned, and contain large cores of calcic labradorite grading outward to oligoclase or andesine. In some of the rocks the plagioclase of the groundmass is nearly as calcic as that of the phenocrysts, in others they are much more sodic. A few of the rocks have some cristobalite in the vesicles. An analysis of one of these rocks from the Conejos quartz latite is given in table 21, column 11, in pocket.

A dark-gray, vesicular pyroxene-quartz latite of basaltic habit is widespread in the Conejos quartz latite in the Conejos quadrangle and it has been found elsewhere. It is especially abundant in the boulders of the Los Pinos gravel that have been derived from the Conejos. This rock is commonly associated with other pyroxene-quartz latites and it is everywhere very subordinate in amount. It contains a few phenocrysts of labradorite and olivine and is mineralogically much like the tabular feldspar-pyroxene-quartz latite.

The typical amygdaloidal basaltic quartz latite at the base of the tuff of the Piedra rhyolite near Bulldog Mountain in the Creede district contains abundant 1-mm tablets of plagioclase, with some augite and altered olivine, that grade into a very fine-textured groundmass made up of plagioclase laths and a somewhat smaller amount of augite grains and magnetite, with considerable brown, clouded interstitial glass. A small amount of quartz is present in some of the rocks; it may be secondary, although it seems to be interstitial to the feldspars of the groundmass. The larger feldspar crystals have cores of labradorite or sodic labradorite and grade outward into albite. The outer zones are filled with glass inclusions. The average composition of the phenocrysts is near andesine. The feldspars of the groundmass range from albite to andesine. The olivine, which is variable in amount, is completely altered to iddingsite, fibrous and strongly birefracting serpentine, carbonates, and iron oxide. The augite is commonly reddish brown from the partial oxidation of the iron, probably before the consolidation of the rock. Some of the sections show areas dusted with iron oxide. which probably represent resorbed crystals of amphibole or other dark minerals. A few of the rocks are holocrystalline and carry considerable interstitial albite and some orthoclase. Superficially the rocks resemble basalts, but they differ from normal basalts in the more sodic character of their feldspar and the small amount of dark minerals; they may well be called olivine-quartz latites. They grade into normal pyroxene rocks.

The filling of the vesicles is varied. The most common is a soft, dull, opallike material with shrinkage cracks. It no doubt represents a gelatinous filling now partly crystallized It is pale yellow-green or a related color. In part it is amorphous and in part it is made up of fibers projecting from the walls of the cavities. These fibers have a mean index of refraction of about 1.60, a moderate birefringence, and a positive elongation. The material is probably nontronite, celadonite, or a related mineral. Calcite is abundant in some cavities, and cristobalite and several undetermined zeolites were also found.

The dark flow of Piedra rhyolite south of Bristol Head is much like that just described and most of the flows near Bristol Head are similar but lack olivine and contain hornblende and hypersthene.

The dark gravel at the base of the Piedra rhyolite in the southern part of the Del Norte quadrangle is made up chiefly of boulders of a black, fine-grained basaltic rock which carries about 30 percent of small phenocrysts of calcic labradorite, 10 percent of augite, 5 percent of hypersthene, and a few percent of apatite and magnetite, in a very fine-textured groundmass. There is some cristobalite in some of the gas cavities. The feldspar of the groundmass is sodic. Less common pebbles are lighter colored, gray or brown, than the typical pebbles, and carry brown hornblende or hornblende and biotite, as well as the two pyroxenes; but are otherwise similar. The matrix and fine material is made up of well-rounded grains of quartz, fe'dspar, and fragments of rhyolite and latite.

TABULAR FELDSPAR-PYROXENE-QUARTZ LATITE

A dark pyroxene-quartz latite with conspicuous tablets of plagioclase is an abundant and widepsread rock in all three quartz latite formations of the Potosi volcanic series. It is the chief rock in the dark layers of the Treasure Mountain rhyolite, is locally present in the Piedra rhyolite, and is the principal rock of the pyroxene-quartz latite of the Silverton volcanic series. In all the formations it is present chiefly in flows, intrusive bodies, flow breccias and thin beds of pyroclastic breccia and is in small amount in the fragments of the thick bodies of tuff-breccias.

It is present in nearly all large bodies of the Conejos quartz latite and especially (1) near the base of the Conejos along the southern border of the mountains and as lenses of massive rock higher up in the formation; (2) in upper Cebolla Creek in the Uncompahgre quadrangle; (3) in the upper part of the formation in the Del Norte and adjoining quadrangles, and is well exposed on Observatory Hill near Del Norte; and (4) in the Summitville quadrangle.

It makes up most of the Sheep Mountain quartz latite of the Sheep Mountain area in the Summitville quadrangle, and a silicious variety forms much of the massive rock of the area near Carson. It makes up an important part of the Huerto quartz latite, and is especially abundant in the mass near Huerto Peak.

This quartz latite is resistant and tends to crop out as dark-gray cliffs. Most of the rock contains no vesicles but near the tops of flows, and in the pyroclastic beds, it contains vesicles a few millimeters in largest dimension. Rarely the vesicles are filled with calcite, chalcedony, or zeolites. The rock is commonly dark gray to black, but locally it is reddish brown. It is characterized by abundant tablets of plagioclase and some phenocrysts of dark-green pyroxene and rare olivine in an aphanitic groundmass. The plagioclase phenocrysts are tabular parallel to (010), and nearly equant in their dimensions in that plane, but about one-fifth as thick as their maximum dimension. These plagioclase crystals are commonly about the color of the groundmass, because of inclusions of the groundmass, and are recognized from their cleavage surfaces; in some of the rocks that have undergone oxidation or alteration they are white and conspicuous. They commonly show a tendency to be oriented with their fla faces parallel to the base of the flows and give the rock a more or less platy structure. They range in size from less than a millimeter to several centimeters and are likely to be regular in the average size throughout a flow or a group of flows. The largest phenocrysts were seen in a flow in the Conejos quartz latite at the head of the San Juan River along the old road from Summitville to Pagosa Springs. By far the greatest part of the rocks have feldspar phenocrysts from 1 to 8 mm long. The feldspar phenocrysts are labradorite in most rocks but in some they are as calcic as bytownite and in some as sodic as andesine. They make up from 20 to 40 percent of the rocks, rarely much more or less.

Nearly all the rocks carry phenocrysts of both hypersthene and augite, the latter in larger amount; a few have brown hornblende or biotite, more or less resorbed; most of those near the basalts carry some olivine. The groundmass is mostly finely textured and made up chiefly of plagioclase, more sodic than the phenocrysts, with a variable amount of pyroxene, magnetite, and orthoclase, and in most of the rocks some determinable quartz. Some glass or submicroscopic material is present in many of the rocks. The average feldspar in most of the rocks is andesine, in a few it is more sodic, and in a very few more calcic. The latter are quartz-bearing basalts and contain abundant dark minerals, especially olivine with little quartz and orthoclase. The rocks show a moderate range in composition (see table 21). They are mostly fresh, but the hypersthene is in part altered to bastite or chlorite, and the olivine is in large part altered to red-brown iddingsite or rarely to serpentine or talc. Locally calcite and epidote are abundant, and near the intrusive necks and mineralized areas the rocks are extensively altered.

The more silicious rocks are lighter colored, carry a more sodic plagioclase, no olivine, and more hypersthene than the olivine rocks. Their groundmasses contain a lesser amount of dark minerals and have some interstitial quartz and alkalic feldspar, which commonly form spongelike or micrographic intergrowths. Some of the rocks contain some hornblende, partly bordering the augite. In some of the rocks hypersthene and augite are the only ferromagnesian minerals; but more than half carry some hornblende, and in a few hornblende exceeds the pyroxene in amount. In a very few rocks no pyroxene is present. Biotite is present in small amount in some of the rocks. The hornblende is chiefly chestnut brown, in part paler brown, greenish brown or green. It is more or less resorbed and in some only the skeleton remains. The chief products left by the resorption are hypersthene, feldspar, and magnetite. The groundmass consists of minute fluidal laths of oligoclase in a very fine to indistinctly crystalline or glassy matrix that in some specimens is clear and in others clouded or brown. In a few the groundmass extinguishes in areas 2 mm across in spongelike, micropoikolitic crystals. In all, the groundmass is made up chiefly of sodic and potash feldspar with some free silica. Some of the rocks show pores or porous streaks with abundant cristobalite, some have tridymite. The rocks are all very much alike in composition and are quartz latites, the chief difference being in the proportion of hornblende. This proportion depends largely on the extent to which resorption has proceeded.

The tabular feldspar-quartz latite of the Huerto Peak mass of the Huerto quartz latite contains a few augite phenocrysts and has some orthoclase and quartz in the groundmass. In the eastern part of this body some of the rocks contain a few phenocrysts of biotite, more or less resorbed. Some of the rocks have irregular, porous streaks of somewhat lighter color and coarser crystallization than the dense parts, which carry tridymite, biotite, and rarely some hornblende.

Many of the intrusive rocks of Potosi age are made up of rock resembling the tabular feldspar-pyroxene-quartz latites. The rock of the dikes and smaller bodies is like that of the flows but larger bodies, such as the sill of V Mountain in the Summitville quadrangle and the stock in Trout Creek in the eastern part of the San Cristobal quadrangle, contain the phenocrysts of tabular feldspar in a fine-grained groundmass that carries some quartz and orthoclase.

The typical tabular feldspar-pyroxene-quartz latites described above are much alike in texture, and in mineral and chemical composition. In chemical composition they range from 50 to 60 percent of SiO_2, and the other oxides vary rather regularly with the silica (see fig. 45.). They are all pyroxene-quartz latites similar to basalts, or dark granodiorites.

Ten analyses of the tabular feldspar-pyroxene-quartz latite, together with their norms and modes, are given in table 21. Analysis 1 represents the stock of Conejos age of Trout Creek in the eastern part of the San Cristobal quadrangle. Analysis 2 represents the laccolith of V Mountain in the Summitville quadrangle. Both these rocks are granular but they, in common with many of the other intrusive bodies, have the habit of the tabular feldspar rock. Analysis 3 represents the thick flow, or intrusive body, in the Conejos near Summitville. Analysis 4 represents the common type of this rock in the Conejos of the Del Norte quadrangle. Analysis 5 represents the rock of the area near Summitville.

Rocks of this group from the Sheep Mountain area are: analysis 6, representing the massive bodies in the Carson volcano in the San Cristobal quadrangle; analysis 7 representing the chief rock in the Summitville quadrangle and analysis 8, representing a rock more silicious than usual from the Summitville quadrangle.

Analyses 9 and 10 were made of specimens of the Huerto quartz latite from the large area south of the Rio Grande in the San Cristobal quadrangle.

OTHER PYROXENE-QUARTZ LATITES

Pyroxene-quartz latites lacking the conspicuous tabular feldspar grade into the normal tabular feldspar rock in one direction, and into hornblende-pyroxene rocks in the other. In the Conejos quartz latite, such rocks make up most of the flows, and much of the fragmental material in the Conejos quadrangle and are also abundant in the Uncompahgre, San Cristobal, and in the southern part of the Del Norte quadrangle, and in the La Garita and Carnero Creek drainages. They were also found in the San Cristobal quadrangle, south of Bristol Head, and in small amount in the Cebolla drainage area to the north. In other places they are found associated with and grading into hornblende-pyroxene quartz latite and are described under the latter rock. Such dark rocks make up a considerable part of the Huerto quartz latite of the Huerto Peak mass and are present in small amount in the other quartz latite bodies.

Analysis 12 represents the type of this quartz latite in the Conejos of the Conejos quadrangle. Analysis 14 is a typical specimen of the dark quartz latite that is associated with the tabular feldspar-pyroxene rock in the Huerto Peak mass of the Huerto quartz latite.

The Piedra rock that crops out just below the mouth of Deerhorn Creek on the eastern approach of the bridge across West Willow Creek and in the two prospects to the west is a biotite-pyroxene-quartz latite. It carries abundant large phenocrysts of plagioclase, augite, resorbed biotite, and magnetite. The groundmass is made up of plagioclase laths embedded in a felted to micropegmatitic intergrowth of quartz and orthoclase, specked with iron oxide. Chloritic aggregates were probably derived from small hypersthene prisms. The plagioclase phenocrysts are zoned and range from calcic to sodic andesine; the smaller laths of the groundmass are somewhat more sodic.

HORNBLENDE-PYROXENE-QUARTZ LATITES

Hornblende-pyroxene-quartz latites form more than half the material of the Conejos quartz latite, most of that of the Sheep Mountain quartz latite, and less than half of that of the Huerto quartz latite. They form only a small part of the dark rocks of the Treasure Mountain, Alboroto, and Piedra rhyolites. In all of the formations they make up the greater part of the thick breccia beds and a smaller part of the flows.. In the southern part of the San Cristobal quadrangle, flows of such rock have been recognized in the Conejos in small amount under Fort Mountain and under Alboroto Mountain in the upper part of the formation, where they are associated with and grade into pyroxene-quartz latites. In the east central part of that quadrangle, south of Bristol Head, the Conejos is made up predominantly of hornblende-pyroxene-quartz latites. Farther north in the quadrangle and to the north and east of it, in the Cebolla Creek basin, hornblendic rocks are represented in the formation in small amount, except in the western part in the basins of Mill and Brush Creeks, and to the west, where hornblende-pyroxene-quartz latites are rather common.

Farther east, in the Cochetopa and Saguache quadrangles, hornblende-pyroxene-quartz latites, mostly breccia beds, make up nearly all the Conejos quartz latite of the Sawtooth Mountain and Razor Creek Dome areas and the area eastward as far as Middle Creek in the Saguache River basin. To the south, in the Creede and Del Norte quadrangles, flows of hornblende-pyroxene rocks are common in the basins of Carnero and La Garita Creeks, where they grade into pyroxene rocks. They are rare in the mountains just north of the Rio Grande but to the south in the upper drainage area of San Francisco Creek and near the heads of Lime Kiln and Raton Creeks they were found in considerable bodies, associated with pyroxene-quartz latites. In the Summitville quadrangle and the New Mexico area flows of hornblendic rocks are subordinate but in the Conejos quadrangle they form a considerable part of the massive rock in the Conejos.

In the Sheep Mountain quartz latite dark hornblende-pyroxene-quartz latites make up most of the fragments of the breccia, some of the flows of the Carson volcano in the central part of the San Cristobal quadrangle, and nearly all of the rocks of the northeastern part of the Mountains, in the Saguache, Cochetopa, Creede, and Del Norte quadrangles.

Such rocks make up most of the Huerto quartz latite of the masses under Bristol Head and east of Lake City.

The hornblende-pyroxene-quartz latites differ from one another greatly in color and texture. Most of them contain conspicuous and abundant phenocrysts; for any group of flows and tuffs the size of the phenocrysts is fairly characteristic, and for any flow the proportion of phenocrysts is uniform. The most abundant phenocryst is white, zoned plagioclase in stout tablets averaging about andesine in composition. Phenocrysts of green or brown hornblende, augite, hypersthene, and rare biotite are present in variable proportions. The groundmass is commonly made up of tablets of sodic plagioclase, magnetite, and pyroxene grains in a matrix of glass or of a spongelike intergrowth of quartz and orthoclase. Some of the rocks contain as much as 15 percent of quartz and 25 percent of orthoclase in this matrix. Tridymite is abundant in some of the rocks and cristobalite is perched on the walls of the larger gas cavities of a few.

In the extreme northwestern part of the Del Norte quadrangle, the flows of Conejos quartz latite capping the ridge between the Middle and South Forks of Carnero Creek are dark, vesicular hornblende-pyroxene-quartz latites which are basaltic in appearance and show few phenocrysts. Similar flows were found in the Conejos under the Sheep Mountain quartz latite in Dry Gulch and in the lower basin of Carnero Creek.

Some of the quartz latites of the Conejos have hornblende as their chief dark mineral. A sample from such a rock (Con 591) from the southwestern part of the Conejos quadrangle at the north base of McIntyre Point is represented by analysis 15. This specimen resembles analysis 12 of table 21 of the pyroxene-quartz latite except for the abundant hornblende and strong zoning of the plagioclase.

Some of the Conejos quartz latites of the Cochetopa and Saguache quadrangles contain slender prisms of hornblende. Many of the rocks of Razor Creek Dome contain abundant biotite and little hornblende and are biotite-pyroxene-quartz latites.

The rocks of the lower horizon of the Sheep Mountain quartz latite in the Cochetopa and Saguache quadrangles are tridymite latite. Its few small and inconspicuous phenocrysts give the rock a felsitic habit. The common phenocrysts are andesine or andesine-oligoclase and biotite. Some of the rocks have hornblende and rare augite. The biotite-rich rocks have a fissile fracture or platy structure. The groundmass is usually composed of microlites of oligoclase or andesine often obscured by ferritic globules, trichites, or secondary particles, in a base that is submicroscopic in some rocks and composed of colorless faintly polarizing particles in others. Locally, aggregates show the character of tridymite and no doubt some alkalic feldspar is present. In a few of the rocks biotite and augite are present as minute, irregular patches throughout the groundmass. Phenocrysts of these minerals are rare in such rocks. An analysis of a typical specimen of the rock of the lower horizon is given in table 21, column 18.

The rocks of the middle part of the Sheep Mountain quartz latite of the Cochetopa and Saguache areas are hornblende-pyroxene-quartz latites and are represented by analysis 17 of table 21. Phenocrysts make up about one-third of the rocks and labradorite, augite, and hornblende are the most abundant; whereas hypersthene is present in small amount in about half the rocks examined. This rock resembles some of the Conejos quartz latites of this area.

The lowest flow of the dark horizon in the Piedra rhyolite below the main tuff member in Windy Gulch near Creede is a quartz latite with abundant phenocrysts of plagioclase and fewer of hornblende and biotite. The plagioclase has the average composition of sodic labradorite; the larger crystals carry abundant peripheral inclusions of glass. The hornblende is partly or completely resorbed, leaving the usual skeleton of magnetite grains and augite. The groundmass carries abundant laths of andesine, which grade into the larger phenocrysts, in a very fine matrix that contains grains of magnetite and augite and an indeterminate material which is probably largely quartz and orthoclase. Tridymite is abundant in the small vesicles.

The hornblende-quartz latite of the Creede report (Emmons and Larsen, 1923, p. 36–38) is at the base of the Piedra quartz latite or overlies the lower rhyolite member. It is made up chiefly of light-colored quartz latites. These grade into darker rocks. The common rock contains abundant phenocrysts of andesine or andesine-labradorite with sodic borders, much hornblende, and biotite. The hornblende is brown, less commonly green, and both varieties are present in distinct crystals in some thin sections. The hornblende crystals, and to a less extent the biotite, are much resorbed. The groundmass varies greatly; in some specimens it is spherulitic, in others microfelsitic, microgranular, micropegmatitic, or glassy. It is made up chiefly of quartz and alkalic feldspar. The associated darker quartz latites differ from those just described chiefly in the character of their groundmasses, which are made up largely of minute laths of oligoclase with rods and grains of augite. The phenocrysts are more abundant than in the lighter-colored rocks and in a few of the specimens those of feldspar are tabular.

The quartz latite tuff-breccia that overlies the lower rhyolite member of the Piedra quartz latite near Rio Grande Pyramid in the San Cristobal quadrangle is made up of a hornblende-pyroxene rock much like the rocks at the same horizon near Creede. The rocks contain abundant phenocrysts, rarely more than 1 mm long, of stout crystals of andesine-labradorite, brown hornblende, and less augite and hypersthene. The hornblende is in part resorbed and the augite is stained red-brown by magmatic oxidation. The groundmass is submicroscopic, and it has the appearance of a mixture of orthoclase, sodic plagioclase, and quartz.

SILICEOUS QUARTZ LATITES WITH LARGE PHENOCRYSTS

Light-colored quartz latites with large, conspicuous phenocrysts of white plagioclase are scattered in small amount in the Conejos quartz latite and they make up most of the Sheep Mountain quartz latite of the Del Norte and Creede quadrangles. Rocks of this kind were not found in the rhyolitic units of the Potosi volcanic series. They are nearly as siliceous as some of the rocks of the rhyolite formations of the Potosi and are rhyolitic quartz latites. They are also much like some of the rocks of the Fisher quartz latite. They are more siliceous than most of the rocks of the quartz latite formations and for the most part fall between positions 10 and 15 on the variation diagram in a range in which there are few rocks in the Potosi.

In the Conejos these quartz latites are found in the Saguache quadrangle in the basin of Long Branch Creek, and in the basin of Indian Creek. In the northern part of the Creede and Del Norte quadrangles a large body of such rock, mostly massive, is present in the upper drainage area of Carnero Creek. Such rock was also found east of the village of South Fork in the eastern part of the Creede quadrangle, in the Tusus Creek basin in New Mexico, and elsewhere. These rocks commonly occur in thick local flows and to a less extent in breccia beds. The largest body of this type of quartz latites is in the upper drainage area of Carnero Creek. An analysis, norm, and mode of this rock are shown in table 21, column 20.

The rock of the body in Long Branch in the Saguache quadrangle is similar. It containes phenocrysts of labradorite, biotite, and hornblende in a cryptocrystalline groundmass made up of plagioclase, orthoclase, biotite, augite, ferritic material, and tridymite. An analysis of a sample (LaG 1120) from the body east of the village of South Fork in the Creede quadrangle, is shown in table 21, column 19. The rock of the Indian Creek mass contains phenocrysts of oligoclase, orthoclase, and biotite.

Quartz latites with large phenocrysts of white feldspar, much like those just described from the Conejos quartz latite, make up nearly all of the Sheep Mountain quartz latite of the Del Norte quadrangle and the adjoining areas. It is commonly in thick, irregular flows and many of the flows have a basal zone of obsidian which carries phenocrysts similar to those of the main part of the flow.

An analysis of a typical specimen of this rock, collected from the canyon of Carnero Creek about 3 miles above La Garita Postoffice, is shown in table 21 column 21.

The rocks in the drainage basin of the north fork of Carnero Creek are very similar to the rock just described except that the feldspar phenocrysts are as much as 10 mm long; some orthoclase phenocrysts are present, hornblende is less abundant, and tridymite is abundant.

The rock of the great flows in the basin of Bennett Creek in the southwest corner of the Del Norte quadrangle has phenocrysts of plagioclase 3 mm long and smaller phenocrysts of hornblende, biotite, and pyroxene. The flows near Del Norte are conspicuously banded and have millimeter phenocrysts of plagioclase and of hornblende, much resorbed. The rocks west and north of Del Norte are similar but are less well banded, have smaller phenocrysts, less pyroxene and more rhyolitic material in the groundmass. They contain some tridymite. The body that lies about 3 miles north-northeast of Del Norte (Indian Head) has feldspar crystals 5 mm across, and some biotite and augite.

The Sheep Mountain quartz latite of the northeastern part of the Creede quadrangle, near Browns Peak, is similar. The groundmass of the more coarsely crystalline rocks is made up of stout oligoclase crystals in a matrix of orthoclase and quartz. These rocks closely resemble some of the rocks of the Fisher quartz latite. A thin flow near the middle of this section has a few sanidine crystals as long as 20 mm, a very few crystals of quartz, and smaller crystals of plagioclase, biotite, hornblende, and augite, in a groundmass of plagioclase, pyroxene, and iron ore. It probably has some altered olivine. Tridymite is abundant in the gas cavities.

RHYOLITES AND RHYOLITIC QUARTZ LATITES

GENERAL STATEMENT

Rhyolites and rhyolitic quartz latites make up by far the greater part of the Treasure Mountain, Alboroto, and Piedra rhyolites, a number of fairly large local bodies in the Conejos quartz latite but only a small part of the formation, the upper unit of the Sheep Mountain quartz latite in the Cochetopa and Saguache quadrangles, and local bodies in the Huerto.

More than half the rocks of the Treasure Mountain, Alboroto, and Piedra are quartz latites but most of these quartz latites are near the rhyolites and are different from the dark quartz latites that make up the Conejos, Sheep Mountain, and Huerto. Rocks intermediate between the two are present in very small amount (see fig. 57). Mineralogically and texturally the rhyolitic rocks of all the formations are much alike but there are some differences that are persistent. The rocks of the three rhyolite members almost invariably have groundmasses that are spherulitic, felsitic, or glassy, and contain no plagioclase microlites, but most of the rhyolitic rocks of the Conejos, Sheep Mountain, and Huerto have microlites of plagioclase in the groundmasses. This is true even of the obsidians. The rocks of the rhyolitic formations tend to have phenocrysts which are larger, more conspicuous, and more abundant than are those of the dark quartz latite formations.

The rhyolitic rocks that carry microlites of plagioclase in the groundmass cover the same range in chemical composition as do the rhyolitic rocks with typical rhyolitic groundmasses. The plagioclase microlites are present in the glassy rocks, as well as in the felsitic rocks. The two types carry phenocrysts in about the same proportion and of about the same size and kind. The phenocrysts of both types are intratelluric and were formed under conditions of slow loss of heat so that any material that was precipitated was able to grow on the phenocrysts and few new centers of crystallization were formed. The rocks with plagioclase microlites must have moved to a new environment where loss of heat was slow enough to precipitate plagioclase crystals but too rapid to allow all the precipitated plagioclase to attach to the phenocrysts, and many new centers of crystallization for plagioclase were formed. For both types, the glass or the felsitic groundmass, made up of alkalic feldspar and a silica mineral, were formed after extrusion, when cooling was so rapid that all the feldspar material formed an apparently homogeneous feldspar.

RHYOLITIC ROCKS IN THE DARK DIVISIONS OF THE POTOSI VOLCANIC SERIES

The rhyolitic quartz latite making the great flow in the Conejos quartz latite in the northeastern part of the Summitville quadrangle somewhat resembles the rhyolitic quartz latites of the Treasure Mountain and it was mapped as Treasure Mountain by Patton (1917, p. 20). An analysis, norm, and mode of a typical specimen are given in table 21, column 22. Some specimens of this rock have augite, and much of it has a relatively coarse groundmass that is either a spongelike intergrowth of orthoclase, albite, and quartz, dusted with ferritic material, or is coarsely spherulitic or microgranular.

The rhyolitic quartz latite in the Conejos quartz latite at the head of Rock Creek in the northwestern part of the Conejos quadrangle resembles the rock in the Conejos in upper Carnero Creek in the Del Norte quadrangle. An analysis, norm, and mode of a typical specimen are given in table 21, column 16. An analysis of a glassy fragment from a bed near the base of the breccia in Bear Creek is given in table 21, column 23.

An analysis of the rhyolitic quartz latite from the welded tuff of the Conejos quartz latite at the head of Cat Creek, in the northwestern part of the Conejos quadrangle is given in table 21, column 24. This rock resembles the quartz latite described in the preceding paragraph. The welded tuff beneath Bennett Peak contains phenocrysts of andesine, biotite, and augite and has much tridymite.

The rhyolitic quartz latite breccia in the Conejos quartz latite in the northwestern part of the Del Norte quadrangle and adjoining areas is made up of fragments that are partly glassy and partly felsitic. The glasses are gray on the fresh surface and white on the weathered surface. The felsitic rocks are light gray. The rocks are banded and contain few visible crystals. The felsitic rocks have a ropy streaking. Less common fragments contain a few crystals of brown hornblende, andesine, and biotite, but are otherwise similar. Some of the felsitic rocks have very perfect perlitic structure, but the cracks are entirely healed and are now marked by sharp narrow lines of darker minerals. The cracks must have developed in the early cooling of the glass which crystallized during the later stages of the cooling.

The main flows of the rhyolite of the Conejos quartz latite of Twin Mountains, northwest of Del Norte, is a nearly white to purple-drab rhyolite with a dull, chalky luster, which carries a few phenocrysts of biotite and white or glassy oligoclase or andesine in a groundmass made up of minute tablets of sodic andesine imbedded in a glass or indistinctly crystalline material, probably cristobalite and alkalic feldspar. In a few of the rocks the groundmass is finely crystalline and made up of plagioclase tablets, orthoclase, and quartz. An analysis, norm, and mode of a typical specimen from Twin Mountains are given in table 21, column 27. An analysis of a specimen from a dike of this type, from southeast of the stock that is north of Del Norte, is given in table 21, column 26. The thick, irregular flow forming the southern peak of Twin Mountains is a hornblende-biotite rhyolite. It is olive gray to purple drab, rather dense, and shows abundant phenocrysts of plagioclase and some of biotite and hornblende. The groundmass is made up of plagioclase laths imbedded in a glass or a microfelsitic mass. Apatite is abundant and iron ore is present.

In the neighborhood of Boot Mountain in the northeastern part of the Creede quadrangle and to the east there is a large body of rhyolitic rock in the Conejos which is represented by analysis 28, table 21.

In the tuff-breccia in the southern part of the Uncompahgre quadrangle, near the mouth of Rock Creek, the common fragment is a nearly white, rather porous rhyolite that carries a few crystals of biotite and quartz and some minute sodic plagioclase laths in a glassy matrix. Another common fragment is a light-colored quartz latite, about one-third of which is phenocrysts as much as 2 mm across. Andesine-labradorite is the chief phenocryst, and resorbed hornblende, biotite, and quartz are in small amount, and apatite, iron ore, and zircon are accessory. The groundmass is made up of quartz, orthoclase, and sodic plagioclase, and ranges from granophyric to spherulitic. Some of the rocks carry more phenocrysts and are much like those of the rhyolitic quartz latites of the Alboroto rhyolite, but others are dense, red-brown felsites.

The rhyolitic quartz latite that makes up most of the fragments in the lower gravels of the Conejos quartz latite in New Mexico is much like the rock that forms the pyroclastic layers in the upper Carnero basin in the northern part of the Del Norte quadrangle, and near the head of Cat Creek in the northern part of the Conejos quadrangle. A typical specimen is represented by analysis 25, table 21.

The rhyolite of the upper unit of the Sheep Mountain quartz latite of the Cochetopa and Saguache quadrangles is inconspicuously porphyritic. The phenocrysts are small in amount and grade from 2 mm long to groundmass size. Oligoclase or andesine is the chief phenocryst. Quartz and biotite occur sparingly in crystals larger than groundmass size. The groundmass is microcrystalline and is made up of orthoclase, quartz, soda-rich plagioclase, biotite, and iron oxide in approximate order of abundance. The analysis of this rock given in table 21, column 29, shows an abundance of free silica.

Rhyolitic quartz latites are not abundant in the Huerto quartz latite. Such a rock from a flow in the northern part of the San Cristobal quadrangle is represented by analysis 30, table 21. This rock resembles the quartz latite of the lower unit of the Sheep Mountain quartz latite. Some specimens of this rock have phenocrysts of augite and hypersthene. Tridymite is present in a few of the rocks. Some of them have a groundmass consisting of a spongelike intergrowth of quartz and alkalic feldspar.

RHYOLITIC ROCKS OF THE RHYOLITIC DIVISIONS OF THE POTOSI VOLCANIC SERIES

With the exception of the local dark quartz latite units, all of the rocks of the three siliceous divisions of the Potosi volcanic series are rhyolitic—rhyolites or quartz latites near the rhyolites. The rocks are commonly light reddish brown, some are darker, some are nearly white; the glasses are commonly black, but local bodies of glass are red, green, or brown, or mottled or banded with these colors. A few of the rocks have pores scattered through them but in most of the rocks the main part is a dense felsite with fluidal lenses or streaks that are lighter-colored and porous. Some of the rocks lack the porous lenses and have scattered, larger gas cavities, not uncommonly an inch or more across. Some are dense throughout.

Nearly all of the rhyolitic quartz latites contain abundant phenocrysts from 1 to 3 mm. long. Plagioclase is the chief phenocryst and biotite is the chief mafic mineral in all the rocks. Augite is present in the rhyolitic quartz latite of the Treasure Mountain rhyolite, hornblende in the Alboroto rhyolite, and both in the Piedra rhyolite. The plagioclase phenocrysts are strongly zoned with recurrent zones in all the rocks and some of the crystals have calcic cores of foreign feldspar that was much resorbed before the main feldspar grew around the core. The common plagioclase in the rhyolitic quartz latite of the Piedra and Treasure Mountain is andesine, that in the Alboroto is oligoclase. Phenocrysts of quartz and sanidine are present in the Piedra and Alboroto rhyolites. Sphene is abundant and in large crystals in the hornblende-bearing rocks but it is rare in the rocks without hornblende. Magnetite is in normal amount, hematite is the red pigment in the crystalline groundmasses but is absent in the glassy rocks. Zircon and apatite are in very small amount. Hypersthene is rare.

The rhyolitic quartz latites grade into rhyolites, and the chief differences between the two are that in the rhyolites, phenocrysts, especially those of plagioclase, are in small amount, sanidine is common though not abundant, and biotite is in small amount and is commonly the only mafic mineral. The plagioclase tends to be more sodic in the rhyolites than in the quartz latites though this is not invariably true. Quartz phenocrysts are not common in the rhyolites.

The groundmasses of all the rocks look about the same but the analyses and compositions of the groundmasses (figs. 45 and 53–56) show that those of the rhyolites tend to be more siliceous. The dense part of the groundmasses of all the rocks is submicroscopic and tends to be spherulitic or a related fibrous intergrowth. X-ray tests of such groundmasses indicate that they are made up of alkalic feldspar and cristobalite. The chemical compositions of the groundmasses indicate that the feldspars of the groundmasses differ in the proportions of Or-Ab-An and that their composition depends on the composition of the feldspathic material present in the liquid at the time of the rapid crystallization of the groundmasses. The porous, light-colored streaks and lenses in the groundmasses are much more coarsely crystalline and in most of the rocks are made up of alkalic feldspar and tridymite. Tridymite is abundant in most of the rocks and it is confined to the porous parts of the rocks. It is abundant in many of the welded tuffs where it serves as a cement for the fragments. In a few of the rocks the porous lenses are made up of feldspar and quartz.

The typical rhyolitic quartz latite of the Treasure Mountain rhyolite is represented in table 21, in pocket, by analyses 33 and 35, and similar rocks from the western part of the San Juan Mountains by analyses 32 and 34.

The typical rhyolitic quartz latite of the Alboroto rhyolite is represented by analyses 37 and 38, table 21.

The lowest flow in the northeastern part of the Ouray quadrangle differs from the rock just described in that it has little hornblende and some augite. An analysis is shown in table 21, column 36.

The ryholitic quartz latite that directly overlies the widespread tuff member in the upper part of the Piedra rhyolite is represented by analysis 40, table 21. The welded tuff that forms prominent local mesas at the top of the Piedra in the Creede quadrangle and to the north, is represented by analysis 41, table 21.

An analysis of a quartz latite from the Piedra rhyolite whose exact position in the section is uncertain is given in table 21, column 39. The specimen (SC 2094) was collected from the southeastern part of the San Cristobal quadrangle. The rock is farther from the rhyolites than most of the Piedra rocks.

The typical rock of the tridymite rhyolitic latite member of the Piedra rhyolite has a distinct flow banding with streaks that are porous and light colored.

It contains conspicuous phenocrysts of sanidine, plagioclase, biotite, and little augite. The plagioclase crystals have cores of andesine or andesine-labradorite, grading through two or more rather broad intermediate zones to narrow borders of albite or oligoclase; the average composition is about that of andesine. They are commonly in part altered to sericite and a clay mineral. The biotite has been more or less resorbed, with the separation of iron oxide. The groundmass is fluidal, with wavy bands. The main part is so finely crystalline as to be only indistinctly polarizing; it is clouded and reddish brown in reflected light from many microscopic specks of hematite. There are many lenses or streaks of clear material which has a much coarser crystallization, the larger ones are porous. They range in width from a fraction of a millimeter to 10 mm, are in part spherulitic or fibrous, in part micrographic or microgranular. Orthoclase and tridymite are the chief minerals of these streaks. Tridymite, which is abundant, is present as aggregates, filling rounded areas or lining the walls of the cavities, and is evidently closely associated with the gas cavities. In a few specimens tridymite is absent, and its place in the centers of the coarsely crystalline bands is taken by quartz. An analysis, norm, and mode of a typical specimen of this rock, collected from the cliffs near Creede, are given in table 21, column 43.

The rhyolitic quartz latite at the base of the tridymite rhyolitic latite member of the Piedra rhyolite in Farmers Creek and elsewhere resembles the overlying tridymite latite but lacks the light-colored, porous lenses. This rock has phenocrysts as large as 12 millimeters across. In addition to the phenocrysts found in the tridymite latite it contains a small variable amount of quartz and hornblende. Tridymite is abundant in the groundmass of some of the specimens and quartz is present in others. An analysis of such a specimen is given in table 21, column 42. The rock resembles that described in the preceding paragraph but lacks the porous lenses, has some quartz in the groundmass and not much determinable tridymite.

Flows and tuff beds of a tridymite rhyolite that closely resembles the tridymite rhyolitic latite member of the Piedra rhyolite, except that it has less of and a more sodic plagioclase, are present in the lower part of the Alboroto rhyolite in the Uncompahgre quadrangle and elsewhere. An analysis and norm of such a tridymite rhyolite from the Alboroto are shown in table 21, column 44.

The most abundant rhyolite in the Potosi volcanic series resembles the tridymite rhyolite described in the preceding paragraph but it lacks the porous, coarsely crystalline lenses and has scattered cavities as much as several inches across. These cavities are so abundant in places that cliff-outcrops look pitted, the cavities make up several percent of the rock, and it is difficult to get a hand specimen of standard size. The rock was called the cavernous rhyolite in the field. In all three rhyolitic formations this rhyolite is commonly at or near the base. In the Treasure Mountain and Piedra rhyolites it filled in a mountainous surface. Its thickness is variable and locally exceeds 1,000 feet. In the Alboroto rhyolite the flows are relatively thin and regular. A black glass is common at the base of the flows. Except for the cavities the rock is a dense felsite, with a few phenocrysts. The main part of the groundmass is clouded with reddish ferritic shreds and is submicroscopic in crystallization, but irregular streaks are clear, much coarser in crystallization, and are made up of alkalic feldspar and tridymite. Tridymite is also present in rounded aggregates as much as a millimeter or more across, probably filling small gas cavities, but the large gas cavities are for the most part free from tridymite or other coatings or fillings. In part the tridymite is in relatively coarse, easily identifiable grains, but these grade into very finely crystalline material. There is no quartz or glass in the felsitic rock and tridymite and cristobalite make up a third of these rocks. They were not found in the glassy rocks. Analyses and norms of this rock from the Treasure Mountain are given in table 21, columns 45 and 46, from Piedra in columns 47 and 48, and of a similar rock from the Alboroto in column 49.

The analyzed specimens are all much alike. The crystalline rocks range in color from dark vinaceous drab to cinnamon drab. The glassy rocks are nearly black obsidians. The phenocrysts are a few millimeters in maximum length and are much the same in all the rocks (see table 21). The plagioclase ranges from An_{20} to An_{50}. The groundmass of sample SC 1191a is chiefly submicroscopic, with some small finely fibrous patches; that of SC 2275 is in part coarsely spherulitic and contains much tridymite or cristobalite; that of SC 741 has beautiful coarse spherulites as much as 2 mm across and dusted with red iron oxide, embedded in a clear aggregate of quartz and orthoclase.

An analysis of a rhyolite from the Treasure Mountain in the Conejos quadrangle is given in table 21, column 50.

Few of the rhyolitic rocks of the Potosi volcanic series contain quartz in the groundmass. The Willow Creek rhyolite of the Creede district (Emmons and Larsen 1923, p. 19–25) is a thick, local flow in the Alboroto. It is made up of a distinctly fluidal rock, most of which is dense, but thin lenses are lighter colored and porous. The groundmass of the dense part of the rock is submicroscopic in crystallization, whereas the porous lenses consist of coarsely crystalline quartz and orthoclase. These lenses are zoned, with a layer of feldspar fibers next to the wall; inward are coarse, well-formed orthoclase crystals in quartz; and the central porous part is nearly pure quartz. They show a remarkable similarity to the zoned pegmatites which have central pods of quartz. This rock contains a few phenocrysts of sanidine, biotite, and altered plagioclase. Four analyses of this rock are shown in columns 51 to 54, table 21. The analyses show a wide range in composition, especially in the proportion of Na_2O and K_2O. There is probably an actual difference in composition among different parts of the flow, but some of the range may be due to alteration, for the rock is exposed only in the mineralized area near Creede and is nowhere entirely fresh.

The rhyolite at the base of the Piedra rhyolite in the basin of Farmers Creek contains phenocrysts of sanidine, quartz, andesine, biotite, and a small amount of hornblende and augite. In most specimens the groundmass is fluidal, submicroscopic, and carries tridymite in pockets and lining cavities. In others the groundmass is coarser, and quartz and orthoclase can be distinguished. The great flow of Mammoth Mountain, near Creede, overlies the rock just described, and contains about the same phenocrysts as the underlying rock but the plagioclase is somewhat more sodic. The groundmass is somewhat fluidal and is filled with shreds of iron oxide. It is largely submicroscopic in crystallization but some intergrowths of quartz and alkalic feldspar can be distinguished. In part it is delicately spherulitic, with minute fibers arranged in a normal position to the fluidal streaks.

Welded tuffs are common in the Potosi volcanic series and some of the beds are widespread. For the most part they are not thick. Many of the welded tuffs have a basal zone of obsidian and closely resemble flows. Some were mistaken for flows during the field work. They tend to be more porous and somewhat less coherent than typical flows. Many of them contain abundant fragments of foreign rock, especially of pumice. Most of them have phenocrysts and a general appearance that are almost identical with those of the associated flows. Under the microscope they are seen to be made up largely of fragments of pumice and cusplike fragments of highly vesiculated rock. Except for the glassy zones at their base, they are commonly holocrystalline and felsitic, with abundant tridymite as a cementing material. Many of these welded tuffs are nearly or quite as strong as the flows. Some of them resemble rock flow, even under the microscope, and under more extreme conditions the pyroclastic material might yield a product that could not be distinguished from a flow. Indeed, it might flow for some distance and completely destroy the evidence of its origin and might yield flow structure, banding, and the porous lenses so common in the bodies called flows. Many of the rocks called flows have a groundmass texture that might be interpreted as the last stage before final disappearance of fragments such as those of the typical welded tuffs.

Two analyses of typical welded tuffs, both from the Treasure Mountain rhyolite are given in columns 56 and 57.

Analysis 55, table 21, represents a tuff of the Treasure Mountain rhyolite from the southern part of the Conejos quadrangle.

The lower few feet of many of the flows in the Treasure Mountain, Alboroto, and Piedra rhyolites consist of an obsidian that contains phenocrysts that in kind, size, and amount are like those of the main part of the flows. The groundmasses except for ferritic trichites, are entirely glass, and they lack gas cavities, or vesicles, and the tridymite and cristobalite that are common in the main parts of the flows. They are black, whereas the felsitic parts of the flows are light gray or brownish, and they have iron in a lower state of oxidation. Glassy zones at the base of welded tuffs are also common and some such tuffs are made up of alternate lenslike bands of glassy and felsitic material. Some of the tuff beds are made up of glassy shards or pumice fragments or contain small fragments of obsidian. In a few places where the tuffs and associated flows are more chaotic than usual, small flows made up of glass are present. Some of these glasses are banded with layers of green, black, white, and red.

CHEMICAL ANALYSES

Fifty-nine analyses of rocks from the Potosi volcanic series are given in table 21 (in pocket). Most of the analyses were made for this report. Most of the rocks analyzed were fresh, a few were more or less altered. The specimens for analysis were carefully selected to represent the rock varieties in each of the six subdivisions, and particularly the abundant rock types. All of the analyses are plotted on a variation diagram (Larsen, 1938) in figure 45, and those of each of the six subdivisions in variation diagrams in figures 53–56. The analyses, norms, and modes are given in the table, and detailed descriptions of the rocks have been given in the preceding pages.

AVERAGE CHEMICAL COMPOSITION OF THE POTOSI VOLCANIC SERIES AND ITS SUBDIVISIONS

The chemical composition of the average rock of each of the subdivisions of the Potosi volcanic series and that for the Potosi as a whole have been calculated with considerable accuracy, taking into consideration the volume occupied by each rock type. This data for the six formations are shown in table 22. The compositions of the three quartz latite formations are similar, as are those of the three rhyolitic formations.

Of the three quartz latites, the Huerto is lower in silica and potash content, and higher in iron, lime, and titanium. It is nearer the basalts than the others. The Sheep Mountain is nearer the rhyolites and has very nearly the composition of the average Potosi rock. The Conejos, which makes up more than half by volume of the Potosi volcanic series, has a composition near that of the average igneous rock, as calculated by Washington (1939, p. 95), though it is appreciably higher in alumina, lime, and ferric iron, and lower in magnesia.

The three rhyolite formations are more nearly alike in average composition than are the three quartz latites. The Alboroto is somewhat lower in silica and higher in total iron and lime content than the others, and the Treasure Mountain is rather high in potash.

A study of the table shows a remarkably uniform magnesia content for the three quartz latites, and this is much lower than in the average igneous rock of about the same general composition. The alumina content is higher than is common but otherwise the quartz latites have about the composition of the average andesites of Daly (1923, p. 16).

A comparison of the Potosi rocks (variation diagram fig. 45) with the average igneous rock of Daly shows that the Potosi rocks are about 1 percent higher in Al_2O_3, nearly 1 percent higher in CaO, and 1 percent lower in MgO than the average rock.

TABLE 22.—*Chemical composition of the average rock of the formations of the Potosi volcanic series, the average Potosi rock, and the average igneous rock*

	Huerto quartz latite	*Conejos quartz latite*	*Average igneous rock*[1]	*Sheep mountain quartz latite*	*Average Potosi rock*	*Alboroto rhyolite*	*Piedra rhyolite*	*Treasure Mountain rhyolite*
SiO_2	55. 68	59. 05	59. 12	61. 50	62. 86	67. 57	69. 59	68. 38
Al_2O_3	17. 69	17. 20	15. 34	16. 19	16. 62	15. 10	14. 99	15. 24
Fe_2O_3	4. 40	4. 56	3. 08	3. 81	3. 60	2. 15	2. 18	2. 70
FeO	4. 09	1. 55	3. 80	1. 58	1. 35	1. 38	. 42	. 41
MgO	1. 91	2. 00	3. 49	1. 98	1. 41	. 92	. 39	. 23
CaO	6. 71	5. 70	5. 08	4. 65	4. 39	2. 93	2. 14	2. 11
Na_2O	3. 28	3. 66	3. 84	3. 91	3. 71	3. 58	3. 93	3. 99
K_2O	2. 71	3. 20	3. 13	3. 94	3. 92	3. 88	4. 75	5. 15
H_2O+	. 99	. 69	1. 15 (H₂O+ and H₂O−)	. 70	. 61	. 54	. 44	. 40
H_2O-	. 68	. 96		. 69	. 79	. 68	. 46	. 57
TiO_2	1. 29	. 98	1. 05	. 92	. 77	. 45	. 39	. 60
P_2O_5	. 46	. 33	. 30	. 30	. 27	. 18	. 09	. 14
MnO	. 18	. 10	. 12	. 14	. 09	. 06	. 08	. 05
BaO	. 07	. 10	----------	. 08	. 10	. 07	. 11	. 13
SrO	. 03	. 05	----------	. 07	. 04	. 02	. 03	tr.
ZrO_2	. 00	. 08	. 04	. 03	. 06	. 03	. 04	. 03
Total	100. 17	100. 21	99. 62	100. 49	100. 59	99. 54	100. 03	100. 13

[1] Washington (1939, p. 95).

CREEDE FORMATION

NAME AND OCCURRENCE

A considerable thickness of rhyolitic tuffs and bedded breccia, which contain local bodies of travertinous spring deposits in their lower part and some intercalated lava flows in their upper part, accumulated in a deep valley or basin that had much the same character and position as the present valley of the Rio Grande from Wagonwheel Gap westward to Trout Creek, a distance of about 25 miles. The name Creede formation has been proposed (Emmons and Larsen, 1923, insert facing page 12; Knowlton, 1923, table facing p. 184) for this deposit, because of its extensive and characteristic development on the slopes on both sides of Willow Creek about the town of Creede.

In general, the Creede deposits occupy an area in which the Hayden (1877 [1881], sheets 15, 17) map represented Green River Eocene beds with Carboniferous limestone above them on the slopes. The Hayden reports (1877, p. 153–157) contain practically no reference to these deposits in the Rio Grande valley, and it seems plain that the tuffs of the Creede formation in the bottom of the valley were called Green River Eocene, and the interbedded travertine deposits that exhibit massive outcrops in some places were referred to as the Carboniferous without any good reason. Collections of plant remains from the lower tuff beds of the Creede formation indicate that these beds are very late Miocene or very early Pliocene in age (Brown, R. W., personal communication).

The character of the basin in which the Creede formation was deposited is well shown by the way in which the beds commonly lap up on the steep slopes of the older basin of deposition. This is also shown by the geologic map (pl. 1). The Creede beds occupy the floor of the valley of the Rio Grande and are surrounded by steep slopes of the older rocks, which commonly rise 3,000 feet or more above the valley in a distance of a few miles. This relation is not due to folding or faulting but to the fact that the Creede formation was deposited in a basin that was deeper than that of the present Rio Grande valley and probably had steeper walls. The resulting irregularity at the base of the Creede formation is well shown on both sides of Creede; to the east the base of the formation rises nearly 2,000 feet within less than a mile, as shown on the geologic map and structure sections of the Creede report (Emmons and Larsen, 1923, pl. 2).

The Creede formation clearly followed the upper formation of the Potosi volcanic series, the Piedra rhyolite, after a period of erosion long enough to allow a valley several thousand feet deep to be carved in the Potosi rocks. This occurred in an area where the formations of the Potosi were of moderate thickness. This period of erosion, together with the fact that the rocks of the Creede formation are not like those of the Potosi, makes the separation of the Creede formation logical.

The upper surface of the Creede formation is also an irregular surface of erosion, because the overlying Fisher quartz latite clearly flowed into deep valleys that cut across the Piedra rocks at least as low in the section as the Treasure Mountain rhyolite. The Fisher also cuts the beds of the Creede formation. The Creede rocks have little similarity to the Fisher rocks. The Creede formation therefore is a local accumulation of rocks that were deposited in the interval between the deposition of the Potosi volcanic series and the Fisher quartz latite.

STRUCTURE AND THICKNESS

In general the tuff beds dip gently away from the mountains toward the south and southeast, and the dips are commonly steeper near the borders of the body. Dips of 10° or even 20° are common near the borders, and much steeper dips occur in places. Away from the borders the dips are low, but accurate estimates of the average dip for any large area are difficult on account of the poor exposures and local undulations. The general structure in the tuffs of the valley is that of a gentle syncline. It is not known how much of the dip is due to tilting since deposition, for beds laid down rather rapidly in a comparatively small basin surrounded by very steep slopes might have a considerable inclination at the time of deposition and this inclination would probably be steeper near the borders of the basin. Some of the dip might be due to setting or compacting of the beds.

No satisfactory estimate of the maximum thickness of the Creede formation can be made, because the structure is uncertain, the top is nowhere preserved, and the base is exposed only on the steep sides of the basin. About 500 feet of the lower member is exposed on both sides of Willow Creek below Creede, and neither the top nor the base is shown; just east of Creede, where the top of the lower member is preserved, about 900 feet is exposed. Approximately 1,000 feet of the upper member is exposed east of Windy Gulch. In the middle of the valley the lower member was probably considerably thicker.

GENERAL CHARACTER

The Creede formation has been subdivided on the Creede special map (Emmons and Larsen, 1923, pl. 2) into three lithologic units, which, however, have no sharp lines of separation. In the maps included in this report the formation has not been subdivided. The lower member is made up entirely of fragmental material, the greater part of which was deposited by water, although some of it represents talus and similar accumulations. Much of this material is a thinly laminated white shaly tuff; part is sandy, and part is breccia and conglomerate. The material is entirely of igneous origin, and a greater part of the larger fragments were derived from the rocks of the Alboroto rhyolite, whereas the finer tuffs were deposits of volcanic ash from local eruptions.

Interbedded with the tuff of the lower member are beds of travertine, which were deposited by springs, probably hot, at different horizons at the time the tuff was being laid down. They are in part surface deposit, in part deposits in the channels through which the waters flowed, and in part deposits formed by cementation and replacement of the tuffs. They occur in irregular bodies whose contacts are not everywhere sharply marked.

The material of the upper member is somewhat coarser than that of the lower member; it is made up mainly of rather well-bedded breccia, conglomerate, and tuff. A considerable part of the fragments consist of a kind of rhyolite that is found only here and in the associated thin intercalated flows.

LOWER MEMBER

The lower member of the Creede formation is made up in large part of fine-grained and well-bedded material (fig. 27) which is commonly creamy or light grayish. In part it is very thin bedded and shaly, and closely resembles a siliceous shale, although composed almost wholly of volcanic material. Much of this tuff carries plant remains, some of which are well preserved. Thicker beds of sandy material and beds or lenses of conglomerate are present. Most of the pebbles are well-rounded fragments of igneous rock; some are subangular or even angular. Near the contact with the underlying rocks coarse and angular material is much more abundant, and at the base of the original steep slopes of the older rocks the local material of the Creede beds really represents an indurated talus from the cliffs. In the upper part of the member, west of Rat Creek, the material is more thickly bedded and much of it is sandy or conglomeratic.

The shaly tuff is rather uniform in character and is made up in large part of fragments of rhyolitic glass and an occasional fragment of feldspar, quartz, and biotite. It is no doubt an ash from a volcanic vent nearby. The sandy beds carry abundant crystals of orthoclase, plagioclase, quartz, and biotite, rare fragments of other minerals, and a varying number of fragments of felsitic or pumiceous rhyolite.

The pebbles of the conglomeratic part of the tuff consist chiefly of fragments of the underlying rocks but include also a great variety of other rocks, chiefly rhyolites and quartz latites. The fragments of the conglomerates and breccias near Creede were derived chiefly from the Piedra rhyolite (Willow Creek and Campbell Mountain rhyolites of the Creede district), but in part from rocks similar to the quartz latites of the Alboroto rhyolite. Large angular blocks of tridymite latite similar to that of the Piedra are present just east of Creede. The nearest exposures of the tridymite latite are much higher on the slopes on Bulldog Mountain, or in the high mountains a few miles to the northeast. The fragments may well represent landslide or talus blocks from cliffs of this rock that have since been removed by erosion. A few fragments of a variety of other rhyolites and quartz latites that cannot be correlated with any of the rocks of the vicinity are also present, and these are most abundant in the thin lenses of conglomerate that occur in the thin-bedded tuffs at some distance from the mountains. In other places, as near Wagonwheel Gap, the fragments in the tuff are chiefly rhyolotic quartz latites similar to those that formed the adjacent slopes at the time of deposition. Where the fragments are angular, especially near the contacts, most are identifiable as belonging to the adjacent rocks. In the Iowa tunnel and elsewhere near the contact with the lower rocks the material is made up of somewhat indurated small angular fragments of the Piedra rhyolite (Willow Creek rhyolite of the Creede district) and no doubt represents simply an accumulation of talus at the base of the steep slopes of the rhyolite during the Creede epoch.

In general both the tuff and conglomerate are fairly well indurated and are much harder than the somewhat similar tuff of the Piedra rhyolite. Near the travertine bodies the tuff is filled with calcite and much of the coarser material is cemented by reddish-brown or yellowish hydrated iron oxide or by a green ferruginous material. Locally, especially in the upper part, the tuff and breccia are cemented by silica. Under the cliffs above Seven Mile Bridge, above Creede, there is considerable gypsum in the tuff, and in protected places there are crystals of mirabilite.

INTERBEDDED TRAVERTINE

In the tuff of the lower member of the Creede formation there are many bodies of travertine. The largest of these is just east of Sunnyside Creek, where it forms prominent cliffs; other bodies are shown on the Creede

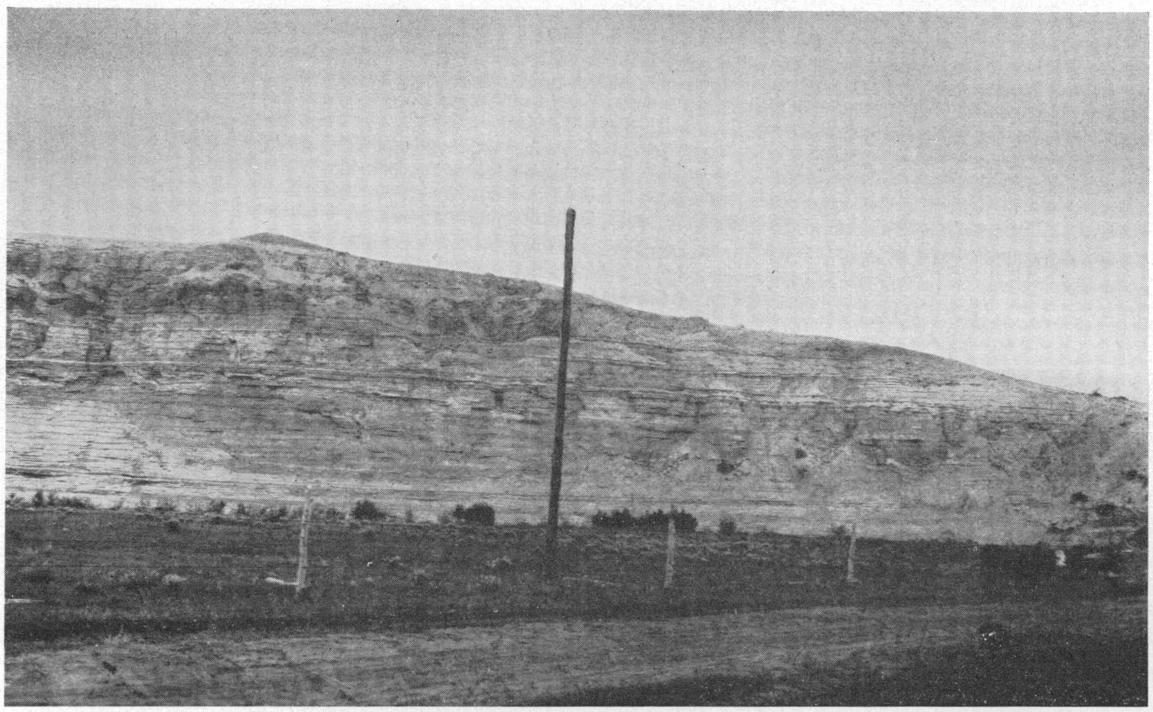

FIGURE 27.—Thin-bedded tuff of the Creede formation containing abundant plant and insect fossils. View is of north bank of the Rio Grande above Sevenmile Bridge, Creede quadrangle.

and vicinity map (Emmons and Larsen, 1923, pl. II) between Creede and Sunnyside and between Creede and Dry Gulch. These travertine bodies are also characteristic of the Creede formation beyond the Creede area. Large bodies are present in the lower part of the Lime Creek basin near the western extremity of the Creede formation, between Fir and Shallow creeks, in the drainage basin of Deep Creek. They are more abundant near the borders of the Creede formation than in the middle. The bodies are irregular, and their contacts are in places indefinite. Most of the travertine is a light-grayish deposit of fine-grained calcite, in some places very dense, in others rather porous or highly cellular. There is commonly much limonite, especially in the more porous variety, and some of the material is highly ferruginous. Locally, as in parts of the body north of the 9,208-foot hill west of Willow Creek, there is a light, porous deposit of gypsum, stained and coated with limonitic material. Part of the travertine incloses fragments of rock. Locally it carries much chalcedony, with some quartz, filling original cavities, or as veinlets, and in places it contains deposits of siliceous sinter.

The travertine and less common siliceous sinter were deposited around the openings of springs, probably hot, which must have been abundant around the borders of the old basin. The travertine is usually mixed or interbedded with the fine-grained tuff, and in some places it seems to act as a cement for the tuff; in part it forms lenses or less regular bodies in the tuff. Some of the travertine was probably deposited in the conduits of the springs; the strip through the middle of the body east of Sunnyside, which forms the pronounced outcrop of this body, is believed to have been so deposited. It forms a dikelike outcrop striking a little north of east above the 9,100-foot contour, with very steep walls, more than 100 feet high in places, on the south side and a bench or low depression on the north side. It is almost entirely travertine.

Tufa deposits, somewhat similar to the travertine in the Creede formation, have been formed elsewhere on a large scale around the borders of undrained interior lakes by the precipitation of calcium carbonate from the waters of the lakes. The abundance of silica and iron in the travertine of the Creede formation and the presence of bodies of cellular gypsum and limonite, together with the small size and irregular form and distribution of the bodies, make it seem unlikely that this travertine was so deposited.

UPPER MEMBER

The upper member of the Creede formation is made up of considerably coarser material than that of the lower member, and the material is better sorted, more distinctly bedded, and more rounded than the taluslike material that constitutes most of the coarse part of the lower member. Besides fragments of rhyolites found only in this member (some of the conglomerates are made up entirely of such rhyolites), thin flows of similar rhyolites are interbedded with these conglomerates. The two members are not sharply distinct.

The clastic rock varies greatly in the degree of sorting and rounding of the fragments, the coarseness of the material, the petrographic character of the fragments, and the amount of induration. On the whole it is considerably coarser than the lower member of the Creede formation, is somewhat more indurated, and carries abundant fragments of rock similar to the associated flows. A small part of the material is thin bedded and of fine shaly texture, is somewhat more sandy, and the greater part is conglomerate or breccia.

A large part of the material is well bedded and sorted and consists of fragments as much as several inches across, generally not well rounded, in a large amount of matrix. The fragments consist chiefly of the Piedra rhyolite, with some of the Treasure Mountain rhyolite, but locally, west of Windy Gulch, they consist almost entirely of rocks similar to the associated rhyolite flows, especially of the banded type of massive rock. In a few places rocks resembling the tridymite rhyolitic latite and more or less similar to the rhyolite breccia of the Piedra group are present; other rocks are rare. The matrix is dark red or drab, rarely white, and is fine, hard, and dense, except for occasional cavities; and the rock superficially resembles a flow breccia. The cementing material is chiefly quartz and chalcedony, with considerable iron. Barite and jarosite were found in a number of places, chiefly in the cavities; they do not appear to be confined to the vicinity of the veins, as they are common in Windy Gulch. A large part of the breccia has been cemented by ferruginous quartz and some sulfates.

The fine-textured layers are in large part indurated to hard, flinty rocks, in most places stained red or drab by iron. They carry a few poorly preserved fragments of fossil plants. The sandy layers in the main consist either of broken crystals of feldspar and biotite or of fragments of felsitic rhyolite, and have a cement of ferruginous quartz.

The coarser beds of conglomerate, which are interbedded with the lava flows in Windy Gulch and near the Commodore mine and are also present in lenses in the overlying breccia, are made up of well-rounded pebbles, the largest a foot or more across, with a moderate amount of sandy matrix. They are usually cemented by silica and iron compounds to a hard rock. Most of the fragments are rock like that of the associated flows; some are fragments of a rock with more conspicuous phenocrysts, and the pebbles of this rock are much altered.

In the lower part of the section in the drainage basin of Windy Gulch and to the northeast as far as the Bachelor mine, a number of thin flows are present and alternate with beds of conglomerate made up of fragments of rock similar to that of the flows. They are local, thin, and poorly exposed and are closely associated with the conglomerates, which in turn grade into the normal breccia.

The greater part of the flows is made up of a porous drab rock which carries phenocrysts from 1 to 2 mm in cross section, of glassy orthoclase, white porous feldspar, and dark-brown plates of biotite. These phenocrysts make up nearly half the rock and are embedded in a porous, aphanitic material. There are a few quartz phenocrysts, and the white feldspar is a peculiar microperthite in porous, skeleton crystals and is partly altered to sericite. This gives an imperfect wavy extinction, as the intergrowths are almost submicroscopic. Orthoclase predominates. The biotite is partly resorbed. Accessory apatite, magnetite, and zircon are sparsely present. The groundmass shows beautiful wavy, fluidal bands of lighter tone and coarser crystallization. In part the crystallization is submicroscopic, but irregular streaks and bands are made up of closely packed spherulites, here minute, there large. The rocks are fresh except for the presence of a little secondary calcite and sericite. The albite may have been derived from a more calcic feldspar. In one of the sections the phenocrysts have ragged borders caused by their influence in orienting the adjoining groundmass. The groundmass is granophyric and coarsely, though irregularly, crystalline. Just south of the Commodore mine one of the flows shows white blotches, which can be recoginzed with a pocket lens as areas of radiating fibrous spherulites.

Another type of massive rock found only west and south of the Commodore mine carries many rough cavities an inch in largest dimension. It has fewer phenocrysts than the type described above and a much finer groundmass, but is otherwise similar.

South of Bulldog Mountain a third type is exposed partly as a massive rock and makes up much of the breccias. It is a pale purple-drab rock, with broad bands and lenses of lighter tone. It carries abundant crystals of glassy orthoclase and a few of white feldspar and dark-brown biotite. The plagioclase is near albite and is somewhat altered to sericite. The orthoclase crystals include well-formed crystals of albite. The groundmass of the broad dark bands is finely crystalline; that of the light bands is rather coarsely crystalline, with the quartz and orthoclase intergrown. The fibers or prisms of feldspar tend to grow out from the walls, and the quartz fills in between them. All the flows are rhyolites rich in soda.

WEATHERING AND TOPOGRAPHY

The beds of the Creede formation are among the least resistant of all the large bodies of rock within the area, and they have had a marked influence on the development of the topography. The broad valley of the Rio Grande, with its comparatively gentle contiguous slopes from Trout Creek to Wagonwheel Gap, a distance of about 25 miles, corresponds to the area occupied by these tuffs and is in marked contrast to the steep, rugged slopes surrounding the valley and to the canyons of the Rio Grande both above and below. Equally marked is the contrast between the rugged rock canyon of Willow Creek above Creede, where it is cut in the Willow Creek rhyolite, and the broad valley and rolling hills below Creede, where it is eroded in the Creede formation.

ORIGIN

The greater part of the clastic material of the Creede formation was clearly deposited by water. The conglomerate was probably laid down in part along the shore of the lake, in part by contributory streams during freshets. Near Creede, conglomerate is much more abundant in the upper part of the formation and forms most of the clastic material in the upper member. Indeed, the upper member near Creede is probably largely fluviatile material. Ancient talus and similar subaerial accumulations make up a small part of the formation. The fine shaly tuff must have been deposited in comparatively still water, and its considerable though local distribution, together with its great thickness and the form of the basin of deposition, are evidence that it accumulated in a local intervolcanic lake. The form of the old basin beyond the present Rio Grande valley is not known. It is bounded on the north, east, and west by high mountains of older rocks but could extend to the south between Trout and Goose Creeks, in the area occupied by the younger, Fisher quartz latite.

The material of this formation was derived from four sources. Much of the fine tuff represents volcanic ash which was thrown out from some unknown volcanic vent nearby and fell in a lake or on the sides of the basin surrounding it and was deposited, after sorting, in the quiet water of the lake. The greater part of the coarse material was derived by the ordinary processes of erosion from the mountains surrounding the basin and was brought into the lake by the torrential streams that fed it. This part is made up almost entirely of the underlying rocks. The travertine, as has already been shown, was deposited by hot springs contemporaneously with the deposition of the fine tuff. Finally, a number of thin lava flows are present in the upper part of the formation.

FISHER QUARTZ LATITE

DEFINITION

In the eastern part of the San Cristobal quadrangle, in the western and southern parts of the Creede quadrangle, and in the adjoining parts of the Uncompahgre and Cochetopa quadrangles to the north and the Summitville quadrangle to the south, a great thickness of irregular flows and chaotic breccia beds, made up of intermediate quartz latites and characterized by larger phenocrysts than are common in the other volcanic rocks of the San Juan Mountains, overlies an irregular surface of erosion of the Potosi volcanic series, as well as the lake beds of the Creede formation, and is in turn overlain by the rocks of the Hinsdale formation.

These rocks were first observed in the mountains southwest of Lake City, and in the preliminary statement of the geology of this area by Cross in the report by Irving and Bancroft (1911, p. 29) they were included in the Potosi volcanic series. A more detailed study of these rocks over a larger area has shown that they everywhere have certain textural and mineralogical characteristics which differ appreciably from those of the rocks of any of the divisions of the Potosi, and that they rest on a surface of erosion and successively overlie rocks of the Silverton volcanic series, the different subdivisions of the Potosi, and also the Creede formation. These rocks are believed therefore to be considerably younger than Potosi, as well as different petrographically, and the name Fisher quartz latite is proposed for this formation from its characteristic development in Fisher Mountain in the Creede quadrangle, a few miles southwest of Wagonwheel Gap. The name Fisher quartz latite was furnished by us to Patton (1917, p. 20) and used by him in his report on the Platoro-Summitville mining district. In the report of the Creede mining district by Emmons and Larsen (1923, p. 71–73) the single flow there present belonging to this formation was called the Fisher quartz latite.

DISTRIBUTION AND THICKNESS

Rocks that can with assurance be placed in the Fisher quartz latite are confined to an area about 25 miles wide in a northeast and southwest direction. This area extends from the extreme southern part of the Uncompahgre and Cochetopa quadrangles to the slopes north of the Alamosa River, south of the town of Summitville, in the Summitville quadrangle. These rocks underlie about a third of the western half of the Creede quadrangle, somewhat less of the eastern part of the San Cristobal quadrangle and of the northeastern quarter of the Summitville quadrangle, and they extend for only short distances into the extreme southern part of the Uncompahgre and Cochetopa quadrangles. In all they underlie about 200 square miles.

In the north-central part of the Conejos quadrangle quartz latites which have large phenocrysts and which are much like the rocks of the Fisher quartz latite and the overlying Potosi rocks, form Chiquita Peak and underlie the Hinsdale formation of Green Mountain and a large area to the south. They may be related to the Fisher.

The Fisher quartz latite crops out in six somewhat distinct areas, each of which probably represents material accumulated around a volcanic vent or group of vents. The rocks of individual areas have many features in common but several types of rock are usually present. In contrast with the comparative regularity of the formations of the Potosi volcanic series, and Hinsdale formation, the Fisher quartz latite occurs as isolated masses of relatively small extent and of great, though variable, thickness. The base is everywhere irregular and the top is also irregular and appears always to have been so.

The formation is thick, and under Fisher Mountain it attains a thickness of more than 2,500 feet. In nearly all the areas the maximum thickness is nearly or more than 1,000 feet.

The most northwesterly area in which Fisher rocks crop out is just west of Lake San Cristobal in the extreme northern part of the San Cristobal quadrangle and the adjoining parts of the Uncompahgre quadrangle. The area includes the body that forms the upper slopes of Red Mountain and the southeastern slopes of Grassy Mountain and underlies only about 7 square miles.

To the south, across the Lake Fork of the Gunnison River, the Fisher quartz latite that forms the crest and extends well down the southeast slopes is not so thick. An arm of this rock extends down the ridge south of Ruby Creek, to and across the valley of North Clear Creek, where it forms Castle Rock. It cuts across the contours in a remarkable way and clearly filled a valley. To the south, near Lost Lakes, a small body of Fisher quartz latite is probably an extension of these flows. The total area underlain by the Fisher rocks in this area is only about 9 square miles.

In the northeastern part of the San Cristobal quadrangle and the northwestern part of the Creede quadrangle, extending for only short distances northward into the Uncompahgre and Cochetopa quadrangles, there is a group of high mountains whose upper slopes are made up of Fisher rocks. The several bodies in this area were probably at one time continuous and formed a group of high volcanic mountains, but erosion has cut through these rocks at the head of Spring Creek, leaving only remnants of the Fisher rocks between the two main bodies. Similarly, small isolated bodies of this rock extend for several miles south down the ridge between Rat and Miners Creeks. In this area about 35 square miles are underlain by Fisher rocks. In several of the peaks of this area the thickness is more than 1,000 feet.

To the south, just north of Wagonwheel Gap, two large and several smaller bodies of Fisher quartz latite, underlying an area of about 18 square miles, overlie the Alboroto and Creede formations and clearly filled in a mountain valley. Wagonwheel Gap is formed by a thick flow of this rock.

The largest body of Fisher quartz latite is farther south in the southwestern part of the Creede quadrangle and adjoining parts of the San Cristobal quadrangle and underlies much of the drainage area of Goose and Red Mountain Creeks, as well as smaller parts of the surrounding mountains (fig. 28). This body underlies an area of about 100 square miles. It attains a thickness of 2,500 feet under Fisher Mountain and east of Red Mountain Creek. Outliers just above the alluvium south of the Rio Grande are plastered against the lower slopes of Snowshoe Mountain, whereas the higher mountains consist of the underlying Alboroto rhyolite.

A large body of this rock, underlying about 25 square miles, with some small detached bodies, is exposed in the northeastern part of the Summitville quadrangle around the old mining town of Summitville

RELATION TO OTHER ROCKS

The Fisher quartz latite overlies the different formations of the Potosi volcanic series from the Conejos quartz latite to the Piedra rhyolite and it also locally overlies older rocks and the Creede formation. It everywhere filled in an irregular topography of considerable relief, as is shown by the base of the formation wherever well exposed. This is especially well shown in the narrow strip of Fisher rocks that crosses North

FIGURE 28.—Castellated tuff breccia and arch of the Fisher quartz latite, east of South River near the eastern border of the San Cristobal quadrangle.

Clear Creek at Castle Rock in the San Cristobal quadrangle, where it overlies the Piedra rocks on the upper slopes on both sides of the creek and the Alboroto rhyolite on the lower slopes. It clearly filled in a valley or canyon and it drops from an altitude of about 13,000 feet under the Continental Divide on the north to about 10,400 feet in Clear Creek. A part of this is due to later tilting, but much of it is due to a difference in altitude at the time of the Fisher eruptions. The irregularity is not so striking in the northeastern part of the San Cristobal quadrangle, but in the area to the east the irregular way in which the base of the formation cuts across the topography is well shown in many cliff exposures. East of the San Luis Peak the Fisher rocks form the lower slopes and the peak itself is made up of the older Alboroto rocks. The irregularity is also well shown in the bodies north of Wagonwheel Gap and in most of the contacts of the body to the southwest of Wagonwheel Gap, particularly the contact south of Pierce Creek and that in the Red Mountain Creek area. In this latter area the contact was at first thought to be a fault

In most places the Fisher quartz latite is not overlain by younger formations although locally it is overlain by Hinsdale formation. The volcanic mountains of Fisher rocks seem not to have been levelled off by the erosion that preceded the Hinsdale, and they were probably covered only on their lower slopes by Hinsdale or later rocks.

The Fisher quartz latite, therefore, was extruded after the Potosi volcanic series and the Creede formation had undergone much erosion but before the surface had been levelled to mature topography. They were erupted before the great depression of the central part of the mountains that preceded the development of the San Juan peneplain.

GENERAL CHARACTER

The Fisher quartz latite is a characteristically chaotic aggregate of flows and breccias. The outcrops are mostly light gray to brownish and somewhat darker than those of the rhyolites of the Potosi volcanic series. As compared with the flows of the formations of the Potosi, the flows are of small areal extent and variable thickness, and they dip at irregular and commonly steep angles. Successive flows may dip at very different angles and in different directions, and their relations are so irregular that it is commonly difficult to distinguish between the flows and irregular intrusive bodies. Some of the flows or groups of similar flows are more widespread than others, and they are then more regular. The breccia beds are likewise mostly chaotic and are made up of poorly sorted, angular or subangular material. In many places fragments several feet across are common. The fragments in most of the beds consist almost entirely of a single kind of rock, commonly much like that of the associated flows. In the area around Red Mountain Creek in the southeastern part of the San Cristobal quadrangle, the breccia beds are better bedded and sorted in much of the lower part of the formation and are in part volcanic sands, in part conglomeratic with well-rounded fragments of somewhat variable rocks. They were clearly water worn. Similar beds are less extensive near the base of the formation to the east. In contrast to this, in the extreme northeast part of the San Cristobal quadrangle and the adjoining areas the formation is mainly breccia, poorly bedded and sorted and made up of angular fragments of a single rock type. A few thin bodies of massive rock of small extent are present and show relatively steep dips and no regularity in structure. At first glance the bodies of massive rock seem to have been intruded but they are probably irregular flows.

To the east similar breccia forms most of the body east of Spring Creek, but to the west flows become more abundant, thicker, more widespread, and more regular. Chaotic breccia and nearly as much massive rock in irregular flows, some of them a hundred feet or more in thickness and extending for several miles, make up the formation in the great body in the southwestern part of the Creede quadrangle. The bodies in the Summitville quadrangle are similar but probably have a greater proportion of flow rock. Yet, great, comparatively regular flows make up most of the Fisher quartz latite in the areas east of Lake San Cristobal and thinner, more regular flows predominate in the areas south of Lake San Cristobal.

The bodies north of Wagonwheel Gap are also mostly thick flows, and the body to the south, which is east of Goose Creek and north of Soda Creek, is almost entirely made up of thick flows.

In the Fisher quartz latite as a whole, breccia is somewhat more common than flow rock. Intrusive rock is very subordinate. Although some flows or groups of flows have a moderate distribution and form local horizons in the section, no regularity in the succession of the flows or tuff beds could be recognized over any large area. A rock that forms the base of the formation in one section may be at the top only a few miles away. Indeed, the rock types seem to be concentrated areally rather than in horizontal layers; a section with a thickness of 1,000 feet or more on one side of a canyon may be chiefly of one rock, whereas that on the other side may be of a different rock. The relations are truly chaotic and in striking contrast with the regular succession of nearly flat, widespread flows and tuffs in the rhyolites of the Potosi volcanic series.

The Fisher quartz latite is present chiefly in the high mountains. The irregularity at its base as well as the variable resistance and chaotic relations of different parts of the formation, especially the tuffs and flows, gives rise to a rugged, irregular topography whose cliffs of hard flow rock separate gentler slopes or broken cliffs of badland character. Mesas are not common nor are regular cliffs, and those present are usually of small extent and of rather steep dip. The crests of the ridges are mostly rounded and some of the peaks are rather sharp.

The tuff beds show little induration and are rapidly eroded. The large fragments in a sandy matrix give rise to steep slopes, with many pinnacles, spires, mushroom forms, perched rocks, arches, and a typical badland topography. Such forms are especially well developed on the slopes east of Red Mountain Creek.

The weathering of the rocks is largely mechanical, and fresh rock is usually present at or very near the surface. Locally, however, the rocks have been much altered by hydrothermal action that was probably closely associated with the hot solutions emanating from the volcanic centers from which the rocks were extruded. In the Red Mountain area, east of Lake San Cristobal, there are large bodies of the formation that have been bleached white or pink and completely decomposed to a rock made up of quartz and alunite, with some iron oxide, sulfides, and other minerals. In the northeast corner of the San Cristobal quadrangle the rocks are also much altered, particularly on Painted Peak and on the east slopes of Mineral Creek, but in this area alunite was not found in abundance although a clay is abundant, and pyrite and iron oxide are locally abundant. The rocks of the great area in the southwestern part of the Creede quadrangle are mostly rather fresh, but large bodies are altered in the Copper Mountain area south of Lime Creek, and elsewhere. In the Summitville quadrangle parts of the formation are much altered to quartz and alunite or quartz and clay.

PETROGRAPHIC CHARACTER

GENERAL DESCRIPTION

The most conspicuous and characteristic features of the rock of the Fisher quartz latite are the large and conspicuous phenocrysts which are distinctly larger than those in the rocks of the Potosi volcanic series and are commonly a centimeter across and in some rocks are several centimeters across. Only in a few places do the rocks lack large phenocrysts. These phenocrysts in most of the rocks make up about one-third of the material. Plagioclase feldspar, ranging from oligoclase in some rocks to sodic labradorite in others make up the chief phenocrysts. Orthoclase phenocrysts are present in only a few of the rocks, but in some they are nearly as abundant as the plagioclase. They are commonly much rounded by partial resorption. Quartz phenocrysts are not common but they are present in some of the light-colored rock and in much-embayed crystals in some of the other rocks. Brown, rarely green, hornblende is probably the chief dark mineral but augite is nearly as common, and hypersthene and biotite are present in nearly half the rocks. The biotite and hornblende in most of the rocks are more or less resorbed; in some they are completely resorbed and their original presence can be determined only by the characteristic aggregates of magnetite and augite grains. As the resorption progressed farther, the pyroxene, and especially the hypersthene, became more abundant. Certainly in most, and probably in nearly all, of the rocks, even the pyroxene rocks, the greater part of the pyroxene was formed from the resorption of hornblende or of hornblende and biotite. Sphene is abundant in large crystals in many of the rocks, especially in the lighter-colored rocks; zircon is less common; and apatite and magnetite are usually present in small amounts. In most of the rocks the groundmass is dusted with iron oxide and pyroxene, and is made up of small sodic plagioclase laths in a variable amount of spongelike, rhyolitic material of alkalic feldspar and quartz. In many rocks the groundmass lacks the plagioclase tablets and is either spherulitic or made up of micrographic intergrowths of alkalic feldspar and quartz or tridymite. Glass is present in some of the rocks, and at the base of many of the flows the groundmass is a black glass, but the phenocrysts are in about the same proportion and of about the same size as in the holocrystalline rocks. Tridymite is common in the porous parts of many of the rocks and the characteristic white spherulites of cristobalite are perched on the walls of the gas cavities of many.

The rocks of the Fisher quartz latite are nearly or quite all quartz latites and they have only a moderate range in composition. The average rock and by far the greater part of the rocks are nearly an average quartz latite. Both chemically and mineralogically the Fisher rocks resemble the Potosi rocks, but the Fisher rocks, as shown by comparing the distribution diagrams (fig. 57), are chiefly in a range between the rhyolitic and quartz latitic formations of the Potosi, where there are few rocks. The Fisher rocks when plotted on a variation diagram (fig. 46) fall very near the variation curves for the Potosi.

The rocks are mostly light to dark red brown and cover about the same range of colors as does burned brick. Some are nearly white, some are dark gray. The tendency has clearly been to develop the higher oxide of iron in the groundmass and in many of the rocks the augite is stained red from a partial oxidation.

Most of the rocks are rather dense, though nearly all carry some pores and some are highly vesicular.

There is little regularity in the succession of the rocks or in their distribution. This is well shown in the basin of East Goose Creek where on the east side of the canyon under Table Mountain in the rocks—both flows and breccia beds, more than 2,000 feet in thickness—are nearly all dark hornblende-pyroxene rocks, but those of about equal thickness on the west side of the canyon under Beautiful Mountain are lighter colored and are predominantly hornblende-biotite-quartz rocks.

The detailed descriptions will be given by areas beginning in the northwest and going south and east.

AREA WEST OF LAKE SAN CRISTOBAL

The Fisher quartz latite in the area to the west of Lake San Cristobal is mostly in the San Cristobal quadrangle but extends for a short distance into the Uncompahgre quadrangle and forms Red Mountain, Grassy Mountain, and the small knob to the west of Williams Creek. It underlies an area of about 7 square miles. As usual, it filled in a rough topography and it occupies a troughlike depression. The rock of this area shows little variation, and much of it represents a single great flow; breccia makes up only a small part of it. Extensive alteration, chiefly alunitization, has taken place in the rock of Red Mountain.

The fresh rocks are commonly reddish brown; a few are slate gray; they are dense and are characterized by large crystals of feldspar which are from 5 to 10 mm in longest dimension. All the rocks show some plates of biotite and some show augite. The phenocrysts make up from about a third to half the rocks, and contain chiefly feldspar, andesine, and orthoclase in nearly equal amounts, much less biotite, and still less augite. The accessories are apatite, magnetite, zircon, hematite, and rare sphene. The groundmass is thickly dusted with minute trichites of hematite, and under crossed nicols large-sized areas extinguish as units but are filled with intergrowths or inclusions in a spongelike manner. It is made up of intergrowths of quartz and orthoclase with some plagioclase, and in some specimens it is a distinct micropegmatite intergrowth of quartz and orthoclase. In a few specimens the groundmass is spherulitic or glassy. The large feldspar crystals are chiefly orthoclase, which is commonly filled with inclusions of the groundmass, and which in many specimens has microperthitically intergrown plagioclase in the outer zone. The plagioclase crystals are smaller and average andesine in composition; in some specimens they are bordered by microcline. Biotite is the chief dark mineral and it is more or less resorbed. Augite is present in about half the rocks and is commonly considerably altered. The rocks are biotite-quartz latite and biotite-augite-quartz latites rather near the rhyolites. The rock of Grassy Mountain contains little augite. An analysis of a specimen from the south slope of Grassy Mountain is shown in table 23, column 13.

The rock is altered over large areas, notably on Red Mountain. The common type of alteration is to a white quartz-alunite rock which still shows in part the texture of the original rock. Less commonly carbonates, chlorite, and epidote or, rarely, piedmontite are largely developed, and in rare cases the feldspars are largely sericitized. Pyrite is rare in these altered rocks but in some, minute crystals of a bluish-gray opaque mineral are rather abundant.

AREA SOUTH OF LAKE SAN CRISTOBAL

The Fisher quartz latite capping the Continental Divide south of Lake San Cristobal is mostly rather thin flows dipping regularly to the southeast. They underlie an area of about 8 square miles. These rocks are all much alike, lack the large phenocrysts that the Fisher rocks usually carry, and are pyroxene-quartz latites with more or less biotite and rare hornblende. They resemble the rocks east of Mineral Creek in the extreme northeast corner of the San Cristobal quadrangle. In the southern part of this area, south of Ruby Creek, the rocks are red-brown, rather porous to vesicular, and carry conspicuous white feldspar crystals as much as 2 mm across. They are made up of about one-third phenocrysts chiefly of andesine-labradorite, considerable hypersthene, nearly as much augite, some biotite, and rare hornblende. The groundmass is a brown glass in some specimens, and a fine intergrowth of sodic plagioclase laths, orthoclase, and quartz in others. Tridymite is abundant in some of the rocks and cristobalite is present in some. Much of the iron has been oxidized to hematite and even the augite is stained red. An analysis of this rock is given in table 23, column 7. Farther north and near Castle Rock, to the south, the rocks are less vesicular, carry somewhat larger phenocrysts, and are dark gray. They are almost identical with the rocks east of Mineral Creek, which will be described in a succeeding paragraph.

LOST LAKES AREA

To the south, near Lost Lakes, the Fisher quartz latite is made up mostly of flows of biotite-pyroxene-quartz latite similar to those of the ridge between Mineral and Rough Creeks, to be described later. They differ from the rocks to the north near Kitty Creek chiefly in that they have larger phenocrysts.

AREA IN NORTHEAST CORNER OF SAN CRISTOBAL QUADRANGLE AND TO THE NORTH AND EAST

A considerable body of Fisher quartz latite forms the high mountains to the east of Cebolla Creek, mostly in the San Cristobal quadrangle but extending for a short distance into the Uncompahgre, Creede, and Cochetopa quadrangles. There are many small outliers beyond the main body and one good-sized body in the Stewart Peak-Organ Mountain area. This is next to the largest area underlain by Fisher rocks and has an area of about 37 square miles.

The body to the east of the main fork of Mineral Creek is made up mostly of chaotic breccia with some irregular flows. In the southern and western parts, flows become more abundant. Nearly all of the flows and much of the breccia of this area are made up of a rather dense, rarely vesicular, dark greenish-gray, rarely red-brown biotite-pyroxene-quartz latite that carries inconspicuous glassy phenocrysts of plagioclase as much as 1 centimeter across. They are equant in form, are bounded by crystal faces, are variable in size, and are dusted with many inclusions of the groundmass, especially on the borders. These andesine-labradorite phenocrysts make up about a quarter of the rocks; the dark minerals much less. The chief dark minerals are augite, hypersthene, and biotite, but hornblende is present in some of the rocks. The groundmass is very finely crystalline, shows an abundant dust of magnetite and dark mineral, and is made up mostly of felted sodic plagioclase and some quartz and orthoclase. The biotite and hornblende are more or less resorbed. The hypersthene is mostly altered to bastite, and the augite is locally altered to calcite and chlorite. An analysis of this type is shown in table 23, column 4. Similar rocks are present to the west as far as Painted Peak, but they are subordinate to other rocks and occur chiefly as thin irregular flows or sill-like intrusives in the breccia. Similar rocks constitute most of the formation on the Continental Divide south of Lake San Cristobal and are locally developed in the basin of Goose Creek in the Creede quadrangle.

Farther west, on the ridge between Mineral and Rough Creeks, the rocks of both the breccia and the flows are biotite-pyroxene-quartz latites which are brownish red to gray, and range from rather dense to highly cellular. Phenocrysts make up about one-third of the rocks. Orthoclase in crystals up to 2 cm is in small and variable amount, and plagioclase averaging andesine-labradorite in smaller crystals, is the chief phenocryst; biotite, augite, and hypersthene are the chief dark minerals. In some places hornblende in part replaces the hypersthene. The biotite and hornblende are more or less resorbed. Augite in some specimens forms a border around hypersthene crystals. The glassy orthoclase crystals are commonly surrounded by a rim of white plagioclase. The groundmass is dusted with iron oxide and augite and is for the most part finely crystalline, rarely glassy, and is made up of oligoclase laths with interstitial intergrown quartz and orthoclase. Tridymite is rather abundant in the cavities. To the west, Painted Peak and the ridge to the north are made up of rocks similar to those described in the preceding paragraph, but they carry somewhat more hornblende. Cristobalite is present in some of these rocks.

A rather unusual type of biotite-hornblende-augite-quartz latite at the head of Mineral Creek forms the ridge that extends north from the peak that has an altitude of 12,980 feet. Both the great flow and the associated breccia beds of this ridge are made up of a rock that ranges in color from very light gray to light reddish brown or dark reddish brown. In part the rock is dense except for a few irregular cavities that are lined with crystals of tridymite; rarely it is rather porous. It characteristically carries large phenocrysts of orthoclase that are in places more than an inch across and may make up 10 percent or more of the rock, although in others they are smaller or less abundant. In part these orthoclase phenocrysts are glassy, in part porcelain white. They are mostly more or less rounded from corrosion, and they commonly include some sodic plagioclase. Plagioclase phenocrysts are much smaller, rarely more than a centimeter across; embayed quartz in crystals as much as 5 mm across is present in all the rocks. Biotite and hornblende are in crystals as long as 5 cm. The microscope shows that phenocrysts make up nearly half the rock. They are chiefly plagioclase, ranging from albite to andesine and averaging oligoclase, but biotite and brown or green hornblende, more or less resorbed, make up about 10 percent of the rock. Augite is present chiefly in the groundmass, and it increases as the hornblende and biotite are resorbed. Apatite, sphene, zircon, and magnetite are accessory. The groundmass is very fine textured and is made up mostly of sodic plagioclase with some orthoclase and quartz and is dusted with iron oxide and augite. Tridymite is common in the porous parts and makes up several percent of some of the rocks. An analysis of this rock is given in table 23, column 10.

The small bodies of Fisher quartz latite to the south between Miners and Rat Creeks are made up mostly of a single flow of biotite-augite-quartz latite, that is purple drab in the denser rocks and light quaker drab in the more porous rocks. Except for the basal glassy layer, all the rocks show a few small gas pores, and some are decidedly porous. The phenocrysts nearly equal the groundmass in amount and are commonly from 2 to 4 mm across; a few are 1 cm or more. They are chiefly porcelain-white andesine-labradorite with rather conspicuous black flakes of biotite and prisms of pale green augite. Zircon, apatite, and magnetite are accessory. The groundmass is largely submicroscopic in crystallization and is rhyolitic in character. Some tridymite is present in the porous parts of some of the specimens.

A specimen collected in the Uncompahgre quadrangle at an altitude of 11,900 feet from the ridge west of Spring Creek on the north slope of the peak having an altitude of 12,082 feet, is somewhat different. It is brownish gray and nearly half is made up of phenocrysts as much as 2 mm across. Plagioclase is the chief phenocryst, augite is abundant, hypersthene is somewhat less so, and olivine, altered to iddingsite, is present in small amount. The groundmass is made up of laths of plagioclase with considerable orthoclase.

The Fisher quartz latite that makes up the body that includes Stewart Peak and Organ Mountain is mostly breccia but has some flows. In the head of Spring Creek 1,500 feet of breccia are exposed and are overlain by a flow. The rocks are much like those of the area to the west.

NORTH OF WAGONWHEEL GAP

The Fisher rocks north of Wagonwheel Gap flowed over rather steep slopes that were cut in the Alboroto, Piedra, and Creede formations. They are divided into two main bodies of about equal size, as may be seen from the map (pl. 1), and each of these bodies is made up of a single kind of rock, though the rocks of the two bodies differ considerably. Both bodies are of nearly all massive rock in thick flows. The total area underlain by the two bodies is about 18 square miles.

The southern body, mostly between Bellows and Blue Creeks, is irregular at its base and its upper surface forms rugged mountains. It reaches a thickness of more than 1,000 feet. It is made up almost entirely of a biotite-hornblende-tridymite latite that is light red-brown to greenish in color and is made up about one-third of phenocrysts, as much as 5 mm across and much broken. The largest and most abundant of the phenocrysts are andesine to andesine-labradorite feldspar, complexly twinned and carrying large inclusions of the groundmass. Orthoclase and quartz phenocrysts are rare and are more or less resorbed. Augite is present in some of the rocks, and as the hornblende and biotite become more resorbed augite increases in amount. Large sphene crystals are the chief accessory mineral, iron ore and apatite are always present, and zircon is rare. The groundmass is a perlitic glass at the base of the flows; higher up spherulites are present, and in most of the flows is a finely, rarely coarsely, spherulitic intergrowth of alkali feldspar and cristobalite. Cristobalite is present in some of the gas cavities. Analysis 12 in table 23 represents this rock.

The northern body, lying between the forks of Bellows Creek and including the small bodies north of Blue Creek, is comparatively regular, both at its base and top, and it reaches a thickness of about 600 feet. It is made up of a biotite-pyroxene-quartz latite which differs from the rock of the southern area, chiefly in that the phenocrysts are a little smaller. Phenocrysts of quartz, orthoclase, and sphene are almost entirely lacking, and the mafic minerals are biotite, augite, and hypersthene. The groundmass is dusted with iron oxide and is made up of plagioclase laths with interstitial indistinctly crystalline to fine spongelike intergrowths of quartz and orthoclase. Analysis 6 in table 23 represents this rock.

MCLELLAND MOUNTAIN BODY

The McLelland Mountain body, southeast of Wagonwheel Gap, underlies an area of about 8 square miles. It is more than 1,000 feet in maximum thickness and is made up almost entirely of massive rock in thick flows. Only three flows were recognized. The rocks are red brown biotite-tridymite latites that are fluidal and banded with some porous bands. The better-banded rocks superficially resemble the tridymite latite of the Piedra rhyolite-latite. The rock of the lower flow is made up nearly half of phenocrysts, as much as a few millimeters across, of which labradorite is the chief, and biotite, partly resorbed, exceeds augite. The groundmass is fluidal, submicroscopic, and rhyolitic. Tridymite is abundant in the porous layers. The upper flows are similar but have somewhat fewer phenocrysts and have some small plagioclase laths in the groundmass. An analysis of the rock from the southeast slope of McLelland Mountain at an altitude of 10,650 feet is shown in table 23, column 14.

AREA OF GOOSE AND RED MOUNTAIN CREEKS

A body of Fisher quartz latite, which is south of the Rio Grande and mostly in the Creede quadrangle but extends into the San Cristobal quadrangle, is the largest body of this formation. It is equant in shape, covers an area of about 100 square miles, and in many sections has a thickness of more than 2,000 feet. The base is strikingly irregular, as may be seen from the geologic map (pl. 1) and the top forms rugged mountains including Beautiful Mountain, Table Mountain, Copper Mountain, South River Peak, and Fisher Mountain.

Clastic beds make up somewhat more than half the formation in this area. They are, for the most part, poorly bedded, poorly sorted, and made up of angular fragments of various sizes, some several feet across. The fragments of any bed are all of one kind of rock and many of the beds have only a scant matrix between the fragments. However, chiefly in the lower part of the formation and notably in the basin of Red Mountain Creek, but also in that of Leopard Creek and in the upper drainage area of Goose Creek and elsewhere, the material is fairly well bedded and sorted, and the fragments are more or less rounded. In Ivy Creek there are alternating layers of fine, well-bedded tuff and coarse angular breccia. In this western part of the area the clastic beds show more evidence of transportation than elsewhere. Those layers, containing abundant fine material, weather into striking hoodoo forms with perched rocks, spires, arches, and similar features. These are well shown in the cliffs east of Red Mountain Creek and in the Ivy Creek area. These finer tuffs are nearly white.

Flows and chaotic tuff-breccia are more abundant in the upper part of the Fisher quartz latite than the lower. They make much of the section near Mt. Hope. The flows are characteristically irregular and their bases pitch up or down across the contours in a most irregular way. They may reach a thickness of several hundred feet. A few feet of black glass is found at the base of many of the flows, especially the lighter-colored ones.

The rocks are normal Fisher rocks and show a moderate range in composition and texture. All are quartz latites. The different kinds of rock are irregularly distributed and some of the chief kinds will be described in some detail, beginning with the more siliceous.

Rocks resembling the biotite-hornblende-tridymite latite that forms the body of Fisher rocks that is between Bellows and Blue Creeks (see p. 178) were found on the lower slopes west of Goose Creek as far south as Roaring Fork. They also form most of this formation in the basin of Lime Creek and eastward as far as West Goose Creek. In the latter area the feldspar phenocrysts are oligoclase-andesine to andesine, and the groundmass in some of the rocks is a fine spongelike intergrowth of quartz and feldspar.

The great thickness of Fisher rocks under Beautiful Mountain and that of the peaks 4 miles east of South Mountain are of this type, with feldspar averaging oligoclase or oligoclase-andesine. Similar rock with sodic andesine feldspar crystals as much as 2 cm across, and some phenocrysts of quartz and orthoclase are present in the lower drainage area of Leopard Creek, and higher in Leopard Creek are rocks with smaller phenocrysts, much biotite, and some hornblende. Some of the rock of lower Leopard Creek has more hornblende and biotite and the groundmass is dusted with iron oxide and carries plagioclase laths in a fine spongelike intergrowth of quartz and orthoclase.

A specimen from the lower slopes of Copper Mountain west of Goose Creek, is a biotite-quartz latite with 3-mm phenocrysts of andesine, some orthoclase, less quartz, and some biotite, in a fluidal submicroscopic rhyolitic groundmass.

Much of the rock of the mountains west of Goose Creek, north of Roaring Fork and north of the west fork of Goose Creek, is also similar to the biotite-hornblende-tridymite latite between Bellows and Blue Creeks described on page 178, but it has somewhat more hornblende and the groundmass is dusted with iron oxide, and is made up of minute plagioclase laths in a submicroscopic to finely crystalline rhyolitic matrix. The resorption of the dark minerals is variable. Some of the rocks in the lower drainage area of Leopard Creek are similar but lack phenocrysts of quartz, orthoclase, and sphene. In one rock from this area the biotite is almost completely resorbed and some hypersthene is present. Similar rocks, but with hornblende as the chief or only mafic mineral and with phenocrysts as much as 2 mm across, are locally present in the lower part of the formation in the area around Leopard Creek.

Nearly all the rocks, both of the flows and tuff-breccia, of the upper slopes of Table Mountain and of the ridge north of Sawtooth Mountain are of a dark-gray hornblende-pyroxene-quartz latite. Many of the rocks are dense, but some have abundant small, rough-walled gas cavities. The rock is made up about one-quarter of phenocrysts, variable in size but rarely more than 3 mm across. White feldspar, with abundant inclusions of the groundmass in the central part, strongly zoned but averaging labradorite, are the chief phenocrysts. Deep-brown hornblende, more or less resorbed and having dark reaction rims, is next in abundance; augite and hypersthene are nearly as abundant, and large grains of magnetitic iron ore are subordinate. The groundmass is finely crystalline and carries a considerable but somewhat variable proportion of small laths of oligoclase-andesite, some magnetite and pyroxene in a brown clouded glass or a submicroscopic matrix. Tridymite is absent in most of the specimens, but it is abundant and in large crystals in a few that are holocrystalline and have fewer but larger and flatter pores. Cristobalite is present in some of the rocks. A few of the rocks have pyroxene only in the groundmass and some have a little hornblende. Two analyses of this rock are shown in table 23, columns 2 and 3.

A somewhat similar hornblende-pyroxene rock forms most of the Fisher quartz latite of the high mountains around South Mountain. It has rare biotite phenocrysts, and most of the pyroxene is in the groundmass. The augite commonly grows around the hypersthene. The augite is red on the borders, and these borders give extinction angles like those of aegirite-augite. The hornblende is more abundant than in the rocks near Table Mountain. It is deep red-brown and is more or less resorbed, yielding phlogopite, pyroxene, feldspar, and magnetite. The groundmass is much like that of the Table Mountain rocks, but it carries more pyroxene and in some there is an interstitial spongelike intergrowth of quartz and orthoclase, in others there is much cristobalite. Cristobalite is abundant in the cavities of some of the rocks.

An interesting group of thin flows of hornblende-pyroxene andesites caps the ridges on both sides of Red Mountain Creek. The porous parts are red-brown, the denser parts rather dark gray. In the hand specimen all the rocks show a few quartz crystals, much fractured and embayed and as much as 2 mm across. Most of the rocks show few other crystals but those to the east show hornblende. Phenocrysts make up about one-fifth of the rock. Plagioclase and brown hornblende, or the ghosts left from its resorption, are the chief phenocrysts; augite is in variable amount; quartz phenocrysts make up several percent of the rock in the western part but to the east it is completely resorbed. Orthoclase and hypersthene phenocrysts are rare, and zircon, apatite, and iron oxide are accessory. The feldspar is andesine and has clear centers but carries abundant minute inclusions of the groundmass in the outer zones. The hornblende is almost completely resorbed and is represented only by remnants and ghosts in the western part, but to the east this resorption becomes progressively less. The ghosts left from the resorption of the hornblende are grains of magnetite, augite, feldspar, and rare biotite. The augite travels some distance from the original hornblende. Where the hornblende is only slightly resorbed pyroxene is in small amount and the rocks are hornblende-quartz latites; but as the resorption of the hornblende becomes greater the pyroxene increases in amount and the rocks finally become pyroxene-quartz latites. The quartz is everywhere fractured and much embayed, and it is rounded from resorption and bordered by a corona of augite grains. The resorption of the quartz is progressively greater to the east and, in the Creede quadrangle, only remnants of the quartz remain or, finally, only the reaction zone of augite grains. The groundmass is fine textured and is made up chiefly of andesine laths with many rods of augite, grains of magnetite, and some undetermined material that is probably rhyolitic in composition. There is much cristobalite partly in spherulites on the walls of the gas cavities and partly streaked through the groundmass. Tridymite is probably also present in some of the rocks. Many of the rocks might be called hornblende-pyroxene-cristobalite latites. An analysis of this rock is shown in table 23, column 1. The analyzed rock has its original hornblende almost entirely resorbed.

To the east and southeast these rocks seem to carry progressively more and larger phenocrysts, the hornblende becomes less resorbed but the quartz more resorbed, and they seem to grade into the hornblende-pyroxene rocks described in the preceding paragraph.

Pyroxene-quartz latites, with little or no hornblende or biotite, were found in many places but they are subordinate in amount and were nowhere seen to make up an important part of the formation. They seem to be mostly local variations of the other andesites.

Basaltic rocks with labradorite, pyroxene, and altered olivine in a glassy groundmass were found only in a few narrow dikes.

NORTHEASTERN PART OF THE SUMMITVILLE QUADRANGLE

The Fisher quartz latite is found only in the northeastern part of the Summitville quadrangle and extends only for a short distance into the Creede quadrangle. The largest body occupies the high mountains to the west of the old mining camp in Summitville. Other smaller bodies crop out in the basin of upper Pinos Creek and an outlier caps Lookout Mountain. The rock underlies an area of about 26 square miles and it probably originally covered a much larger area, but much of it has been removed by erosion. As elsewhere, it was spread over a youthful surface of considerable relief, with deep canyons and high mountains. Its lowest contact, therefore, cuts sharply across the contours. The distribution and the irregularity of its base are shown on the geologic map (pl. 1).

The formation consists in considerable part of irregular beds of chaotic breccia, with associated irregular flows. There are some more regular and widespread flows and some rather well-bedded tuff. For the most part, the fragments of any breccia bed are all of one kind of rock and the associated flows are likely to be similar. The material is poorly sorted and the fragments are angular or subangular.

The rocks range from light gray to reddish-brown but a few are greenish. Most of them are dense but some have abundant gas pores and a few are nearly pumice. From one-quarter to one-third of most of the rocks consists of large phenocrysts, not uncommonly 1 cm across and rarely 5 cm. White plagioclase is the chief phenocryst; biotite and hornblende are present in nearly all the rocks; quartz is abundant in many and absent in others; orthoclase is in small amount. Some of the darker rocks have smaller phenocrysts. The groundmass is mostly aphanitic but is glassy in the basal parts of many of the flows. Most of the rock around the mining camps is greatly decomposed. In most of the rocks the plagioclase phenocrysts are oligoclase or oligoclase-andesine, and the biotite and hornblende are more or less resorbed. The groundmass is made up of fine laths of plagioclase, some orthoclase and probably quartz, grains of augite, and a dust of iron oxide. Many of the rocks have abundant tridymite in the gas pores and a few have cristobalite.

The rock of North Mountain has 4-cm phenocrysts of glassy orthoclase and smaller phenocrysts of oligoclase, quartz, biotite, and resorbed hornblende. The groundmass is made up of small plagioclase laths, orthoclase, quartz, and some dark minerals. Similar rocks with little hornblende extend to the south and form South Mountain. Farther south in Cropsy Peak, this rock is overlain by a flow in which the orthoclase phenocrysts are smaller and in lesser amount, quartz is subordinate, and hornblende is more abundant and free from resorption. The orthoclase crystals are surrounded by white oligoclase, with some intergrown orthoclase. In some specimens the orthoclase core forms only a small part of the crystal, and in others it is entirely lacking. As the orthoclase becomes smaller in amount the phenocrysts become smaller. Rock of this kind forms the mountains to the west and south of Cropsy Peak. An analysis of the glassy base of this flow is shown in table 23, column 15. On the west slopes of Cropsy Peak the rock has a somewhat more calcic feldspar, the hornblende is much resorbed, the biotite less so, and some augite appears in the groundmass. All the rocks of this area are much like the rocks with large orthoclase and quartz phenocrysts that are locally developed at the head of Mineral Creek in the San Cristobal quadrangle. They have been described by Patton (1917, p. 23–33).

Two specimens collected from what was thought to be the base of the formation in the East Fork of the South Fork of the Rio Grande were very different and may not belong to the Fisher quartz latite. The one carries phenocrysts of labradorite, brown hornblende, augite, and hypersthene in a groundmass made up of oligoclase laths in a glass. There is some cristobalite in the gas cavities. The other has a few crystals of bytownite and some resorbed hornblende in a fine-textured groundmass.

SOURCE OF THE ROCKS

The Fisher rocks, unlike the formations of the Potosi volcanic series, piled up as relatively steep cones around their vents and in no place did flows spread over large areas. A number of these volcanic cones were formed and they have since been much modified by erosion, but for most of them the erosion was not sufficient to expose the central volcanic neck. A few small plugs of Fisher rocks are exposed in the upper drainage area of South River and elsewhere. However, dikes, sills, and small plugs of Fisher age are abundant, and were found in the central part of nearly every large Fisher extrusive body. Some of the dikes are several miles long and attain a width of 1,000 feet. In addition, the rocks near the centers are commonly much altered to quartz, alunite, pyrite, and some other minerals. Some of the bodies of alunitized rock are more than a mile across.

ASSOCIATED INTRUSIVE ROCKS

The cap of Red Mountain west of Lake San Cristobal in the northern part of the San Cristobal quadrangle is a remnant of a large body. Although this mass is not associated with an exposed intrusive body, there is a large area of mineralization and of alunitization in the Red Mountain area which has affected the Fisher quartz latite and older rocks and is believed to indicate close proximity to an intrusive body of Fisher age.

In the northeastern part of the San Cristobal quadrangle and adjoining areas, one of the largest bodies of Fisher rocks is cut by many deep canyons, yet no large intrusive body and only a few of moderate size were found in this area. The main center was probably under Painted Peak. Throughout this area there are some dikes, sills, and less regular intrusive rocks much like the associated extrusive rocks. It is difficult or impossible to distinguish the flat-lying intrusive ones from the irregular flows, and these smaller bodies have not been separated in the mapping. Some of the sill-like bodies are more than 1 mile in length and as much as 200 feet thick. Some larger intrusive bodies cut the Piedra northwest of Painted Peak and others cut the Piedra in the basin of Rough Creek, northeast of Painted Peak. There are considerable alteration and mineralization in both areas, particularly in the Rough Creek basin.

The mapped body near the head of the East Fork of Cebolla Creek, about a mile west of Painted Peak and half a mile northwest of the peak having an altitude of 13,338 feet, is an intrusive stock, poorly exposed and covered by landslides on the north. It is probably only about one-quarter of a mile across. It is made up of a dense, fine-grained quartz latite porphyry which contains a few tabular feldspar crystals as long as 1 cm. The rock contains about 40 percent of phenocrysts of labradorite, augite, hypersthene, and altered olivine, named in order of their abundance. The groundmass is made up mostly of smaller, more sodic feldspar, with some orthoclase and quartz. In the specimens with fewer phenocrysts the rock has nearly a fine, even-grained texture.

Several bodies of intrusive rhyolite cut the Piedra and Fisher rocks in the basin at the head of Rough Creek and in other parts of the Painted Peak area. These rocks are chemically not like any of the Fisher rocks but are more like the rhyolite of the Hinsdale formation or some of the rhyolites of the Piedra. Because their age is uncertain, they have been described under the rhyolites of unknown age.

The smaller intrusive rocks in the Painted Peak area are mostly much like the associated extrusive rocks of the Fisher quartz latite, but, on the whole, contain fewer and less conspicuous phenocrysts. Many of the rocks carry no large phenocrysts but some carry a few 1 cm or more in length. About one-third of most of the rocks is phenocrysts, of which labradorite is the chief. Biotite, more or less resorbed, is moderate in amount in most of the rocks and is the only dark mineral in some of the dikes and sills east of Cebolla Creek. Pyroxene is present in most of the rocks and it is the only dark mineral in some. Augite exceeds hypersthene in amount. Hornblende is present in only a few of the rocks but in the small mass just east of Rough Creek it is the only dark mineral. Magnetite is abundant in all the rocks. The groundmass in most of the rocks is fine-textured and is made up of laths of sodic plagioclase in a matrix of quartz and alkalic feldspar. In some specimens the groundmass is glassy. Tridymite is abundant in the porous rocks.

West of the town of Creede in the western part of the Creede quadrangle there are several dikes of a latite porphyry. These dikes strike nearly north and south and some of them are several hundred feet across and several miles long. They cut the Treasure Mountain and Piedra rocks and are much like the Fisher rocks of the area, both in texture and composition, and are believed to be of Fisher age. Most of the rocks are gray. They are dense and show phenocrysts, commonly several centimeters across, nearly equal in amount to the aphanitic groundmass. The phenocrysts are chiefly of white plagioclase in thick plates of rounded to hexagonal outline. Biotite is rather abundant, and in some of the material augite and less commonly hornblende are present. Phenocrysts of orthoclase and quartz are rare.

The microscopic study shows that the plagioclase phenocrysts are not greatly zoned and are andesine-labradorite in average composition. The biotite is commonly resorbed. The accessories are apatite, zircon, and magnetite. Less than half of the rocks show remnants of augite, largely altered to calcite and chlorite; nearly all show areas of calcite and chlorite which probably represent altered augite; a few show, in addition, some green hornblende. The groundmass is usually a rather coarse micrographic intergrowth of quartz and orthoclase, with some small laths of plagioclase. The rocks are commonly somewhat altered; calcite and sericite have developed from the plagioclase, and calcite and chlorite from the augite.

A few miles west of Creede in the San Cristobal quadrangle, in the basin of Shallow Creek, there is a much larger dike or lens of quartz latite porphyry that cuts Piedra rocks; it is much like the dikes near Creede but is coarser in texture. This dike is more than 2 miles long and about 1,000 feet across at its widest part. There are some alteration and mineralization around it. The rock is much like that of the dikes to the east, but there is some augite, the phenocrysts are somewhat larger, and there is nearly as much glassy orthoclase as there is plagioclase. Zircon is conspicuous as an accessory. The groundmass is in some specimens a sponge-like intergrowth of orthoclase and quartz, with some sodic plagioclase. In some specimens the groundmass is spherulitic with large spherulites imbedded in smaller ones. It is considerably nearer the rhyolites than the dikes to the east. This dike is correlated with the Fisher quartz latite largely because of its texture and similarity to the dikes to the east, but chemically it is nearer some of the Piedra rhyolite and it may belong to the Piedra.

The center for the largest body of Fisher rock, lying chiefly south of the Rio Grande and in the western part of the Creede quadrangle, is believed to be near Fisher Mountain. No large intrusive body was found in this area but some dikes and sill-like bodies are exposed, and there are considerable mineralization and alteration of the rocks, especially near the northwest base of Fisher Mountain around the old mining camp of Spar and to the northeast in the basin of Copper Creek. The center is believed to be covered.

Just southwest of this body, in the southeastern part of the San Cristobal quadrangle and adjoining areas, many dikes of andesite porphyry and two stocks of diorite porphyry cut across the Piedra rhyolite and the underlying rocks of the Potosi volcanic series. These intrusive rocks are much like the Fisher rocks in composition and are believed to be of Fisher age. The stock forming Red Mountain, which is the largest of these bodies has an irregular contact with the Piedra rhyolite which it intrudes, and only the larger of these irregulari ties are shown on the map. It carries many inclusions of the Piedra rhyolite, and on the northeast slope of Red Mountain there is an inclusion of white saccharoidal quartzite a hundred feet across. To the south and east of the stock dikes of a somewhat related rock are abundant. The largest of these, less than 100 feet across, have a decided tendency to radiate from the Red Mountain stock. Smaller dikes trend in many directions. An irregular stock of similar character forms the eastern shoulder of Piedra Peak and smaller bodies occur around this main stock. The Piedra rhyolite around the large stocks of Red Mountain and Piedra Peak is bleached and altered for a considerable distance. East of the Piedra Peak stock the rhyolite has been altered to a fine-textured rock, consisting of about 70 percent quartz, 28 percent alunite, and 2 percent pyrite. The stocks of Piedra Peak and Red Mountain and the two smaller bodies southeast of Piedra Peak are made up of a fine-textured granodiorite or granodiorite porphyry. A nearly horizontal sheeting and vertical jointing have broken the rock into small blocks which weather into rounded forms yielding outcrops that simulate boulder beds. The outcrops are commonly red because of superficial oxidization of the pyrite and other iron minerals. The color of the fresh rock is green, or gray, or rarely red. In most places phenocrysts are inconspicuous but locally large hornblende crystals are conspicuous. The dikes are of hornblende-quartz latite porphyry and differ considerably from the typical material of the stock. They are gray or green and are characterized by abundant small feldspar crystals and conspicuous hornblende phenocrysts in an aphanitic groundmass. The stocks consist of granodiorite porphyry. The porphyry ranges in texture from fine, nearly even grained to seriate porphyritic. The phenocrysts are largely andesine-labradorite, with some augite and hypersthene, and a variable amount of hornblende. The hornblende is mostly bright green, less commonly light brownish green, and is always much resorbed. In some of the more coarsely crystalline rocks it has been completely resorbed and pyroxene is more abundant. The groundmass is finely granular and is made up of plagioclase, quartz, and orthoclase. Apatite, iron ore, and biotite are accessory. Nearly everywhere the rock is impregnated with pyrite and is considerably altered. The hypersthene and to a less extent the augite are largely altered to chloritic minerals, with some uralite, calcite, epidote, and similar minerals. An analysis of the freshest material found is shown in table 23, column 5.

The dikes and borders of the stock are made up of quartz latite porphyry that no doubt represents a chilled phase of the magma. Phenocrysts make up about one-third of the rock. Andesite-labradorite is the chief one, bright green hornblende more or less resorbed is abundant, and biotite is usually present. Where biotite is absent, augite is abundant. The groundmass is fine-grained and commonly contains shreds of feldspar, grains of apatite, and perhaps pyroxene, in a glassy or very fine intergrowth of quartz and orthoclase. Some of the dikes carry phenocrysts of andesine, orthoclase, quartz, and biotite, with or without hornblende and pyroxene. The groundmass is mostly quartz and orthoclase.

There is every gradation between the pyroxene granodiorite porphyry in which there is little or no hornblende, and the hornblende-quartz latite porphyry in which hornblende and biotite are the only dark minerals. The difference is clearly due to resorption of the hornblende and biotite. In the final stages only the skeleton of the hornblende phenocrysts formed by a dust of magnetite, pyroxene, and other minerals remains, and, rarely, even this has been dissipated. In most specimens some shreds of the hornblende remain in the center of the skeleton. As the hornblende is more completely resorbed, pyroxene makes up a greater part of the rock. It is clear that at the time the magma was intruded it carried abundant phenocrysts of plagioclase, somewhat fewer of hornblende, and some of biotite. After reaching its new position the magma actively resorbed the hornblende and biotite, and pyroxene separated out in their place. Where the cooling was rapid in the dikes and along the borders of the stock, the hornblende and biotite were only slightly resorbed, but in the center of the larger bodies they were in large part resorbed and pyroxene became the chief or only ferromagnesian mineral. Later hydrothermal action produced the uralitic hornblende.

The sill near the forks of Red Mountain Creek, about a mile north of Piedra Peak, is of hornblende-quartz latite porphyry much like that of the dikes near Red Mountain, but the groundmass is made up of plagioclase laths and magnetite dust in a fine-grained, sponge-like intergrowth of quartz and orthoclase.

Several small dikes of hornblende-quartz latite cut the Fisher quartz latite in the area between Goose and Leopard Creeks south of the Rio Grande, in the western part of the Creede quadrangle. Similar dikes were found half a mile east of the mouth of Blue Creek north of the Rio Grande, and in a few other places in the Fisher Mountain area. These dikes contain in percent from 10 to 20 of labradorite phenocrysts, about 5 of hornblende, 3 of biotite, and 2 of magnetite, in a fine-textured groundmass that is made up about half of andesine laths in a matrix of quartz and alkalic feldspar. A similar dike, cutting the Alboroto latite about 1½ miles southeast of Mt. Hope, has some hypersthene and augite and considerable magnetite.

From the distribution, thickness, and character of the Fisher rocks in the Summitville quadrangle it is believed that a volcano of Fisher age centered near the old mining camp of Summitville. In agreement with this, just west of the Summitville-Platoro mining district is the geographic center and the area of greatest abundance for a group of intrusive quartz latite porphyries. Most of these porphyritic intrusives cut the Conejoz quartz latite but one body in Park Creek, northwest of Summitville, cuts the Piedra rhyolite. The rocks are all very much alike in composition and texture, they are also very much like the Fisher quartz latites of the Summitville area, and they are therefore believed to be of Fisher age. Some of the dikes near Summitville are so nearly identical with the flows of Fisher age nearby as to leave no doubt that they represent the same magma. However, it is possible that some of the intrusive bodies, notably those of the Blanco Basin and those in the Conejos quadrangle, are of Conejos age. The available evidence points strongly to a Fisher age for all of the bodies.

This quartz latite porphyry is present as dikes, small stocks, and sheetlike bodies. The most easterly body is on the east shoulder of Silver Mountain north of the Alamosa River in the Conejos quadrangle, about 8 miles east of Platoro, and the most southwesterly body is at the border of the volcanic rocks east of Blanco Basin, about 16 miles southwest of Platoro. The quartz latite bodies are abundant in a narrow arclike belt, curved to the northwest and about 25 miles long, between these two bodies. Only a few of the larger or more conspicuous bodies are separated on the geologic map. One of the largest of these is the sill east of Blanco Basin. It is about 400 feet thick and is exposed for more than 1.5 miles on the cliffs. It intrudes the pre-Conejos sediments.

Near Montezuma Peak, some miles to the north of Blanco Basin, small bodies of quartz latite are especially abundant. Montezuma Peak is capped by a body of intrusive quartz latite and a body about 0.5 mile in maximum diameter lies 2.5 miles north of Montezuma Peak, and another of about the same size is mapped 1.5 miles northeast of the peak. A large number of dikes, some of them as much as 200 feet across, are clustered around Summit and Montezuma Peaks. Two miles south of Summit Peak, near the head of Adams Fork of the Conejos River, is a body of latite nearly a mile in length.

About 6 miles northwest of Montezuma Peak, near the forks of Silver Creek, an irregular body of this quartz latite cuts pre-Conejos shales and sends out many apophyses in all directions, and one dike striking about N. 60° W. has a width of about 75 feet and a length of 2 miles. About 4 miles northeast of this in the basin of Park Creek, the largest outcrop of this quartz latite is exposed. It is about 1.6 miles long and has a maximum width of about 0.5 mile. It cuts the Piedra rhyolite and older rocks.

Near Summitville dikes of similar rock are especially numerous, but no large bodies were found.

These quartz latite porphyries are remarkably uniform in composition and appearance. They are characterized by a large proportion of unusually large feldspar phenocrysts, abundant hornblende, and a fine-grained groundmass. Orthoclase, though not abundant, forms conspicuous, rounded phenocrysts reaching a maximum length of 40 mm. Plagioclase phenocrysts form from 10 to 30 percent of the rock and occur as euhedral white crystals from 5 to 15 mm in length. Lustrous black crystals of hornblende, with a maximum length of 10 mm, form from 2 to 4 percent of the rock, and biotite in crystals of about the same size as those of hornblende form less than 1 percent of the rock. Augite is in small amount. The groundmass ranges from light to dark gray and is mostly finely granular, but in some rocks it is microperthitic and in others it is made up of a network of euhedral plagioclase and anhedral orthoclase. Quartz is present in the groundmass. The rocks are so much alike that detailed descriptions of only a few of the rocks are necessary.

The quartz latite of the sill east of Blanco Basin has about 10 percent of large rounded orthoclase phenocrysts, 25 percent of oligoclase-andesine, a few percent of hornblende, and some augite and biotite. Apatite is an important accessory. The groundmass is made up of rounded grains of microperthitic intergrowths of orthoclase and oligoclase and contains some quartz.

The body near the mouth of Oil Canyon is similar, but the groundmass is made up of interlocking grains. In the Park Creek body the groundmass consists of euhedral crystals of oligoclase in a fine-grained matrix consisting largely of orthoclase. The hornblende shows some resorption and magnetite and augite have developed. The texture and the resorption of the hornblende indicate a shallow intrusive body.

The rock of the body on the east shoulder of Silver Mountain in the Conejos quadrangle is of the usual type. The plagioclase phenocrysts have a meshlike structure due to abundant inclusions of glass. The hornblende is much resorbed. The groundmass is composed of euhedral plagioclase, hornblende, and augite, in a cryptocrystalline matrix. Vesicles are filled with tridymite. These rocks seem to be poorer in quartz than the extrusive rocks of the Fisher quartz latite and approach latites in composition.

Many of the dikes in the Summitville-Platoro mining district carry abundant orthoclase phenocrysts and some of quartz; biotite is the chief or only mafic mineral. They are nearer the rhyolites and are similar to some of the extrusive rock of the Fisher. An analysis of a specimen of this latite is shown in table 23, column 11.

CONDITIONS OF ACCUMULATION

The greater part of the clastic beds of the Fisher quartz latite shows little or no evidence of more than slight transportation, wear, or sorting by water, for the fragments are mostly sharply angular, the layers are thick, and the fragments of any layer are of variable size and are all of one kind of rock. The associated flows are of the same kind of rock as the breccia beds, and they are steep, irregular, and of small extent. Locally, as in the lower part of the formation in the large area south of the Rio Grande in the western part of the Creede quadrangle and adjoining parts of the San Cristobal quadrangle, the beds are thinner, better sorted, contain more fine material, and the fragments are fairly well rounded. There is little uniformity in the layering of the material either in the clastic beds or the flows. Many of the flows and beds dip rather steeply and irregularly. The different rock types are not distributed in widespread layers but rather as thick local accumulations, and a cliff section of 1,000 to 2,000 feet may be made up of one kind of rock, although a similar section only a mile or so away may be of a different type. Apparently neither the flows nor the clastic material have been carried far from the crater through which they were erupted.

To a large extent these rocks filled in the irregularities in a surface of considerable relief. At present, the Fisher quartz latite forms a number of widely separated mountain groups without any close connection between them, and it seems probable that each of these mountain groups represents an aggregate of volcanic centers around which the material accumulated. The formation was probably never so uniform and widespread as the Alboroto and Piedra rhyolites, but formed groups of mountains that were not much more extensive than the present outcrops. Most of the areas of the Fisher quartz latite are associated with extensive alunitization and with some intrusive rocks. There is evidence of volcanic centers, though the actual vents are not exposed. However, such mountains as Painted Peak are probably the Fisher volcanic cones somewhat modified by erosion.

CHEMICAL PETROLOGY

Chemical analyses of 13 rocks from Fisher quartz latite from the related Los Pinos volcano of Chiquita Peak and 2 from No Agua volcano are shown in table 23, together with the norms, modes, and position in the quantitative classification. Eleven of the analyses were made for this report in the chemical laboratory of the United States Geological Survey, 2 are quoted from Patton (1917), and 2 were made at Harvard. The analyzed rocks were carefully selected to represent the different rock types in the formation, and they give a comprehensive picture of the chemistry of the formation. A calculation of the average composition of the formation, based on the analyses and taking into account both the estimated areal distribution and thickness of the different types, is given in column A.

The analyses and microscopic study show that the Fisher quartz latite has only a moderate range in composition. They all carry abundant quartz and orthoclase, both in their norms and modes, and all are quartz latites, most of them near the middle of the range for quartz latites. The rocks nearest the rhyolites, represented by analyses 14 and 15, make up only 1 or 2 percent of the formation and were found chiefly in the Summitville quadrangle. The biotite-tridymite latite represented by analysis 13 makes up about 4 percent of the formation and was recognized only in the McLelland Mountain area in the central part of the Creede quadrangle, where it forms the several flows of that thick body. The quartz latite of Crown Mountain represented by analysis 12, makes up about 15 percent of the formation and was found chiefly in the San Cristobal quadrangle and adjoining areas. The different quartz latites, represented by analyses 6, 7, 10, and 11, are widely distributed and make up about 30 percent of the formation. They are near the average quartz latite in composition and also near the average rock of the Fisher quartz latite. The rocks represented by analyses 4 and 5 are widely distributed in the Creede and San Cristobal quadrangles and make up about one-third of the formation. The quartz latites represented by analyses 1, 2, and 3 are near the average augite andesite of Daly. They were found chiefly in the Creede quadrangle, south of the Rio Grande, and in the adjoining part of the San Cristobal quadrangle and make up about one-sixth of the formation.

A variation diagram presenting the 17 analyses of the Fisher and the Los Pinos gravel is shown in figure 46.

LOS PINOS GRAVEL

NAME AND DEFINITION

An extensive body of gravel was first found under the basalt of the Hinsdale in the summer of 1914 in the southeastern part of the Summitville quadrangle where it is nowhere more than 250 feet thick. To the east in the Conejos quadrangle and to the south in New Mexico, it becomes much thicker. It overlies the Treasure Mountain rhyolite in most places in Colorado but locally overlies the Sheep Mountain quartz latite. In New Mexico the Treasure Mountain wedges out and these gravels overlie the Conejos quartz latite or older rocks. These gravels are regularly overlain by the basalt and latite of the Hinsdale and are in part interbedded with similar basalt.

In the northern part of the Conejos quadrangle at the northern boundary of the Los Pinos gravel a local group of flows and pyroclastic beds overlies the Potosi volcanic series with a little irregularity and forms much of Green Ridge and Chiquita Peak. To the south these definitely volcanic rocks grade into the typical Los Pinos which is here made up in part of pyroclastic and in part of sedimentary tuff material. Farther from Green Ridge the Los Pinos contains less pyroclastic material and more sands and gravels. In the whole Colorado area nearly all of the fragments are of quartz latites like those of the Green Ridge volcano but with more glassy and scoriaceous rocks. The age of the Green Ridge volcano is somewhat uncertain. Its rocks resemble those of the Fisher quartz latite. However, the canyon topography over which the Fisher was erupted in most places is absent in the Conejos area.

Indeed, in this area the whole section from Conejos to Hinsdale shows little erosion between the formations and the whole section seems to be conformable, although only the two lower formations of the Potosi volcanic series are present. Thus some of the best kinds of evidence for the correlation of the rocks common in the central part of the mountains are absent here.

Atwood and Mather (1932, p. 100, 101) and Cross and Larsen (1935, p. 95) considered the Los Pinos gravels to be a member of the Hinsdale volcanic series and they placed the Summit peniplain at the base of the Los Pinos gravels. However, Butler [1] (1946, p. 1183, abs.), after a careful study of the Los Pinos gravels and associated rocks in New Mexico, south of the Conejos quadrangle, concludes that

> The Los Pinos shows (1) no appreciable unconformity between it and the Potosi series, (2) that it is partly older than and partly contemporaneous with the Santa Fe formation (upper Miocene to lower Pliocene), (3) that its material was supplied largely by contemporaneous vulcanism rather than by erosion of older rocks, and (4) that the volcanic series of the Hinsdale formation is unconformable on both the Los Pinos and Santa Fe formations. This unconformity probably merges with the San Juan peneplain, which was previously considered older than the Los Pinos formation.

The rocks of the Los Pinos gravels are therefore correlated with the Fisher quartz latite.

DISTRIBUTION, THICKNESS, AND STRUCTURE

The sands and gravels of the Los Pinos gravel are confined to the southern and southeastern flanks of the San Juan Mountains. Its northwestern limit extends from the extreme southeastern part of the Summitville quadrangle, to the northeast, across the Conejos quadrangle, and into the south-central part of the Del Norte quadrangle. Beyond this the Hinsdale and older formations are covered by the sands and gravels of the San Luis Valley. To the north, in the Del Norte quadrangle, thin local bodies of gravels and gravelly tuff immediately underlie the basalts of the Hinsdale but they were belived to belong to the Potosi volcanic series at the time they were mapped. However, they may represent local deposits of the Los Pinos beds. Locally in the Uncompahgre quadrangle a few feet of gravel are present at the base of the Hinsdale but they have not been separately mapped.

It is believed that the present northwestern limit of the sands and gravels of the Los Pinos is approximately the original limit, because the gravels are pinching out in that direction and not far to the west the basalts of the Hinsdale formation overlie the Potosi volcanic series with little or no gravel between them. It therefore seems clear that the higher part of the San Juan peneplain (Atwood and Mather, 1932, p. 1–25) occupied about the same position as the higher part of the present San Juan Mountains.

To the south and southeast the Los Pinos gravel becomes rapidly thicker. Except for the local volcanic pile of Green Mountain, it is nowhere more than 500 feet thick in Colorado. In that State they rest on a rather regular surface of older rock, but in New Mexico they rest on a less regular topography and many hills and mountains of older rocks project above the uppermost part of the Hindsale formation.

GENERAL CHARACTER

The Los Pinos gravel is variable in character. Most of the material is waterlaid, though lava flows and pyroclastic beds are locally present. The material ranges from coarse gravel, with some fragments a foot or more across, to sand. In general the material near the borders of the formation, where it is thin, is coarser and contains a greater proportion of pyroclastic materials. The flows are mostly in the Conejos quadrangle, where they make up much of the thick section of Chiquita Peak and Green Ridge, and no doubt were extruded by a local volcano. Local flows were also formed in the northern part of New Mexico. Pyroclastic beds are associated with the flows of the Green Ridge-Chiquita Peak area, and they are also present in other parts of the Conejos quadrangle and in the northern part of New Mexico.

For the most part the material is well bedded and individual beds are mostly thick, but they range from 1 foot or less to 100 feet or more. The bedding is not usually regular; cross-bedding is common. The beds are separated in part by claylike partings and in part by a rather abrupt change in either the character or size of the fragments making up the beds. Lenses or more regular layers of conglomerate locally separate the sandstone beds in the New Mexico area, as do widespread layers of tuff, not uncommonly only 1 or 2 inches thick and more or less altered to bentonite. The pyroclastic layers are of a chaotic aggregate of angular fragments as much as several feet across, almost entirely of one kind of rock. In some the fragments are highly vesicular and are welded together, and the material must have been derived from a vent nearby; but others show some evidence of sorting and rounding and there is every gradation from the material that seems to be truly pyroclastic to the normal sands and gravels that were deposited by water and were derived from the breaking down of older rocks. The fragments of most of the pyroclastic bed are rather light colored, coarsely porphyritic quartz latites similar to those of the flows of the Chiquita Peak-Green Ridge area. Such layers are well exposed in the Conejos River basin

[1] Butler, A. P., 1946, Tertiary and Quaternary geology of the Tusas-Tres Piedras area, New Mexico: Unpublished Ph. D. thesis, Harvard University.

where no flows were found, as well as in the Chiquita Peak area where they are associated with flows.

The fragments of the sands and gravels differ considerably from place to place, and in most beds a single kind of rock makes up nearly all the fragments. The pebbles are mostly well rounded and are almost unweathered, and the minerals of the sands, even the mafic minerals, are fresh. Locally a thin outer skin of the pebbles is weathered and rarely the pebbles are friable through weathering. In some places the sands are cemented by calcite or silica but in most places they have little cementation. Except around the hills of pre-Cambrian rocks in New Mexico and the quartz latite volcano of Chiquita Peak-Green Ridge, all of which represent hills that rose above the Summit peneplain, the fragments show no close similarity to underlying or other rocks nearby. In Colorado, where most of the formation is gravel or coarse grit, the fragments are nearly all of volcanic rocks, and in the lower part of the formation most of them are of coarsely porphyritic quartz latite much like the predominant rocks of the Chiquita Peak-Green Ridge volcano. Fragments of granodiorite resembling that of the Cat Creek area to the north are rather abundant, but fragments from the underlying formation of the Potosi volcanic series are not abundant. In the upper part of the section rocks much like those of the Conejos quartz latite make up a considerable part of the fragments. Fragments from pre-Cambrian rocks are in small amount. Near the top of the formation, interbedded with the higher basalt flows, are beds of very fine wind-sorted and wind-deposited rhyolitic tuffs.

In New Mexico the Los Pinos gravel becomes, on the average, better bedded and sorted, the pebbles are better rounded, more sand is present, the fragments of quartz latite of the Chiquita Peak type are less common, and the material was derived mostly from pre-Cambrian rocks. In the Tusas quadrangle and particularly in the Brazos special area, the material around the hills of pre-Cambrian rocks was clearly derived from the hills nearby, and represents simply talus and poorly sorted wash from the adjoining hills. It is impossible to distinguish the Los Pinos material from the recent talus and wash.

DETAILED PETROGRAPHY

The details of the petrography can best be brought out by descriptions of typical sections and these descriptions will be arranged from north to south. The strictly massive rocks of the Chiquita Peak-Green Ridge area will be described later in a separate section.

In the southeastern part of the Conejos quadrangle there are many excellent outcrops of the Los Pinos gravel. The best of these are along the Conejos River between Mogote post office and Broil's Bridge and in the east bluff of Fox Creek west and northwest of Los Mogotes. A detailed section is given below.

Section of Los Pinos gravel in south bluff of the Conejos River 3 miles west of Mogote post office, Conejos quadrangle

		Thickness (feet)
10.	Hinsdale formation (basalt flow)	50
	Los Pinos gravel:	
9.	Sand, fine, yellow, tuffaceous	35
8.	Sand, fine, well-bedded, with irregular lenses of black lavas and of lighter-colored quartz latite boulders. Larger boulders, as much as 2 ft across. Crossbedded. Coarser in upper part and has more pebbles. Boulders are from Conejos and Chiquita Peak volcanoes	140
7.	Sands, grading into sandy gravels. Some boulders 2 ft across and 6-in cobbles; many are flat. Well-bedded. Fragments chiefly quartz latite, some granodiorite, and granite	100
6.	Gravel. Quartz latite pebbles predominate but those of granodiorite are abundant. Granite, alunitized rock, quartz latites from Conejeos, and other rocks are rare	50
5.	Sand of quartz latite with pebbles	15
4.	Tuff of pebbly quartz latite	25
3.	Sand, well-bedded, with some pebbles as large as 1 in and some layers of boulders up to 2 ft. All material is of porphyritic quartz latite of Chiquita Peak type. Some lenses and layers, especially near base, of angular, pyroclastic, quartz latite tuff-breccia	220
2.	Rhyolitic tuff	15
1.	Covered	40
	Total, Los Pinos gravel	680

The section here seems to be made up of three parts. About 300 feet of the lowest part is exposed. It is composed mostly of coarse quartz latitic sand, well-bedded, and moderately indurated (2 to 4). Mixed with this sandy material are pebbles averaging 1 inch across and many boulders as much as 1 foot in diameter. Near the base and near the top of this part of the section are thin beds of pure quartz latite tuff, which are in part lenticular, but near the top there is a nearly white, persistent bed of tuff (3). From 95 to 99 percent of the pebbles and boulders of this lowest part are a coarsely porphyritic quartz latite similar to that occurring in Green Ridge. The sands are composed of feldspar, pale-green augite, and biotite similar to the minerals in the latite, and they are evidently derived largely from the latite. The lower tuff beds contain much glass, but the minerals are like those in the latite boulders, and the feldspar is all andesine. A small proportion of minerals is derived from granitic rocks. The upper tuff beds contain a large proportion of fragments of flattened glass bubbles and minerals derived from the quartz latite similar to those just described. Besides these minerals, there are found quartz, microcline, and green hornblende, all of which were probably derived from granitic rocks. In both tuff horizons there is evidence that many of the mineral grains are derived directly from latitic tuff, being set free from the glass by the explosive violence of the eruptions. Many of the feldspar grains and some of the augite have adhering masses of volcanic glass. A large proportion of the augite grains have parallel groups of terminal planes giving them a cockscomb appearance. These fine needlelike terminations would not be likely to be retained if the minerals were set free by ordinary erosion, and water transportation over any great distance would destroy them.

The middle part of the section, which is about 165 feet thick (5–7), is of similar materials. Pebbles and boulders are more abundant than in the preceding group, but still are decidedly subordinate to sands. No pumiceous tuffs are present. Porphyritic quartz latite like that just described makes up most of the fragments, but a much greater variety of rocks is present. Granodiorite boulders ranging from coarsely crystalline to finely crystalline are common, and in some beds they may exceed latite in abundance. Boulders derived from volcanic rocks that have been silicified and alunitized, probably by the contact action of the intrusive rocks are common. Another abundant type of boulder is Conejos quartz latite of basaltic habit.

The third part of the section (8 and 9), totaling about 175 feet in thickness, contains in its lower part about 50 feet of firm, evenly sorted, light-colored sand with lenses of coarser material that resembles filled stream channels. Above this are about 100 feet in which sands, boulder beds of latite of porphyritic habit and quartz latite of the Conejos predominate. The sand and boulder layers are poorly bedded and crossbedding is common. Above this are about 30 feet of fine-grained, evenly sorted, yellow tuffaceous sand. Overlying the whole are about 50 feet of basalt of the Hinsdale formation.

The Los Pinos gravel is well exposed in the scarp on the east side of Fox Creek but in general the exposure is similar to the section just described. The predominant pebble is a coarsely porphyritic quartz latite similar to that in Chiquita Peak; somewhat less abundant are olivine andesites of basaltic habit, and very much less abundant are granodiorites and contact-altered volcanic rocks. Tuff beds are abundant and some of these are rather striking. There are layers of almost pure white pumiceous tuff, in places in sharp contact with beds of well-sorted sandy tuff composed of glass bubble walls and mineral fragments.

Just south of the Colorado-New Mexico State line, the Los Pinos gravel is well exposed in the canyon of Rio de los Pinos. In an exposure of the upper part of the formation, just under the basalt, about 4 miles below Ortez, N. Mex., the pebbles range in diameter from 1 to 8 inches and are made up in percent, as follows: 64 of dark quartz latites of the Conejos type, 13 of basaltic rocks, 10 of rhyolite, 7 of diorite, 3 of silicified volcanics, and 3 of quartz latite.

Farther south, in the basin of Antone Creek, the pebbles are smaller, more sand is present, and some of the sand grains were derived from granitic rocks. Some of the layers are made up mostly of arkosic sand, with some fragments and pebbles of quartz latite. On the whole, volcanic material, mostly of dark quartz latite, predominates. Small fragments of rhyolitic pumice are present in small amount.

A few miles to the west in the Brazos special part of the Tusas quadrangle about 1.5 miles above the mouth of Canyon Marga, a good exposure of a part of the Los Pinos gravel shows the following beds from the top of the exposure downward:

	Thickness (feet)
Los Pinos gravel:	
Conglomerate, moderately coherent, made up of subangular fragments of granite with rare volcanic rocks in a matrix made up largely of rhyolitic tuff with some granitic fragments. Opal cement	50
Rhyolitic tuff, made up of glassy fragments and containing about 30 percent of sand from pre-Cambrian rocks	19
Rhyolitic tuff, containing well-rounded boulders of dark rocks and smaller subangular fragments of rhyolite. The matrix is in part rhyolitic tuff, in part fragments from granitic and various volcanic rocks. Cemented by opal and some calcite	42
Conglomerate made up of granite pebbles in an arkosic matrix cemented by calcite	20
Total	131

In this section the minerals show little alteration. The granite fragments are similar to rocks exposed within a mile or so of the exposure, but the volcanic fragments must have come from a somewhat greater distance.

Immediately beneath the basalt of the Hinsdale formation in a cut on the east bank of the north branch of Rio Brazos near the northeast corner of T. 31 N., R. 5 E., 40 feet of uncemented gravel in a sandy matrix are well exposed. The abundant sandy matrix is made up of a mixture of volcanic and granitic material. The fragments are well rounded, as much as 6 inches across, and are made up of about the following percents of rocks: dark quartz latites 72, basaltic 18, rhyolite 3, and silicified volcanics 7. Most of the volcanic fragments were derived from the Conejos quartz latite which is exposed to the west. Some of the fragments are of the porphyritic Green Ridge type and this type predominates in some parts.

THE QUARTZ LATITE OF CHIQUITA PEAK-GREEN RIDGE

In the north-central part of the Conejos quadrangle a local accumulation of dark flows and breccia beds forms most of Chiquita Peak and the core of Green Ridge and caps Jacobs Hill. On the east flank of Green Ridge these quartz latite flows have a thickness of more than 2,400 feet but they thin out in all directions, and only 4.5 miles to the northwest they are only 300 feet thick, and in Chiquita Peak only 635 feet thick. These flows and pyroclastic beds are of local extent and are confined almost entirely to the area north of the Alamosa River, but in this area they make up most of the rocks mapped as Los Pinos gravel. They clearly were accumulated around a local vent whose center was near the crest of Green Ridge. They were probably contemporaneous with the lower part of the sands and gravels of the Los Pinos. Other related smaller centers of these eruptions must have been active during this time, for angular, pyroclastic layers of similar material are present in the formation for many miles to the south and most of the fragments in the lower part of the formation are of this type of rock for 40 miles to the south.

The greater part of the Chiquita Peak section is composed of irregular chaotic flows of quartz latite, but the peak is capped by a thick flow. The rocks in Jacobs Hill are similar to those in Chiquita Peak. Green Ridge is formed of a core of the quartz latites with a thick mantle of later basalt of the Hinsdale formation. Originally a peak composed of flows, volcanic breccias, and boulder beds seems to have been built up, which was later eroded and partly dissected. This was followed by the extrusion of basaltic flows originating from a vent near the present crest of Green Ridge which almost completely mantled the older series. Since then, erosion has dissected Green Ridge and exposed the older rocks on nearly all sides. On the east a large gulch has cut back nearly to the crest and the quartz latites are exposed to an altitude of about 10,900 feet. On the south and north they are exposed to an altitude of about 9,000 feet, and on the west to about 10,000 feet.

The eastern part of Green Ridge is composed very largely of flows, the lower of which are rather chaotic, but the upper are thick and fairly regular. On the south slope of Green Ridge breccia beds are more abundant than on the east slope. The lower 200 feet just north of Gato Creek is formed of water-laid boulder beds which are almost exclusively of rocks of the Chiquita Peak-Green Ridge type. Above this is a thick horizon of pumiceous tuffs and breccias. Still higher in the section, chaotic flow breccias predominate, and just beneath the basalt of the Hinsdale formation there is a thick continuous flow of quartz latite. The north side of Green Ridge is similar to that of the east side for the most part, but in sec. 13, T. 37 N., R. 6 E., the rocks are largely tuff-breccia containing small angular fragments of porphyritic quartz latite in a black glassy groundmass.

South of the Alamosa River, southeast of Chiquita Peak, are beds composed of water-laid tuffs and subangular boulders that for the most part are of rocks characteristic of Chiquita Peak. The upper and lower limits of the beds are very hard to determine, but it seems to be 50 to 100 feet thick on the Alamosa. These boulder beds seem to have been deposited almost simultaneously with the Chiquita Peak-Green Ridge eruptive bodies, for they can be traced almost continuously into typical beds of Chiquita Peak.

The rocks of Chiquita Peak are quartz latites; some have a few small phenocrysts, others are coarsely porphyritic. On the whole they form a fairly uniform group in which porphyritic quartz latites are characteristic. The most characteristic type is a dark gray pyroxene-quartz latite, with phenocrysts of andesine and augite visible in the hand specimen. Andesine phenocrysts reaching a maximum diameter of 8 millimeters form about 20 percent of the rock, and have a composition about An_{45}. Pale-green to colorless augite forms about 9 percent of the rock, and hypersthene and hornblende each a fraction of 1 percent. Magnetite is abundant in large irregular grains. The groundmass is composed of glass, with a few microlites of plagioclase and augite. No crystalline orthoclase occurs in the mode.

A variant of the same type has a fine-grained felted groundmass of andesine microlites in a glassy matrix. Still another variant possesses a completely crystalline groundmass composed of anhedral oligoclase and augite, with little orthoclase.

A closely related type is a hornblende-biotite-quartz latite that occurs in the lower part of the Chiquita Peak section and is especially conspicuous as boulders in the Los Pinos gravel. In this type the proportion of the phenocrysts ranges about as follows: andesine 20 to 30 percent; hornblende 5 to 15 percent, and biotite from a fraction to 3 percent. The feldspar has about the composition An_{40}, slightly more sodic than that in the pyroxene rocks. The hornblende and biotite are both deep brown. The groundmass ranges from completely glassy to a felted fabric of andesine microlites in a glassy matrix. Intermediate types containing both augite and hornblende occur.

The tuff beds of the Chiquita Peak are nearly white and are composed of glass, andesine, and biotite. The feldspar has about the composition An_{40}, and the index of refraction of the glass in the groundmass is about

TABLE 23.—*Analyses, norms, and modes of Fisher quartz latite and Los Pinos gravel*

	1	2	3	4	5[1]	6	7	8	9	10	11	12	13[2]	14	15	16	17	Avg.
ANALYSES																		
SiO_2	57.56	59.26	59.95	58.73	60.00	60.54	60.25	60.09	61.52	62.36	62.51	64.59	66.18	65.29	69.13	73.51	76.35	62.17
Al_2O_3	15.06	17.27	16.92	15.73	18.10	16.01	15.55	16.21	16.12	14.95	14.64	15.22	14.41	15.56	14.31	12.86	12.34	15.58
Fe_2O_3	6.75	3.63	4.70	4.14	1.75	3.63	5.95	5.75	3.36	5.15	.63	2.73	2.35	4.13	.64	.35	.47	3.55
FeO	1.59	3.30	2.42	2.85	3.77	2.34	.53	.85	2.32	.89	2.93	1.79	1.26	.55	1.10	.42	.60	1.99
MgO	3.43	2.01	1.64	2.69	2.41	2.49	2.91	2.92	2.03	1.82	1.88	1.83	.90	.78	.83	.15	.03	1.96
CaO	6.01	6.01	5.83	5.29	5.30	5.44	4.93	5.11	4.73	3.88	3.80	3.91	3.20	3.41	2.31	.60	.38	4.64
Na_2O	3.12	3.78	3.12	3.08	3.36	3.69	3.41	3.07	3.72	3.59	3.01	3.52	3.72	3.66	4.19	4.38	4.29	3.13
K_2O	2.84	2.00	2.78	3.34	2.10	3.80	4.39	3.79	3.70	3.74	3.78	3.72	4.76	4.61	4.55	4.32	4.39	3.76
H_2O+	.61	.71	.88	1.32	.73	1.07	.46	.90	1.84	.85	1.44	1.27	.60	.94	2.45	3.26	.91	
H_2O-	.31	.17	.60	.76	.76	.23	.20	none	.12	1.52	.80	.59	.07	.60	.06	.24	.00	
TiO_2	1.50	.91	.91	1.10	.93	1.10	.51	.72	1.00	.69	.73	.70	1.20	.85	.50		.09	.95
P_2O_5	.38	.32	.31	.32	.63	.51	.61	.18	.27	.31	.36	.29	.13	.26	.18	.01	.02	.36
MnO	.09		.08	.14	.13		.09	.08		.09	.08		.06			.02	.06	.09
CO_2	.07		.00		tr			none		.10	3.75		.94		tr			.05
ZrO_2					.02		.04				.06				.10	.02	tr	.10
SO_3	.10							.07			.15						.06	
S	.00				.02		.02			.01	tr						.01	.01
F							.04											.04
V_2O_3							.02			.02								.02
BaO	.06				.09		.13			.08						.00		.09
SrO	.14				.01		.05			.07								.07
Total	99.62	99.37	100.14	99.49	100.11	100.85	100.09	99.74	100.73	100.12	100.55	100.16	99.78	100.64	100.35	100.14	100.00	98.56
NORMS																		
Q	13.56	14.76	17.70	14.58	17.40	12.42	11.64	13.86	14.64	17.88	19.56	20.58	20.46	19.26	21.78	29.10	33.48	
or	16.68	11.68	16.68	19.46	12.23	22.42	26.13	22.24	21.68	21.68	22.24	21.68	28.36	27.24	27.24	25.58	26.13	
ab	26.20	31.96	26.20	26.20	28.30	31.44	28.82	26.20	31.44	30.39	25.15	29.38	31.44	30.92	35.63	37.20	36.15	
an	18.90	24.46	23.91	19.18	22.50	15.85	13.90	19.18	16.40	13.90	15.29	15.01	8.34	12.51	6.39	2.78	1.39	
di	6.70	2.65	2.38	4.13		5.62	5.40	4.10	3.89	2.81	.68	1.94	2.59	1.30	3.34		.46	
hy	5.50	5.32	3.00	5.03	10.22	3.60	4.80	5.40	3.30	3.30	8.07	3.70		1.40	1.16	.93	.53	
mt	.93	5.34	5.10	6.04	2.55	4.18	.46	.93	4.41	1.16	.93	3.71	.93		.93	.46	.70	
il	2.89	1.67	1.67	2.13	1.82	2.13	.91	1.37	1.98	1.37	1.37	1.37	2.28	1.06	.91		.15	
hm	6.24		1.12			.80	5.60	5.20	.32	4.32		.16	1.60	4.13				
ap	1.01	.67	.67	.67	1.34	1.34	1.44	.33	.67	.67	1.01	.67	.34	.67	.34			
tl														.59				
Symbol	II.4.″3.3(4)	″II.4.″.3.″4	I(II).4.3.(3)4	II.4″.3.3″	″II.4.3.4	″II.4(5).2(3).3(4)	II.4(5).2″.3	″II.4″.″3.3	(I)II.4.″2(3).3(4)	(I)II.4.2.″3(4)	(I)II.4.(2)3.3	I(II).4.2(3).3″	I″.4.2.3	I″.4.2.3	I″.4.″2.3″	I.4.1.3(4)	I.(3)4.1.3″	
	Harzose	Tonalose	Yellowstonose	Harzose	Tonalose	Adamellose	Adamellose	Harzose	Adamellose	Adamellose	Harzose	Toscanose	Toscanose	Toscanose	Toscanose	Liparose	Liparose	
MODES																		
Quartz	0.5									2								
Orthoclase										3			7					
Plagioclase	1	19	26	22	17	33	9	25	23	9		29	27	16	20±	.5	0.5	
(An content)	(60)	(57)	(58)	(47)	(48)	(48)	(45)	(42)	(39)	(31)		(37)	(26)	(52)		(15)	(15)	
Biotite				1	.5	1.5	10	5	10	2		6	3	4		2		
Hornblende	14	8	2	1.5	tr	1	tr	1	2	2		2						
Augite	2	1	2	2	6	4	10	3	2	1		.5	1	1				
Hypersthene	1	2	3	2	1	4												
Magnetite	2	2	4	1	2	3	1	3	2	2		2	2	2				
Groundmass	79	68	63	70	73	54	70	60	61	78		61	58	71		99	99	

[1] Corundum, 2.04. [2] Wollastonite, 1.39.

NOTES TO TABLE 23

1. Quartz-bearing, hornblende-pyroxene-quartz latite (SC 2650). From southeastern part of San Cristobal quadrangle. Mesa between Red Mountain and Middle Creek, 4 miles north of Piedra Peak. Vinaceous drab, has scattered small vesicles. Contains phenocrysts of white plagioclase, hornblende, and very few of quartz. The plagioclase has inclusions of the groundmass in an outer zone. The groundmass contains small andesine tablets, magnetite, and augite, in a submicroscopic matrix. Cristobalite is present in the porous parts. Analyzed by J. G. Fairchild, 1924.

2. Hornblende-pyroxene-quartz latite (LaG 1540). From Creede quadrangle, shoulder west of Mt. Hope at altitude of 12,500 ft. Slate gray, dense, looks vitreous. Phenocrysts variable in size, most are less than 2 mm long. The plagioclase crystals have few inclusions of the groundmass and have feeble recurrent zoning. The hornblende is brown and much resorbed. The groundmass is made up of tiny tablets of oligoclase imbedded in an abundant matrix that is submicroscopic. Analyzed by J. G. Fairchild, 1924.

3. Hornblende-pyroxene-quartz latite (LaG 1534). From southwestern part of Creede quadrangle, ridge east of Table Mountain, at altitude of 12,350 ft. Neutral gray, rather dense. Phenocrysts are for the most part less than 2 mm long. The plagioclase contains some inclusions of the groundmass and has recurrent zoning. The hornblende is brown and somewhat resorbed. The groundmass has some tablets of oligoclase as long as 0.1 mm and some dust of magnetite and pyroxene in a finely crystalline matrix that has an index of refraction much below that of balsam and is made up of alkalic feldspar and a silica mineral (probably cristobalite). Analyzed by J. G. Fairchild, 1923.

4. Biotite-pyroxene-quartz latite (SC 1663). From northern part of San Cristobal quadrangle, west slope of Mineral Creek, near head, at altitude of 11,400 ft. Deep neutral gray, dense. Has abundant, inconspicuous tablets of plagioclase as long as 10 mm. Seriate porphyritic; the plagioclase grades from the large crystals to tablets 0.1 mm long in the groundmass. Some of the plagioclase has zones filled with inclusions of the groundmass. All have recurrent zoning. The hornblende is largely resorbed, the hypersthene is altered to bastite. The groundmass has plagioclase tablets, grains of iron ore, and pyroxene in a rather coarse sponge of quartz and alkalic feldspar. There is some secondary chlorite and carbonate. Analyzed by J. G. Fairchild, 1923.

5. Typical granodiorite porphyry (SC 2819). From east of the summit of Red Mountain, at altitude of 12,650 ft, in the southeastern part of the San Cristobal quadrangle. Slate gray, dense, fine-grained. Seriate, few of the crystals are longer than 1 mm and few are shorter than 0.1 mm. The hornblende is much resorbed. The augite is in irregular grains; the plagioclase has rather strong progressive zoning. The biotite is late and grows with and about the pyroxene. The finer material has much interstitial quartz and orthoclase. Analyzed by W. T. Schaller, 1914.

6. Biotite-pyroxene-quartz latite (LaG 1027). From central part of Creede quadrangle, north of Rio Grande, western end of mesa between forks of Bellows Creek, just north of point 11,511. Dark vinaceous drab. Some small irregular white feldspar as long as 6 mm. The phenocrysts grade to very small crystals. Most of the plagioclase has little zoning but some of the large crystals have remnants of calcic cores. The groundmass has abundant thin tablets of oligoclase, most of which are less than 0.1 mm long, and an abundant felted matrix that is made up of alkalic feldspar and a silica mineral. Analyzed by R. E. Bailey, 1923; alkalies by F. A. Gonyer, 1942.

7. Quartz latite (SC 1315). From north-central part of San Cristobal quadrangle, north of Cascade Gulch, northeast slope of mountain having altitudes of 13,100 ±ft. Quaker drab. Some irregular small pores. Has white plagioclase as long as 5 mm. The plagioclase is little zoned, the biotite and chestnut-brown hornblende are much resorbed, the small augite crystals and the borders of the larger grained augites are red-brown from oxidation of the iron in them. The groundmass has a dust of iron oxide, and pyroxene grains and tablets of oligoclase as long as 0.1 mm in an abundant finely crystalline matrix that is probably alkalic feldspar and cristobalite. There is much coarse cristobalite in the porous parts of the rock. Analyzed by Chase Palmer, 1913.

8. Quartz latite (Con 2). From Los Pinos gravel, northern part of Conejos quadrangle, north slope of Green Ridge, above Goat Ranch. Vinaceous drab. Irregular pores. Abundant white plagioclase as long as 20 mm and some biotite in a felsitic groundmass. The plagioclase is strongly zoned, the augite is in small crystals which are collected in bunches. The groundmass contains small plagioclase tablets, augite, and brown hornblende in a submicroscopic matrix. The biotite is dull and somewhat resorbed. Cristobalite is present in the porous parts. Analyzed by F. A. Gonyer, 1931.

9. Vitreous quartz latite (Con 606) of Los Pinos gravel. From northern part of Conejos quadrangle, northeast slope of Green Ridge, ridge east of house, at altitude of 8,500 ft. Neutral gray, rather porous. Much like rock just described except that groundmass is gray and glassy. The groundmass is chiefly glass with tiny crystals of oligoclase. Contains few gas cavities which resemble shrinkage cracks and cut across the plagioclase phenocrysts. Analyzed by J. G. Fairchild, 1925.

10. Biotite-hornblende-augite-quartz latite (SC 1683). From northeastern part of San Cristobal quadrangle, head of Mineral Creek. Dense, netural gray. Contains some phenocrysts of sanidine as long as 30 mm and smaller crystals of quartz, plagioclase, biotite, and hornblende. The plagioclase is not strongly zoned, the biotite and brown hornblende are much resorbed. The groundmass has stout crystals of plagioclase as long as 0.5 mm and grains of magnetite and prisms of hornblende in a submicroscopic matrix. There are a few large sphene crystals. The pyroxene prisms tend to collect in nests. Analyzed by George Steiger, 1913.

11. Quartz-biotite latite, South Mountain type. From a dike in Cropsy Gulch, Summitville quadrangle. "Contains phenocrysts of glassy sanidine, plagioclase, quartz, and biotite in a very finely crystalline groundmass." (Patton, 1917, p. 31-32) Analyzed by G. Rohwer and E. Y. Titus.

12. Biotite-hornblende-quartz latite (LaG 1021), Bellows Creek type. From Creede quadrangle, north of Rio Grande, between Farmers and Bellows Creeks, draw on west slope of hill 9740 at altitude of 9,100 ft. Dense, light neutral gray. Has abundant phenocrysts, as long as 10 mm of plagioclase, biotite and hornblende. The plagioclase phenocrysts have a wide range in size, they have little zoning and some inclusions of the groundmass. The groundmass has no plagioclase laths and has a good spherulitic texture. Analyzed by R. K. Bailey, 1923.

13. Quartz latite with large phenocrysts (SC 2137), Crown Mountain type. From San Cristobal quadrangle, west of Lake San Cristobal on ridge south of Grassy Mountain at altitude of 10,400 ft. Dense, neutral gray. Feldspar crystals as long as 10 mm. The plagioclase is strongly zoned. There is some secondary carbonate. The groundmass is distinctly crystalline and granophyric to microgranular. Analyzed by J. G. Fairchild, 1923.

14. Biotite-augite-tridymite latite (LaG 1598), McLelland Mountain type. From central part of Creede quadrangle, from southeast slope of McLelland Mountain at altitude of 10,650 ft. Quaker drab. Has abundant flat porous layers or lenses and approaches the tridymite latites of the Potosi. The groundmass is rhyolitic. The porous parts of the rock have abundant tridymite. Analyzed by J. G. Fairchild, 1925.

15. Biotite-hornblende-quartz latite vitrophyre. Cropsy Peak type, Summitville quadrangle, Lookout Mountain near Summitville. Quoted from Patton (1917, p. 31). Analysts, George Rohwer and E. Y. Titus.

16. Glass. From No Agua volcano, New Mexico (N. M. 87). Rather dense, pallid purplish-gray glass, streaked with porous lenses. There are a few tiny feldspar microlites about 0.3 mm across in the glass and a little secondary calcite in the pores. The index of refraction of the glass is 1.497 ±0.001. Analyzed by George Steiger, 1923.

17. Obsidian. From No Agua volcano. *n* of glass 1.486 ±0.001. Analyzed by E. S. Shepherd.

Avg. Average composition of the Fisher quartz latites, taking into consideration the estimated volumes of the various rock types.

1.505, indicating that the tuff has nearly the same chemical composition as that of the flow rocks.

Two analyses of typical quartz latites from Green Mountain are given in table 23, columns 8 and 9.

The rhyolite volcano of No Agua, N. Mex., is said by Butler[2] to be of Los Pinos age. It is made up chiefly of obsidian and felsitic lavas that contain a few phenocrysts. Analyses 16 and 17 of table 23 represent the glass from these flows.

The quartz latites of Green Mountain and Chiquita Peak resemble the rocks of the Fisher quartz latite, and the relation of the rocks to the underlying Piedra rhyolite and the overlying basalt of the Hinsdale formation are sufficiently similar to indicate that these rocks are of about the same age as the Fisher.

[2] Page 77 of footnote reference on p. 186.

OUTCROPS AND TOPOGRAPHY

In outcrop the Los Pinos gravel are light colored. They are poorly cemented and friable and are highly porous. Where they are overlain by hard flows of basalt the basalt forms a mesa bordered by a dark cliff and the sands form a smooth, lighter-colored, gentler slope with long ridges separated by steep gulches, and covered with debris from the sands and overlying basalt. Where the sands are not protected by harder rocks they show a typical badland topography: barren, sandy, glaring in the bright sun, and uninviting. Only the major streams have water except during freshets, and even the water of the major streams largely sinks in the thirsty, porous sand. The slopes tend to be uniform, the hills without much character, and the gulches closely spaced and all much alike.

Chiquita Peak, in the northern part of the Conejos quadrangle, rises as an impressive mountain with steep slopes because of the more resistant character of its lava flows and tuff-breccia beds.

SOURCE OF THE MATERIAL

Clearly, the material for the Los Pinos gravel was derived from a number of sources: A part was from the wearing down of older rocks, particularly pre-Cambrian and Conejos rocks, and a part from extrusive material, more or less sorted by water.

The Los Pinos gravel is not found or is very thin northwest of the southern part of the Summitville quadrangle and of the Conejos quadrangle, but it thickens to the south and east. It seems clear that at the time these deposits were being laid down this northwestern area, corresponding approximately to the higher part of the present San Juan Mountains, was a highland of low relief. This highland was underlain nearly everywhere by Treasure Mountain or younger volcanic rocks, and yet fragments derived from such rocks are scarce in the Los Pinos, although many of the rocks of these formations are relatively hard. In Colorado and adjoining parts of New Mexico, the lower part of the formation is made up almost entirely of fragments of porphyritic quartz latite of the type near Chiquita Peak. These are partly pyroclastic and are from vents nearby, but may be partly from the Chiquita Peak-Green Mountain volcano. These rocks are very similar to the latite-andesite of the Fisher quartz latite, but no outcrops of this latter formation are seen for many miles. It seems probable that much of this material was derived from small local vents that are now covered with younger rocks.

In this northern area the upper part of the Los Pinos gravel is made up in large part of fragments resembling the rocks of the Conejos quartz latite and, as the Conejos nowhere directly underlies the Summit peneplain to the north and west, but does to the south and west, it seems that the drainage at this time must have been from the latter direction.

Seventeen analyses of rocks from the Fisher quartz latite and quartz latites of the Los Pinos gravel are shown in table 23.

HINSDALE FORMATION

NAME AND DEFINITION

The name Hinsdale volcanic series was proposed by Cross (quoted by Irving and Bancroft, 1911, p. 22) for a group of lavas, that are later in age than the Potosi volcanic series and range in composition from rhyolite to basalt. Later the name was changed to Hinsdale formation (Cross and Larsen, 1935, p. 94). The series was recognized as one of the major divisions of the volcanic formations of the San Juan area but it was then too early to define sharply its limits. Further study to the south and east of the Lake City area has shown that the group of volcanic rocks included by Cross in the Hinsdale volcanic series in the Lake City area directly overlies the San Juan peneplain (Atwood and Mather, 1932, p. 21). These rocks are the most widespread of any of the volcanic series in the area covered by this report and are exposed from the northwestern part of the Uncompahgre quadrangle southeastward nearly to Santa Fe, N. Mex., a distance of about 160 miles. In most parts of Colorado the lavas of the Hinsdale directly overlie older volcanic rocks but in the extreme southern part of the State they overlie the Los Pinos gravel, and some basalts of Hinsdale type are interlayered with the gravels, and some gravels separate basalt flows. These gravels become very thick to the south in New Mexico. The main basalt flows of the Hinsdale formed an extensive basalt plain. Several volcanic domes, somewhat older then the basalt, and some hills of older rocks, rise above the basalt plateau. The basalt plain has been faulted on the east and tilted up on the west at angles of a few degrees to form the present San Juan Mountains. Following this tilting, erosion again became active and has been the dominant process since. A group of widespread volcanic rocks with remarkably persistent features was laid down after the development of the San Juan peneplain and before it was tilted and deformed. Cross proposed that the name Hinsdale volcanic series be defined to include this series of rocks.

In most places nothing overlies the latite-basalt of the Hinsdale formation but in the San Luis Valley and to the south in New Mexico gravels overlie the basalt. The great thickness of sands and gravel of the San Luis Valley is believed to have been deposited later than the titlting that marked the end of the Hinsdale period, and they are therefore believed to be post-Hinsdale in age. So also are most of the gravels on the east side of the Rio Grande in New Mexico. They are post-Hinsdale alluvial fans deposited on the rather level floor of basalt of the Hinsdale by the rejuvenated streams of the Sangre de Cristo Range as they emerged from the canyons in the mountains.

However, some of these gravels may have been deposited before the tilting, for the underlying basalts are interlayered with gravels and it is not improbable that some gravels were deposited on the upper basalts during Hinsdale time. Indeed, the surface of some of the gravel near the Rio Grande west of Taos seems to be flat and to dip toward the east approximately with the basalts, as if tilted with them. If, as is believed, the Hinsdale formation is faulted on the east side of the valley against the older rocks of the Sangre de Cristo Range, gravels of the Hinsdale over the upper basalt would probably have a regular upper surface that dipped toward the east to the fault, whereas the post-Hinsdale gravels would be in the form of alluvial fans deposited on the tilted surface of the Hinsdale and their upper surface and the beds themselves would dip away from the mountains.

SUBDIVISIONS

The Hinsdale formation has been subdivided into two members on the basis of the origin and the petrographic character of the material. This corresponds approximately to a subdivision on the basis of age but there are interlayering of gravels, rhyolite, and andesites, and some recurrence of petrographic types. In general the succession from bottom to top is local rhyolite and quartz-latite flows and tuffs, followed by widespread flows of the basalt that form the great plateaus.

The names and general character are as follows (estimated areas and volumes include the rocks in Colorado and as far south as Espanola in New Mexico):

Subdivisions of the Hinsdale formation

Unit	*Thickness (feet)*	*Maximum estimated original area (square miles)*	*Approximate minimum volume (cubic miles)*	*Character*
Latite basalt..	0-1,000	7,000±	300±	Widespread flows of latite, and basalt. Formed a great plateau.
Rhyolite.......	0-2,000	200	10	Local flows and volcanic cones of rhyolite; in part interlayered with basalt.

RHYOLITE OF THE HINSDALE FORMATION

GENERAL CHARACTER

Local bodies of rhyolite lie on the San Juan peneplain immediately beneath the basalt of the Hinsdale formation, or are interlayered with the basalt in several areas. The largest body is in the northern part of the San Cristobal quadrangle and adjoining parts of the Uncompahgre quadrangle, where from 100 to 500 feet of rhyolite, chiefly welded tuff, underlies the latite-basalt of the Hinsdale rather uniformly. Farther north this rhyolite was not found, and to the south it is present only locally. In the southeastern part of the Creede quadrangle and adjoining parts of the Summitville quadrangle local bodies of rhyolite, mostly as small intrusive bodies or volcanic cones, but in part in tuff layers, are present below and between flows of the olivine latite. Farther south the Valles Mountains consist of large bodies of rhyolite, later than the basalts of these mountains, but probably older than the mesa flows of latite-basalt of the Hinsdale.

The welded rhyolite tuff of the area in the San Cristobal and Uncompahgre quadrangles is a uniform rock with conspicuous phenocrysts of glassy, iridescent sanidine and quartz. It differs from the rhyolites of the Potosi volcanic series but is like the rhyolites of the Valles Mountains, west of Santa Fe, N. Mex. Somewhat similar rock with smaller phenocrysts and a dense groundmass forms Old Baldy Mountain in the northern part of the Summitville quadrangle. A less widespread rock carries few phenocrysts and is in part an obsidian, in part felsitic and spherulitic. It forms most of the small bodies in the Creede and Summitville quadrangles. A small local body of a rhyolite, with abundant small phenocrysts of plagioclase, lies in the San Cristobal quadrangle. This rock would be classified as a leucorhyolite. The other rhyolites of the Hinsdale are leucokalirhyolites.

THE RHYOLITES OF THE SAN CRISTOBAL AND UNCOMPAHGRE QUADRANGLES

There is little variation in the leucokalirhyolite in the San Cristobal and Uncompahgre quadrangles. The rock is uniformly light gray or pink, has a dull luster, and has only a few large gas cavities but many small pores. It is mostly a welded tuff. It carries about 25 percent of 2-mm-sized phenocrysts of bluish, iridescent sanidine, less of embayed, smoky quartz, and very little biotite. The glistening of the sanidines can be seen from horseback in the soil derived from this rock. Plagioclase and biotite are in small amount and green hornblende, augite, sphene, zircon, apatite, and magnetite are minor accessories. Many of the sanidine crystals have minute lamellar intergrowths of albite, and these are probably the cause of the iridescence. The groundmass is very finely crystalline and carries streaks and lenses that are more porous, and coarsely crystalline; rods and fibers of orthoclase project from the walls and much tridymite, or less commonly quartz, project into and line the gas cavities. Tridymite makes up a considerable proportion of most of the rocks and it is probably in greater amount than quartz. These rocks have a limited distribution and they probably came from a single vent or group of vents whose exact location is not known. Rocks that are almost identical form the regular flows and tuff beds of the Valles Mountains of New Mexico and similar rocks form many of the central Valles Mountains. An analysis of this rock is given in table 24, column 4.

In the hand specimen or in the field the rocks of this unit can nearly always be readily distinguished from any of the other rhyolites of the area by their light color, dull chalky luster, lack of large gas cavities but presence of minute gas pores, abundance and size of phenocrysts, bluish iridescence of the orthoclase, almost entire lack of white plagioclase phenocrysts, smoky, embayed quartz, and small proportion of dark minerals.

Very different is the plagioclase rhyolite that caps the mountain north of Hermit Lake in the north-central part of the San Cristobal quadrangle. It is pale gray, has a dull luster, and carries a few 2-mm-sized plagioclase and biotite crystals. The feldspar phenocrysts are andesine or oligoclase-andesine. The groundmass is made up in part of tablets of olioclase in an abundant spongelike matrix that is probably made up mostly of albite, orthoclase, and quartz. Some of the specimens have abundant rounded crystals of cristobalite in the gas cavities. The rock is higher in soda and lime than the leucokalirhyolite of the Hinsdale formation. An analysis of this rock is given in table 24, column 1.

This rock forms a low dome and attains a thickness of nearly 500 feet at the center, but thins out in all directions. It probably forms a group of flows around a low volcanic cone. It seems to overlie the normal rhyolite of the Hinsdale formation and on the northeast flank of the mountains there are huge blocks of Hinsdale basalt indicating that basalt originally overlaid both kinds of rhyolite.

THE LOCAL BODIES OF RHYOLITE IN THE CREEDE AND SUMMITVILLE QUADRANGLES

The typical rhyolite of the Hinsdale formation that is so widely distributed beneath the basalt of the Hinsdale in the San Cristobal and Uncompahgre quadrangles was not observed in the quadrangle to the east and south. However, in the southeastern part of the Creede quadrangle and adjoining parts of the Summiteville quadrangle there are several small isolated bodies of rhyolite of the Hinsdale, each of which represents a small volcanic cone or the neck of such a cone. The rocks are mostly flows that piled up around the vents but some are intrusive and some are tuff-breccias. A layer of white rhyolite tuff was formed between flows of the basalt of the Hinsdale under Ribbon Mesa in the southeastern part of the Creede quadrangle. It is not separated from the basalt on the map.

The rhyolite west of Race Creek forms a hill about 1 mile long and ½ mile wide, with a maximum thickness of about 700 feet. It is clearly a small cone that seems to have partly filled a canyon in the basalt. The core and earliest erupted material are an angular chaotic breccia made up of fragments as much as several feet across, of a nearly white glassy rhyolite with a few small plagioclase crystals and rarely small spherulites. It has abundant much-elongated gas pores which give it a silky luster and a fibrous appearance. Over a steep slope of this breccia there is piled an irregular flow of dark red-brown rhyolite, with no phenocrysts, made up mostly of spherulites with some interstitial glass. The spherulites consist of fine fibers, and from their similarity to other spherulites that can be determined as orthoclase and cristobalite, they are believed also to be orthoclase and cristobalite. The spherulites have the pigment of hematite arranged in concentric rings simulating Liesegang rings, and they were no doubt formed during the crystallization of the spherulites. Overlying this flow, and possibly an upper part of it, is a pale-pink rhyolite having a few biotite crystals, an aphanitic texture, and abundant small rough gas cavities associated with spherulites with lithophysal cavities. The rock is holocrystalline and spherulitic, and the spherulites are made up of rather stout fibers of orthoclase with interstitial cristobalite or tridymite. There are abundant porous streaks associated with coarse crystals, and much tridymite. These rocks are much like the leucokalirhyolites without phenocrysts of the Valles Mountains and Cerro No Agua.

The intrusions near the head of Race Creek in the Summitville quadrangle are both made up of a rock that is much like that described in the preceding paragraph. It is fluidal and is a micrographic intergrowth of quartz and orthoclase. Tridymite is abundant in the gas cavities but makes up less of the rock than does quartz.

The rhyolite cone of Old Baldy Mountain is about a mile across and more than 500 feet high. It is made up in large part of a massive flow of pale pink or red-brown fluidal rhyolite that rather closely resembles the rhyolite of the Hinsdale formation of the San Cristobal quadrangle, except that it has somewhat fewer and smaller phenocrysts, and the orthoclase does not show the blue iridescence. In part the rock shows alternate thin bands of porous and dense rock; other parts carry abundant small lithophysal cavities which are in places lined with drusy quartz crystals. The rocks are made up about one-fifth of phenocrysts, rarely more than 1 mm across, of which quartz and orthoclase are the most abundant, and plagioclase and biotite are in small amount. The groundmass is a rather coarse micrographic intergrowth of quartz and orthoclase. Tridymite is abundant in some of the rocks. Rare inclusions of a granite are present. The eastern shoulder of Old Baldy is made up mostly of angular fragments as much as a foot across, in an abundant matrix of fine material. The fragments are chiefly of a highly porous rhyolite much like that of the associated flow, but a few are of a nearly colorless glass that has few phenocrysts and resembles the glass of the rhyolite of the Hinsdale of the Creede quadrangle to the north. Rare andesitic fragments are present. The flow overlies the breccia irregularly where the two were seen in contact.

The intrusive rock of Elephant Mountain forms a prominent topographic feature with white or iron-stained cliffs. The rock has a distinct fluidal banding that is in part nearly horizontal and in part dips as much as 45° (on the east slope). In places the rock is autobrecciated. Most of the rock closely resembles the flow of Old Baldy. Near the south border the rock carries abundant large cavernous spherulites (lithophysal) or smaller spherulites collected in fluidal layers. The rocks have about 20 percent of phenocrysts, as much as 1 mm across, chief of which are quartz and orthoclase, with somewhat less albite and a little biotite. The groundmass is mostly spherulitic but is in part micrographic and is made up of orthoclase with some quartz and tridymite. The tridymite is partly in nests in the porous parts, partly streaked through the groundmass, and partly in the spherulites. It probably exceeds the quartz in amount.

TABLE 24.—*Analyses, norms, and modes of rhyolites of the Hinsdale formation*

ANALYSES	1	2	A
SiO_2	72.02	75.62	75.10
Al_2O_3	15.28	12.96	12.80
Fe_2O_3	.97	1.00	1.03
FeO	.74	.31	.34
MgO	.26	.03	.10
CaO	2.00	.39	.56
Na_2O	3.79	3.80	3.74
K_2O	4.35	5.20	4.98
H_2O+	.40	.48	.65
H_2O-	.45	.29	.30
TiO_2	.22	.21	.21
P_2O_5	.02	.00	.01
MnO	.11	.04	.05
CO_2	.00	.00	-------
ZrO_2	-------	.02	.02
BaO	-------	.01	.01
SrO	-------	.00	.01
Total	100.61	100.37	100.35

NORMS	1	2	A
Q	28.32	32.94	33.06
or	26.13	30.58	29.47
ab	31.96	31.96	31.44
an	10.01	1.95	2.78
C	.20	.41	.20
hy	.86	.10	.20
mt	1.39	.23	.70
il	.46	.46	.46
hm	-------	.80	.48
Symbol	I.4.2.3	I'.4.1.3	I'.4.4'.3

MODES	1	2
Quartz	-------	3
Sanidine	-------	13
Plagioclase	7	-------
(An. content)	(30)	-------
Hornblende	-------	tr
Biotite	2	2
Augite	-------	tr
Magnetite	-------	1
Groundmass	91	81

1. Rhyolite (SC251). From San Cristobal quadrangle, mountain north of Hermit Lake. Neutral gray, and has a few small pores. The phenocrysts are chiefly less than 0.5 mm across, the groundmass is made up of thin, fluidal tablets of oligoclase and some opaque grains imbedded in an abundant finely crystalline, spongelike intergrowth of quartz and alkalic feldspar. The oligoclase tablets of the groundmass are for the most part less than 0.1 mm long. Analyzed by George Steiger, 1922.
2. Welded rhyolite tuff (SC 906). From northwestern part of the mountains, San Cristobal quadrangle, head of the valley of Big Spring Gulch. Pale brownish drab, rather porous welded tuff, with crystals of embayed, smoky quartz, and of sanidine (moonstone). The phenocrysts are less than 1 mm across, the sanidine has some irregularly distributed thin lenses of albite. The groundmass shows glass shards and is unevenly crystalline. It is made up of alkalic feldspar and much tridymite. The latter mineral is unevenly distributed and tends to fill cavities or mold about the original shards. Analyzed by R. C. Wells, 1913.

A. Average rock of the rhyolite of the Hinsdale formation.

The tuff that lies between the basalt flows under Ribbon Mesa is probably nowhere more than 100 feet thick. It is a white tuff and carries rather abundant crystals of biotite.

CHEMICAL COMPOSITION

Analyses of two rocks from the rhyolite of the Hinsdale formation are given in table 24.

QUARTZ LATITE OF THE SAN ANTONIO PEAK DOMES

In New Mexico, southeast of the Conejos quadrangle, a number of hills rise above the plateau of basalt of the Hinsdale formation. Some of these hills are erosional remnants of pre-Cambrian rocks or of volcanic rocks much like the old lavas of the San Luis Hills. One is a volcano of rhyolite. Others are domes or cones of quartz latite. Shallow canyons have been eroded in these domes and the extent of the erosion compared with that which the basalt of the Hinsdale formation has undergone seems to indicate that the domes are older than the basalt. Yet, the way in which the domes rise above the basalt plateau gives the impression that the domes were built up on the plateau of basalt. In no place was any indication found of a depression typical of the front of a basalt flow where it flows against a slope of older rock. In no place was the rock of the domes found resting on or lying beneath the basalt of the Hinsdale. Cross and Larsen (1935, p. 122) said these domes were younger than the basalt of the Hinsdale. Their age must be near that of the basalt of the Hinsdale but whether younger or older is uncertain.

The name San Antonio Peak volcanic domes will be used for this group of domes which are considered to be related to the Hinsdale formation.

Each dome is made up of a single rock type, possibly because only a few of the upper flows are exposed. The larger domes, Antone Peak, Ute Peak, Cerro Olla, Cerro Montosa, Cerro Tusas, and the hills northwest of Questa, are made up of a dark cristobalite latite that has few phenocrysts. Some of these contain olivine.

LATITE-BASALT OF THE HINSDALE FORMATION

DISTRIBUTION

The latite-basalt of the Hinsdale formation is the most widely distributed volcanic formation in the area studied and it also underlies the largest area. It is found in every quadrangle except the extreme western group, west of the Uncompahgre and San Cristobal quadrangles, and it is present from the northwestern part of the Uncompahgre quadrangle eastward to the San Luis Valley and southward at least as far as the mountains a few miles north of Espanola, N. Mex. Closely related flows extend farther south in New Mexico. Its northern and southwestern limits are erosional, and on the east the flows go under the gravels that fill the San Luis Valley. It is present in a strip about 150 miles long that runs nearly north and south and has a width of 50 to 75 miles in the northern part but is considerably narrower in the southern part. In the northern and western parts of this strip the basalt of the Hinsdale is present only on scattered mesas but it probably originally covered much of the area and has been largely removed by erosion. In the southeastern part, in New Mexico, erosion has not removed so much of the formation, and it underlies the extensive gently dipping plateau that is just west of the Rio Grande in northern New Mexico.

The largest body of this rock is in northern New Mexico and the adjoining parts of Colorado. In general it forms a triangle with one side near the Colorado-New Mexico State line from Bighorn to the Rio Grande canyon and the apex of the triangle at the south end of Black Mesa near the junction of the Chama River and the Rio Grande. The east-west dimension a few miles south of the State line is about 30 miles and the north-south dimension is more than 60 miles.

To the northeast the latite-basalt of the Hinsdale formation is believed to cap San Pedro Mesa near San Luis, Colo. It forms the great dipping mesa of Los Mogotes, just northwest of Conejos. It probably underlies much of the San Luis Valley, for on the west border of the valley remnants of the latite-basalt dipping under and more or less covered by the gravel fill of the valley are found at intervals as far north as La Garita, Colo., and many wells in the valley penetrated this rock. To the west it rises gently and caps scattered mesas, some of them several miles across, as far as Alpine Plateau in the Uncompahgre quadrangle and as far as the mesa near Lost Lakes in the San Cristobal quadrangle. Rio Grande Pyramid is probably an isolated peak of related rock.

RELATION TO OLDER ROCKS AND THICKNESS

In the southern part of the area described in this report, which includes all of the New Mexico area, all of the Conejos quadrangle, the southern part of the San Luis Valley, and the southern part of the Summitville quadrangle, the latite-basalt of the Hinsdale formation nearly everywhere overlies a regular surface of Los Pinos gravel and sands, and in part is interlayered with similar sands. The sands and gravels had filled most of the irregularities in the topography before the spreading out of the lavas, but some mountains and hills of older rocks, partly pre-Cambrian granites or quartzites and partly pre-Hinsdale volcanic rocks, rose above the gravel plain.

The most prominent of the hills of pre-Cambrian rocks that rise above the basalt plain are the granitic hills near Tres Piedras and the mountains of pre-Cambrian rocks southwest of the town of Taos. The San Luis Hills are older volcanic hills, as are also Cerro Cristobal, Cerro Chiflo, Cerro Tres Orejas, Cerro Negro (near Arroyo Hondo), and some smaller bodies. Nearly everywhere these peaks rise abruptly above the basalt plain and make steep contacts with the basalt. They were clearly steep mountains at the time of the basaltic eruptions.

Green Ridge and Chiquita Peak in the northern part of the Conejos quadrangle are probably the remnants of a volcanic cone about 2,000 feet high that had been only moderately modified by erosion at the time the latite-basalts of the Hinsdale formation were erupted. There the Hinsdale in part flowed around the cone but in part must have been erupted from around the highest part of Green Ridge and spread over the steep slopes of the mountain.

Cerro No Agua in northern New Mexico is a rhyolite volcano that was only slightly modified by erosion at the time of the basalt eruptions of the Hinsdale and it rises several hundred feet above the basalt plateau. A number of smaller rhyolitic volcanoes in the Summitville quadrangle and adjoining parts of the Creede quadrangle were more or less buried by the latite-basalt of the Hinsdale.

In much of the San Cristobal quadrangle and in the southern part of the Uncompahgre quadrangle the latite-basalt of the Hinsdale formation overlies a regular surface of rhyolite of the Hinsdale. In the hill north of Hermit Lake in the San Cristobal quadrangle a low cone of these rhyolites was probably never covered by the latite-basalt.

In the Creede, Summitville, and San Cristobal quadrangles and adjoining areas, many mountains of Fisher quartz latite seem to have risen above the San Juan peneplain and were never covered by Hinsdale rocks.

Elsewhere in this northern area the latite-basalt of the Hinsdale rests on the rather regular surface of the San Juan peneplain which is underlain in most places by rocks of the Potosi volcanic series.

In most parts of Colorado the latite-basalt of the Hinsdale is not overlain by younger rocks and it directly underlies great mesas. On the eastern flank of the mountains, however, from the San Luis Valley to the southern limit of the basalt of the Hinsdale, the basalt dips under the gravels that fill the San Luis Valley or that flank the Sangre de Cristo Range.

In the southern part of the Conejos quadrangle, on Mogote Peak and the two small cones to the north, the latite-basalt of the Hinsdale is overlain by flows and breccia from local centers that are probably closely related to the Hinsdale flows and that may represent, in part, the centers from which the local flows of the Hinsdale were extruded.

In most exposures the latite-basalt of the Hinsdale formation is from 100 to 400 feet thick, but locally it is considerably thicker. In the Rio Grande canyon about 500 feet are exposed below Dunns Bridge. In the northern and western part the thickness is commonly less; in the San Cristobal quadrangle it is in most places less than 250 feet. In the Conejos quadrangle the thickness is in most sections not much more than 100 feet, but south of Mogote Peak more than 400 feet are exposed. The centers of the flat domes are no doubt considerably thicker—probably 1,000 feet or so in the mountains south of Cannibal Plateau in the southern part of the Uncompahgre quadrangle and it is probably nearly as thick in Cannibal Plateau, Alpine Plateau, and elsewhere.

RELATION TO TOPOGRAPHY

The latite-basalt of the Hinsdale formation was spread over the San Juan peneplain or on rhyolite of the Hinsdale. Before the tilting of the mountains the latite-basalt made a series of broad, low domes that probably in large part coalesced and formed a great lava plateau with a gently undulating surface. These latite-basalts probably underlay nearly all the area from the eastern part of the San Luis Valley at least as far west as the San Cristobal and Uncompahgre quadrangles, and from the Valles Mountains to the south as far north as the Gunnison River. These dimensions are a minimum, for erosion has removed the lavas to the north, south, and west and faulting has cut them off to the east.

After the tilting of the lavas, erosion became very active in the mountains. The larger streams in part followed the main synclines and other structural depressions, but most of the smaller streams followed the troughs between the low domes of andesite-basalt. These troughs were also favorable for rapid erosion, because the hard lavas were thinner there and the underlying softer rocks more easily reached. After these underlying softer rocks were reached erosion probably accelerated and the lavas gave way, chiefly by undercutting and sliding. In the Uncompahgre and San Cristobal quadrangles erosion has cut more than 2,000 feet below the lava mesas.

The present mesas, therefore, are in large part the upper slopes of the low domes of latite-basalt of the Hinsdale formation. The mesas are in large part surrounded by cliffs, and below the cliffs there are great accumulations of large blocks from the lavas and many landslides. On many of the mesas there is some soil which supports grass, but in some the surface is covered with loose blocks of lava.

Where the trenches of the streams are narrow these latite-basalts form deep canyons, such as the canyons of Rock Creek and Antone Creek in northern New Mexico, and the great canyon of the Rio Grande. In the San Luis Valley of Colorado the Rio Grande flows in a shallow trough cut in the gravels that are above the latite-basalt of the Hinsdale and are probably in part much above it. To the south the top of the basalts rise, these gravels become thinner, and about 12 miles north of the State line the river reaches the basalt of the Hinsdale. Farther south it cuts deeper and deeper into and through the basalts, and at the southern end of Black Mesa and where the Taos Road crosses the River, the river is about 1,000 feet below the mesa at the top of the basalt.

SUCCESSION OF FLOWS

The latite-basalt of the Hinsdale formation commonly consists of a number of superimposed thin flows. Locally a mesa-forming horizon may be a single, comparatively thick flow; elsewhere it is made up of a succession of flows and flow units, some of them very thin. The average thickness of flows is about 25 feet, but some, especially in the northern part of the mountains, are much thicker. The flows of most cliff sections are all much alike and in the canyon walls they pinch, swell, and wedge out, probably to come in again in a short distance, so that it is difficult to tell how widely distributed the individual flows are. However, some are believed to be extensive, and certainly some types of rock are widely distributed.

In most places the formation is made up almost entirely of flow rock, with little or no tuff-breccia, but more or less scoria or breccia is commonly present between the massive flows. Locally, tuff-breccia separates the flows. Such tuff-breccia was found in the San Cristobal quadrangle in the cliffs east of Lost Trail Creek and in the Uncompahgre quadrangle northeast of the old mining camp of Spencer, where the two flows of latite of the Hinsdale are separated by tuff. Light-colored tuffs, moderately thick, separate latite flows in the south-central part of the Creede quadrangle.

In the Conejos quadrangle and in New Mexico, the flows are locally interlayered with sands and gravels. In these areas the succession changes from place to place as the lava flows tend to finger or wedge out in the gravels, or as they rise in the section, join, and merge with the upper mesa-forming horizon as if the flows filled in channels in the gravel plain. Over much of the area the group of flows that form the upper mesa is the thickest and most extensive group, but some of the groups of flows interbedded with the gravels are locally nearly as thick and form continuous cliffs and benches and small mesas for many miles along canyon walls.

No difference in the character of the rocks from any of the lower layers could be recognized, and all the Hinsdale rocks of this area are remarkably similar.

In the southern part of the Conejos quadrangle local flows are interlayered with the gravels that underlie the main mesa-forming flows. These flows are likely to wedge out between gravel beds, or the separating gravel beds may wedge out and the flow join the main horizon of lavas. Such flows are present in the cliffs just north of the village of Mecitas, and in the cliffs of lower La Jara Canyon several such flows are present in the gravels. As elsewhere, the flows in the gravels are identical with those that form the overlying mesas.

Conversely, a thin layer of a fine-textured quartz latite ash was found in the upper part of the latite of the Hinsdale formation section in the southern part of the Conejos quadrangle and adjoining parts of the New Mexico area. It was found in La Jara Canyon, in a small basin near Tres Piedras, and at several places in the Rio Grande canyon.

In the area around Los Mogotes in the southern part of the Conejos quadrangle the latite-basalt of the Hinsdale formation is made up of a number of flows, in part separated by gravels. In the cliffs south of Los Mogotes there are 10 flows with an aggregate thickness of 400 feet, but the flows become rapidly thinner in all directions, and the mesa horizon commonly consists of only a few flows, locally 1, and is rarely more than 100 feet thick. The Mogotes volcano was probably the source of these flows.

In most sections of latite-basalt of the Hinsdale the flows are all of a single kind of rock, but in the San Cristobal and Uncompahgre quadrangles two somewhat different rocks are widely distributed and are commonly found in a single section. The two types were clearly being erupted during the same time, for one forms the lower horizon in one section and the upper in another, and in Alpine Plateau and Cannibal Plateau the two are interlayered.

GENERAL CHARACTER

The latite-basalt of the Hinsdale formation is characteristically a mesa-forming rock. The tops of the mesas are commonly rather smooth and the slopes are gentle, and there is evidence that the stronger dips, which are mostly to the east, are the result of tilting later than the extrusion. Many of the mesas are several miles across, and the great dipping mesa or plateau in northern New Mexico underlain by this rock is about 60 miles long and 30 miles in greatest width. In the high mountains many of the high mesas and plateaus, such as Alpine and Cannibal Plateaus in the Uncompahgre quadrangle, are underlain by latite-basalt of the Hinsdale.

The latite-basalt of the Hinsdale is made up mostly of regular flows. Sandy tuff is rarely found, and breccia is locally present in small amount between the flows. In the field the rocks look like ordinary basalts and quartz basalts, from their olivine content, dark color, and general appearance, and also from their mode of occurrence as dark, thin, regular mesa- and cliff-forming flows. Most of the rock has scattered vesicles as much as an inch or more across, commonly flattened from flow and usually with rather smooth walls; a few are dense and nearly free from visible gas cavities, and some are highly vesicular. The tops of the flows are mostly scoriaceous. Individual flows are seldom more than 50 feet thick and the flows are regular, some extending for miles. In most sections several flows are superimposed with little or no intervening breccia.

In some sections, notably in northern New Mexico on both sides of Los Pinos Creek, rather dense, massive rock, and highly vesicular brecciated rock alternate in irregular layers or lenses only 10 feet or so thick. These are the flow units of Nichols (1936).

The rocks are predominantly dark gray, but some are nearly black, others are pinkish gray, and many of the highly vesicular rocks in the clastic material and scoria are dark red. The greater part of the rocks show few and inconspicuous phenocrysts, which are rarely more than a few millimeters across. The olivine phenocrysts, which are present in nearly all the rock, are glassy and light green or pale yellow if fresh, but they are mostly more or less altered to dull reddish iddingsite. Quartz phenocrysts are present in small numbers in some of the flows, but they are entirely absent in the great series of basaltic flows that forms the plateau west of the Rio Grande in northern New Mexico and the mesas of the adjoining parts of Colorado. These quartz phenocrysts are from 1 to 3 mm across and are always much shattered and embayed from corrosion. Augite phenocrysts are usually not easily seen in the hand specimen, and biotite and hornblende are rare and are always more or less resorbed. Plagioclase phenocrysts are commonly almost entirely absent, but they are present in small numbers in many of the rocks, and they are abundant in a few. In the porphyritic type of rock of the Uncompaghre, San Cristobal, and adjoining quadrangles these feldspar phenocrysts form a considerable part of the rock, are as much as 40 cm across, and are mostly rather porous white plagioclase with a variable but small amount of glassy orthoclase, partly intergrown with the plagioclase. These phenocrysts are especially large and abundant in the extreme northwestern exposure of the latite of the Hinsdale formation in the Alpine Plateau area, and they seem to become progressively less so to the south and east.

The cavities are nearly everywhere lined with albite crystals and except in the basaltic rocks of New Mexico commonly carry also some crystals of biotite and tridymite, and rarer hairlike crystals of hornblende. A few of the rocks carry some rounded, white crystals or spherulites of cristobalite. Rarely zircon was also found in the cavities. In a few places the original gas cavities are partly filled with carbonates and rarely with zeolites.

The quartz latite ash between the basalt flows in the Conejos quadrangle and in New Mexico is well exposed near the top of the cliffs east of La Jara canyon, a few miles north of Los Mogotes Peak. Here a bed of light buff ash, 3 feet thick, underlies the upper basaltic flow. The grains of the ash range from 0.01 to 0.5 mm across. About 30 percent of the grains are individual crystals and the rest is colorless glass. The crystal grains are chiefly quartz, orthoclase, and oligoclase, with a little augite, brown hornblende, biotite, and apatite. The glass fragments are flattened plates derived from the breaking up of lens-shaped bubbles.

PETROGRAPHY

By far the greater part of the rocks are made up chiefly of feldspar, augite, and olivine, named in the order of their abundance. In most of the flows feldspar makes up about two-thirds of the rock, but in a few only about half is feldspar, and some of the flows have less. In a few of the rocks olivine is absent and it makes up only a few percent of many of them. In the flows that underlie the great plateau from the mouth of the Chama River in New Mexico northward and beyond the Colorado-New Mexico State line the feldspar is labradorite and the rocks are olivine basalts. In most parts of Colorado the plagioclase averages andesine or oligoclase, and there is considerable orthoclase; hence these rocks are mostly olivine latites and some, especially in the northwest, are quartz-bearing latites. The accessory minerals are apatite, magnetite, and ilmenite. Some of the latitic rocks of the Uncompahgre quadrangle and elsewhere have some phenocrysts of dark-brown biotite which is always much resorbed, and in some specimens is completely resorbed. In these rocks, as well as in many of the latites that lack biotite phenocrysts, paler biotite is associated with the gas cavities, or with the more coarsely crystalline streaks in the groundmass, or associated with augite bordering resorbed hornblende phenocrysts. Hornblende phenocrysts are much less abundant than are those of biotite, and they too are more or less resorbed. Hornblende also occurs as a later generation in small amount in the gas cavities as minute hairlike crystals. Quartz in small amount forms shattered and resorbed phenocrysts in many of the latites and it is always bordered by a reaction rim of small augite grains. Hypersthene is a rare mineral in the olivine latites but it is rather abundant in some of the pyroxene latites south of Saguache River and elsewhere.

Tridymite is rather abundant in the vesicles of many of the latites and is associated with albite, pale biotite, rare hornblende, and rare zircon. In some specimens these minerals nearly fill the vesicles and drop out as a fine sand when the fresh rock is broken. Cristobalite in rounded crystals and spherulites attached to the walls of gas cavities is much less common and abundant than tridymite but is characteristic of some flows. In a few flows iridescent crystals of fayalite occur on the walls of the gas cavities.

One of the characteristics of the latite-basalt of the Hinsdale formation is that rocks within any area where the top of the formation corresponds to a topographic unit are very much alike, and sections across the flows, though there are many flows with perhaps intervening gravels, show only 1 or possibly 2 closely related rock types. However, only a few miles away the rocks of another topographic area or of another cliff section may be rather different. Similarly the flows that underlie the dipping mesa under Mogotes Peak in the southern part of the Conejos quadrangle are all made up of olivine latite somewhat similar to, but more sodic than, the basalt flows in New Mexico to the south, but the flows at the head of Elk Creek, a few miles to the west, though similar, tend to be porphyritic and carry a few quartz phenocrysts. Those a few miles to the north, in the northeastern part of the Summitville quadrangle, differ in texture, are more sodic, carry a large proportion of augite, and contain biotite and orthoclase; those of Cornwall Mountain, still farther north, are low in dark minerals, lack olivine, and contain abundant biotite and tridymite in the gas cavities.

The rock that underlies the great area in northern New Mexico and southern Colorado between the Chama River and the Rio Grande, and probably the rock that originally formed the largest body of one kind of rock in the Hinsdale formation is an olivine basalt of uniform composition, texture, and mode of occurrence, varying only in size of grain. The rock of San Pedro Mesa, near San Luis, Colo., is similar and is probably the faulted continuation of the flows under the gravels of the San Luis Valley. These basalts, at least in the exposed area, do not extend far into Colorado, because as the rocks at the head of Elk Creek and those under Mogotes Peak retain the texture and most of the characteristics of the basalt, their feldspar is andesine. Rarely, quartz phenocrysts also appear.

The basalt of the Hinsdale formation of the New Mexico plateau is made up of a number of thin flows, and although the horizontal extent of individual flows is uncertain, it must be large, though many of these flows clearly wedge out between beds of sand and gravel. Several flows are exposed in nearly all sections, and in the Rio Grande canyon, both above and below Dunns Bridge, at the mouth of Arroyo Honda, about 250 feet of basalt flows are exposed with little intervening gravel, though there is considerable interbedded gravel in the section at the bridge.

The main part of the rocks is rather massive, with some flattened vesicles, but the upper parts of the flows are commonly highly vesicular. They are dark gray, rarely dark brown. Their texture is persistent, with abundant tabular feldspar crystals of uniform size, which are in most specimens from 1 to 2 mm in longest dimension, arranged with a slight tendency toward parallelism through flow. Between these feldspar crystals there are visible a few olivine grains and some dark interstitial material.

In thin section the rocks are seen to be made up of interlocking feldspar tablets, less olivine and interstitial augite, some magnetite and a variable, but small, amount of interstitial material that is in part a dark glass. The texture is intersertal. Rosiwal measurements of a number of specimens of typical rocks from widely different localities showed that the feldspar ranges from 55 to 63 percent, augite from 16 to 23, olivine from 13 to 19, magnetite from 2 or less to 6, and interstitial glass as much as 9 percent. The plagioclase is labradorite. The augite is characteristically pale gray in thin section, and it is interstitial to the feldpsar and partly encloses the feldspar poikilitically. The olivine is mostly fairly fresh, but it commonly shows some alteration to iddingsite. The interstitial dark paste is partly glass but carries abundant skeleton crystals of feldspar, augite, and magnetite. In some rocks this paste is absent. The rock is an olivine basalt and it is mostly fresh. An analysis of a specimen of this basalt from the railroad cut 4 miles south of Servilleta, N. Mex., is given in table 25, column 4.

A basalt of somewhat different texture caps the peaks northeast of the State fish hatchery on San Francisco Creek in the Del Norte quadrangle. It is made up nearly half of phenocrysts as much as 5 mm across which are chiefly labradorite with considerable augite, somewhat less olivine, and a little magnetite and apatite. The groundmass is made up of rather coarse crystals of labradorite, augite, and olivine, with a little interstitial albite and orthoclase.

Rocks that were classified as olivine basalts were found on the mesas near Trout Mountain in the Creede quadrangle. They contain rare phenocrysts of quartz, and some of the gas cavities carry a few minute hornblende needles. In texture and general appearance they are more closely related to the latites of the surrounding areas than to the basalts of New Mexico.

The basalt of the New Mexico types does not extend far north into the Conejos quadrangle, Colo., but gives place to a rock that is similar in texture, appearance, and composition, except that the feldspar is more sodic, the interstitial glass is largely absent, and the rock is an olivine latite. The feldspar of these rocks has cores of labradorite or andesine-labradorite of good tabular form and a sharply separated, less regularly bordered, broad outer zone of albite or oligoclase. It averages andesine or, rarely, oligoclase. The estimated approximate composition, in percent, is: feldspar 65, augite 22, olivine 10, magnetite and other minerals 3. The mineral grains of the groundmass average about 0.4 mm across. Such rock makes up all the flows of the Mogote Peak area and of the La Jara Creek drainage basin, except those of the mesas on both sides of Hot Creek. They also form the flows on both sides of Gato and Rock Creeks that lap around the base of Green Mountain, and in some places seem to rise steeply on the flanks of Green Mountain and to connect with the flows that cap the mountain. An analysis of a specimen of the rock from the cliffs east of Mogote Peak is shown in table 25, column 5.

The rocks that form most of Green Ridge are similar, but they have some hypersthene in addition to the olivine and augite. The augite shows hourglass structure, and the rocks contain considerable interstitial glass. They are less basaltic than the rocks of Los Mogotes, and are latites. A few iridescent crystals of fayalite are perched on the walls of some of the gas cavities. These flows have a topographic position much higher than that of the basalt of the Hinsdale formation elsewhere, but their petrographic character and the way in which the flows dip down the flanks of the mountain on the north and east slopes to form dipping measa that connect with mesas known to be of basalt of the Hinsdale formation make it seem reasonably certain that the Green Ridge flows belong to the Hinsdale. However, the topographic form of Green Ridge and the altitude of the flows are different here from elsewhere in the Hinsdale. It seems probable that a great volcanic mountain of quartz latite was formed here during Los Pinos (Fisher) time, and that a center for the eruption of latite of the Hinsdale later occupied about the crest of the old volcano. This kind of rock will be called the Green Ridge type. Two analyses of the Green Ridge type of latite have been made and are shown in table 25, columns 6 and 7.

The type of basalt in New Mexico extends into the southwestern part of the Conejos quadrangle, but it becomes somewhat more sodic, and at the head of Elk Creek the typical rock has the texture and appearance of the New Mexico type of basalt, but its feldspar averages about andesine-labradorite, some orthoclase is present, and the rock carries rare phenocrysts of quartz, thus becoming an olivine latite and approaching the composition of the rocks to the north. To the northwest in the Summitville quadrangle quartz becomes a little more abundant and the rock tends to be porphyritic, having larger crystals of sodic labradorite, smaller laths of calcic andesine, and interstitial albite and oligoclase.

The flow capping Horsehoe Mountain south of Del Norte in the Del Norte quadrangle is a quartz-bearing olivine latite much like that of Green Ridge but containing a few quartz phenocrysts. The rock of the mesas on both sides of Hot Creek in the northern part of the Conejos quadrangle is also an olivine latite with conspicuous quartz. It is nearly black, has rough vesicles, different from the smooth-walled vesicles common in the Hinsdale formation, and carries about 2 percent each of quartz as much as 6 mm across and glassy sanidine up to a centimeter long, with some smaller dark plagioclase and red olivine. Phenocrysts make up about one-fifth of the rock, and those of labradorite feldspar are much resorbed. The groundmass is made up of very small feldsapr laths, augite grains, and olivine imbedded in glass. It differs appreciably from the flows both to the north and south, which are of the Magote type of olivine latite.

Quartz-bearing olivine latites of two kinds make up the Hinsdale of the Uncompahgre quadrangle and most of the flows of the San Cristobal, Summitville, Creede, and Del Norte quadrangles. All of these rocks differ appreciably from the basalts of New Mexico in that they carry various amounts of phenocrysts; most of them have some quartz; nearly all carry some biotite, either as phenocrysts or in the gas cavities; many have tridymite; a few have hornblende or cristobalite in the gas cavities; and in all, the feldspar of the groundmass is less conspicuously tabular and tends to be equant.

The more calcic type of this northern region is a dark-gray rock with some flattened, smooth-walled gas cavities that are lined with albite crystals and carry a few plates of biotite, rarer needles of hornblende, and in a few places fayalite and crystals of tridymite or less often of cristobalite. They are not conspicuously porphyritic but carry a few millimeter-sized crystals of olivine, augite, and feldspar, and very few of quartz, in a groundmass that is made up over half of tabular crystals of plagioclase ranging from oligoclase to andesine, some augite, a little olivine, magnetite, and apatite, and interstitial albite, oligoclase, and orthoclase. The feldspar phenocrysts have cores of clear labradorite and broad borders of oligoclase clouded with inclusions and intergrown with a little orthoclase.

The analyzed rock collected from a point 100 yards southeast of the southeast corner of Devils Lake on Cannibal Plateau will be described as the type of this rock. The phenocrysts of fresh olivine, with some augite and feldspar, and a few of resorbed quartz make up only a small part of the rock. The groundmass is made up over half of tablets of feldspar and carries rods and grains of augite, a little olivine, magnetite, and apatite, and subordinate interstitial albite and orthoclase. The feldspar phenocrysts have cores of clear labradorite and broad borders of oligoclase clouded with inclusions and intergrown with orthoclase. The feldspar tablets of the groundmass are oligoclase or andesine, and the interstitial feldspar is albite-oligoclase with a little orthoclase. The average plagioclase is about oligoclase. The quartz phenocrysts are much fractured and resorbed and are surrounded by a corona of augite grains. A chemical analysis and norm of the rock are shown in table 25, column 9. The augite of the mode exceeds the diopside of the norm, and olivine of the mode takes the place of the hypersthene of the norm. Moreover, the plagioclase of the norm is An_{31}, but the average feldspar of the mode is somewhat less calcic. This is explained by the fact that some lime and alumina have gone into the augite, and much of the potash has gone into the plagioclase.

Column 8 of table 25 is an analysis of a specimen of this type of latite from the San Cristobal quadrangle, 1 mile southeast of the turn in Lost Trail Creek.

The less calcic type is not much different chemically, though it carries somewhat more soda and potash and less lime, and nearly all the iron is in the ferric state. Mineralogically the less calcic type has more soda plagioclase, more orthoclase, less quartz and olivine, and more tridymite, and it carries biotite phenocrysts and rarely hornblende. In texture and appearance the two types are very different. The less calcic type is distinctly and mostly conspicuously porphyritic. It will be called the latite of Alpine Plateau. The typical rock of the Uncompahgre quadrangle is predominantly light reddish brown and has irregular rough-walled gas cavities. It carries rather conspicuous phenocrysts of feldspar, partly porous and in some places as much as 4 cm across, partly denser and smaller. It also carries some phenocrysts of augite, biotite, and in most places a little olivine, though less than in the other type. The olivine is much resorbed and in some specimens small crystals of pale biotite and augite fill in the embayments in the olivine. Rare quartz, much fractured and resorbed, is present in some of the rock. The cavities commonly carry tridymite, less commonly cristibalite, and considerable biotite. The latter is in part altered to a red magnetic iron oxide. In some specimens the biotite plates are so abundant in the gas cavities that they drop out like dust or sand when the fresh rock is broken. The large porous feldspars are variable in quantity, but in most flows they make up only a few percent of the rock and are oligoclase with considerable intergrown orthoclase. A few crystals of glassy orthoclase are visible in some of the rocks. The smaller feldspars have clear cores of oligoclase or andesine and broad, irregular, porous borders of albite or oligoclase with intergrown orthoclase. The biotite phenocrysts are dark brown and are more or less resorbed, leaving a skeleton of iron oxide and augite. The groundmass is made up of grains rather uniform in size and equant in form and in some rocks as large as 0.1 mm across. It is made up chiefly of albite in stout prisms, with some orthoclase partly intergrown with the albite and some grains of augite, magnetite, and biotite. The biotite of the groundmass is pale and is in the porous parts of the rock or associated with streaks of coarser crystallization. A few of the rocks carry some small needles of pale-brown hornblende associated with tridymite in the gas cavities. Zircon is a rare constituent. An analysis and description of a typical rock of this kind are given in table 25, column 10.

Some of the rocks of the Alpine Plateau area resemble the rock just described but have more orthoclase, more and larger feldspar phenocrysts, and rarely contains a little hypersthene. An analysis of one of these rocks with somewhat less dark minerals than the average of the group is given in table 25, column 11. The rock is described with the analyses.

The rocks of the mountains south of Cannibal Plateau are mostly porphyritic latite and of a somewhat variable character, though at the north end of the mass much of the rock is of the nonporphyritic type. The highly vesicular rock near the crest is much like the porphyritic latite but has phenocrysts of labradorite and carries phenocrysts of brown hornblende, much resorbed, but no phenocrysts of biotite. The lower part of the basal flow on the northwest slope of this mountain carries abundant inclusions of millimeter-grained gabbro that is made up chiefly of labradorite, with abundant augite bordered by hornblende, little hypersthene, some biotite, and iddingsite, and accessory apatite and magnetite. The basal flow near Water Dog Lake lacks the larger feldspar, has more olivine than most specimens, and has a little resorbed brown hornblende but no biotite.

The rocks of Cannibal Plateau and of the mountain to the south in the southern part of the Uncompahgre quadrangle are mostly of the more calcic, nonporphyritic Cannibal Plateau latite, but the northern part is mostly of the porphyritic latite of the Alpine Plateau area, as are also the lowest flow in Powderhorn Peak and most of the flows capping the ridges west of Powderhorn Creek. To the north, northwest of the old mining town of Spencer, the lower thin flow is of the nonporphyritic latite but the overlying thick flow is of the porphyritic latite.

Farther west in the Alpine Plateau area most of the flows are of the porphyritic latite with more phenocrysts and more orthoclase than usual, and those of the mesas to the north resemble the nonporphyritic type though they carry considerable biotite and are intermediate in character.

In the San Cristobal quadrangle to the south the rocks are much like those of the Uncompahgre quadrangle, though on the whole they carry fewer and smaller phenocrysts. The flows of the mesas at the head of Cebolla Creek, just south of the Cannibal Plateau area of the Uncompahgre quadrangle, and those of Rio Grande Pyramid are all similar to the nonporphyritic latite of the Uncompahgre quadrangle, though only a part of the rocks carry biotite in the porous streaks. On the mesas east of Lost Trail Creek the nonporphyritic latite is less common and the predominant rock resembles the porphyritic latite of the Uncompahgre quadrangle, but the feldspar phenocrysts are smaller, less abundant, and are all plagioclase. No orthoclase, biotite, or hornblende phenocrysts were found and very little quartz.

In the Creede quadrangle and adjoining parts of the Summitville quadrangle the rocks are similar to those of the Uncompahgre quadrangle and for the most part they more closely resemble the porphyritic latite, though they have less conspicuous phenocrysts and are intermediate in character.

The rocks of Handkerchief Mesa are light brownish or grayish, rather vesicular, and show conspicuous crystals of quartz and some of olivine and oligoclase, also a very few of orthoclase, as long as 5 mm. The oligoclase phenocrysts have irregular outlines from magmatic resorption. The groundmass is made up mostly of rather stout feldspar crystals, ranging from albite to oligoclase, considerable augite in ragged rods, and some magnetite. There was originally biotite (or hornblende) in the rock, but it has been resorbed and is indicated only by skeletons of magnetite. There are a few large apatite crystals. Some small pale-brown biotite flakes and a little tridymite line the gas cavities. Feldspar, averaging albite to oligoclase, makes up about two-thirds of the rocks. The rock from Fox Mountain, to the west, is similar, but is dark gray and rather dense and shows few or no quartz crystals. It has a few augite phenocrysts, and augite is intergrown with olivine. The feldspar is andesine and there is a little hypersthene in some of the rocks.

To the east and northeast the rocks are likewise similar. A specimen from Del Norte Peak has a few phenocrysts of orthoclase as long as 3 cm, but it is otherwise much like the rock of Handkerchief Mesa.

The flows of Cornwall Mountain of the Summitville quadrangle lack olivine and are low in dark minerals but are otherwise much like the nonporphyritic latite of the Uncompahgre quadrangle. They carry a few phenocrysts of augite in a fine mat of feldspar tablets, with grains of magnetite. There are considerable amounts of biotite and tridymite in the gas cavities. The rock that forms the small body between French Creek and Big Lake is also a pyroxene latite with much tridymite and biotite in the gas cavities. It carries a few quartz phenocrysts, more prisms of augite, and some of brown hornblende, mostly resorbed, in a fine groundmass of feldspar, augite, and magnetite.

The rock of Mammoth Mountain in the Summitville quadrangle has some resemblance to the nonporphyritic latite though it contains abundant dark minerals. It carries a few phenocrysts of olivine, augite, and remnants of quartz in a groundmass made up mostly of andesine laths, with augite and magnetite and with interstitial albite and a little orthoclase and biotite. The flow that caps Nigger Mountain in the Conejos quadrangle, east of the Conejos River, is similar, but it carries few augite phenocrysts and has more quartz by several percent. Oligoclase makes up about half of the rock, augite about one-third, and pale biotite, olivine, and magnetite each about 5 percent.

The flows of Storm King Mountain in the northern part of the Del Norte quadrangle are olivine latites near the nonporphyritic type. The vesicles are largely filled with a sandy aggregate of tridymite, biotite, and albite, with some hornblende and a few grains of zircon.

To the north, in the southern part of the Cochetopa quadrangle, the rocks are all much alike and megascopically have about the appearance of the normal quartz-bearing variety of latite of the Hinsdale formation, but microscopically they differ appreciably from the olivine latites that make up most of the Hinsdale andesite and that are well exposed on Storm King Peak only a few miles south in the Del Norte quadrangle. The rocks are slate gray, rarely light gray, and for the most part have abundant rough gas cavities, on the walls of which are perched rather abundant white spherulites of crystobalite. Many of the rocks, particularly in the upper flows, carry few visible crystals of quartz, feldspar, and resorbed hornblende. Microscopically they have a few percent of small phenocrysts of hypersthene, more or less altered to bastite, brown hornblende, much resorbed, some augite, pleochroic apatite, and quartz. The groundmass is finely crystalline and is made up mostly of fluidal laths of andesine, with some rods of augite, grains of magnetite, and a little interstitial glass. The gas cavities carry some biotite in addition to the crystobalite. The hypersthene is in part surrounde by augite, and the quartz grains are much resorbed and have a corona of augite grains.

The lower flow of the area east of Poison Gulch and elsewhere carries about 20 percent of phenocrysts as much as 2 mm across, of andesine-labradorite and quartz, with fewer phenocrysts of resorbed brown hornblende, resorbed biotite, augite, and magnetite. The groundmass is made up of small fluidal oligoclase laths, some augite and magnetite, and some interstitial albite and orthoclase.

The rock capping the mountain southeast of the mouth of Mill Creek is an olivine latite, much like that of the quadrangles to the south. It is a slate gray, vesicular rock and megascopically shows rare phenocrysts of quartz and orthoclase. The microscope shows that it carries abundant 0.5-mm grains of olivine and augite in a groundmass made up of fluidal andesine laths, less augite, some magnetite, and a little interstitial albite and orthoclase. The rock south of Taylor Canyon is a vesicular olivine latite.

INTRUSIVE ROCKS AND VOLCANIC CRATERS

Very few intrusive rocks that seem to be related to the latite-basalt of the Hinsdale formation were found and, as will be shown later, it is believed that the sources for the flows of the Hinsdale are for the most part buried under the mesas. Southwest of the center of the San Cristobal quadrangle a stock about half a mile across of rock much like the Hinsdale rocks is on the ridge only a few miles south of Rio Grande Pyramid which is itself a volcanic cone believed to be of Hinsdale age. In the basin of Dyer Gulch, on the east slope of Alpine Plateau in the central part of the Uncompahgre quadrangle, there is a composite intrusive of Hinsdale rocks of about the same size. Other intrusive bodies were found in the northern part of the Alpine Plateau, in the central part of the Uncompahgre quadrangle, and probably also in the Cannibal Plateau area, and elsewhere.

In many places small craters or cinder cones were found associated with the flows of the Hinsdale formation. One cone containing a small intrusive body was found at the base of the Hinsdale just east of the forks of Lost Trail Creek, in the central part of the San Cristobal quadrangle. Cerro de los Mogotes is a much larger volcano of Hinsdale age, and a few miles to the north of it are two smaller cones. Rio Grande Pyramid is a large volcanic cone, rising about 1,000 feet above the floor of older rocks, and is believed to be of Hinsdale age. There must also have been eruptions from the crest of Green Ridge in the northern part of the Conejos quadrangle.

The stock on the ridge a few miles south of Rio Grande Pyramid in the San Cristobal quadrangle is made up of a dense dark-gray basalt and carries abundant phenocrysts of tabular labradorite, 5 mm long, a few phenocrysts of olivine, and fewer of magnetite, in a groundmass, 0.5 mm grained, made up of stout sodic labradorite, augite, and biotite, with some interstitial oligoclase and some orthoclase.

An intrusive body of considerable size at the head of Dyer Gulch in the Uncompahgre quadrangle is made up of two kinds of rock. The older is a dense dark-gray latite that carries about 20 percent of white phenocrysts of feldspar as long as 2 cm, some smaller crystals of biotite, partly resorbed, considerable hypersthene, and some augite in a groundmass that is made up of small, equant grains of oligoclase, with some augite, magnetite, orthoclase, and biotite. The feldspar phenocrysts have cores of andesine or labradorite with broad borders of oligoclase. This rock is riddled by many small stringers of a nearly white tridymite latite that resembles the other except that it has somewhat more and larger phenocrysts, lacks hypersthene, has a somewhat coarser groundmass and a more sodic feldspar, and carries more orthoclase and probably 20 percent of tridymite. The feldspar phenocrysts have cores of labradorite to oligoclase, and borders of oligoclase or albite intergrown with orthoclase; some have irregular outer zones of orthoclase. There is much orthoclase in the groundmass. The tridymite is partly in rounded aggregates, probably originally gas cavities that have been filled, and partly scattered in streaks through the groundmass.

The small cone exposed under the main latite of flows of the Hinsdale on the slopes east of the forks of Lost Trail Creek in the central part of the San Cristobal quadrangle is made up mostly of scoria. The scoria is cut by a small irregular dikelike body.

Rio Grande Pyramid in the central part of the San Cristobal quadrangle is a conical mountain rising about 1,000 feet above the mesa remnant on which it is perched. It is about a mile across at the base and is made up entirely of olivine latite, mostly in chaotic breccia but partly as flows dipping with the slopes. It rests on the San Juan peneplain and is only moderately modified by erosion. The rocks resemble the rocks of the Cannibal Plateau of the San Cristobal and Uncompahgre quadrangles (see p. 202). The cone is probably of Hinsdale age, although it may be younger than the main flows of the Hinsdale. It was clearly a local body and the Hinsdale seems never to have covered the Summit peneplain of the mountains to the north.

Cerro de los Mogotes, situated just north of the Conejos River in the southern part of the Conejos quadrangle, 9 miles west of Antonito, is the only center from which extensive flows are known to have spread. The peak consists of a northern spur, which is a remnant of the old crater rim, and a southern spur which is a massive dike rock. The slopes are gentle, as would be expected from the basaltic nature of the rock. The region on the western side of the San Luis Valley has been strongly tilted to the eastward, but there has been little north-south tilting, hence the northern slope of the cone dipping about 250 feet to the mile probably represents about the original dip of the flows. One mile south of the crater the cone is truncated by the scarp on the north side of the Conejos River, and 1 mile west it is truncated by the scarp on the northeast side of Fox Creek. The central part of the cone was formed by slightly coherent cinders and scoria, which have undergone some erosion, but it is probable that explosions destroyed much of the crater before erosion began. The slopes on the east and north of the crater are little modified by erosion. The south spur of Los Mogotes is formed by an irregular dikelike mass of intrusive rock. The mass has a north-south trend, and it broadens and narrows irregularly.

Twelve flows, probably derived from Los Mogotes, are exposed in the scarp 1 mile south of the crater. These range from 10 to 50 feet in thickness and average about 25 feet. The rocks differ in texture, but are all olivine latite-basalt of nearly the same composition and much like the basalt of the New Mexico area except for their more sodic feldspar. The scoria that forms the inner part of the old crater is a dark-red, highly vesicular rock occurring in small fragments not more than a few inches in diameter. Phenocrysts of labradorite, yellow augite, and olivine, altered to iron oxide, make up a third of the rock; and a deep-red, nearly opaque groundmass mostly very finely crystalline, the rest. The last phase of igneous activity seems to have formed a cinder cone whose flanks were then covered by a single basalt flow.

The intrusive rock of Los Mogotes has grains with a maximum dimension of 1.5 mm and an average diameter of about 0.3 mm. Most of the rock in the intrusive mass is dense and massive, but a small part along the borders is finer grained than that just described and is slightly vesicular. Phenocrysts of feldspar, augite, and olivine, averaging about 2 mm in length, are distinguishable megascopically. The plagioclase ranges in composition from An_{68} to nearly pure albite; the mean composition is about An_{55}. It occurs in subhedral to euhedral laths of labradorite and interstitial albite. The augite is pale green and slightly pleochroic, but much of it has been slightly altered to a pale yellow or gray brown. Most of it occupies angular interspaces between the feldspar crystals. The interior of the original olivine crystals is relatively fresh, though altered along cracks, but a wide irregular border is altered completely to a red, pulverulent material that is no doubt mostly hematite. The magnetite occurs in irregular masses as large as the other minerals of the rock and it is slightly altered along its borders to hematite. Some specimens of the intrusive rock contain much opaline silica which has formed around and within the fragments. This rock is much like the flow rock of Los Mogotes except that the feldspar of the latter is somewhat more sodic. An analysis of a specimen of this intrusive is shown in table 25, column 1.

A dark-gray, very fine-textured, somewhat different rock, probably a part of a different intrusion, is closely associated with the one described in the preceding paragraph. Megascopically olivine is the only mineral determinable. The microscope shows little olivine and a fine groundmass of plagioclase, colorless augite, and magnetite. The plagioclase is less calcic than that in the rock of the main intrusive.

Between 5 and 9 miles north of Los Mogotes are three small cones. Topographically they are low mounds on the basalt plateau. The southern one has no crater but is a low mound of cinders covering a few acres. The northwestern cone is a low pile of cinders with a small crater and a crooked dike. The northeastern cone was not visited.

MINERALS IN THE VESICLES

Tiny, drusy albite crystals line most of the gas cavities. Tridymite is present in the greater part of the cavities in the latites and it makes up several percent of some of the rocks. It was not observed in the basalts. In part it is present in rude hexagonal plates attached to the walls of the cavities; in part it forms a matrix for feldspar crystals in lenses and streaks of dense but coarsely crystalline groundmass. In a few rocks it makes up most of a sandy powder that nearly fills the original cavities. In the upper flow of porphyritic latite of the Uncompahgre quadrangle it is abundant in rounded aggregates or in streaks in the groundmass.

Cristobalite is less common and abundant than tridymite and it forms white hemispheres attached to the walls of the larger gas cavities. It is common in rocks that show some autometamorphism.

Biotite much lighter in color than that of the phenocrysts is present in most of the gas cavities that carry tridymite.

Needles of brown hornblende are less common than biotite and in some rocks are associated with biotite. In a specimen from the summit of Elk Mountain in the Creede quadrangle they have the following optical properties:

$\alpha=1.628$ brownish
$\gamma=1.645$ greenish brown

$Z\wedge c=13°$, 2V large, $r>v$ slight. Optically +.

These data indicate an amphibole of low iron content.

Zircon is a rare mineral in the cavities.

RÉSUMÉ OF PETROGRAPHY

A general review of the rock types and their distribution shows that basalt, with even-textured labradorite feldspar characterized by tabular feldspar and no quartz, tridymite, cristobalite, biotite, hornblende, or visible orthoclase, makes up the thick and widely distributed series of flows of New Mexico, as far south as the Chama River. Basalts with labradorite feldspar were also found in small bodies northeast of the State fish hatchery on San Francisco Creek in the Del Norte quadrangle and on the mesas near Trout Mountain in the Creede quadrangle. To the north of the Colorado-New Mexico State line, along the eastern slopes of the mountains, the flows become less calcic and are olivine latites, but they retain the texture and mineral composition of the basalts of the New Mexico area and extend northward into the Del Norte quadrangle. In this area only the flows on both sides of Hot Creek differ appreciably from the type, and they are porphyritic and carry some quartz phenocrysts.

To the northwest, flows of the New Mexico type extend into the southwestern part of the Conejos quadrangle and into the adjoining parts of the Summitville quadrangle, but they become progressively less calcic and carry an increasing number of quartz phenocrysts northwestward.

Farther north and west the rocks are less uniform. Mesas near one another may be underlain by rather different rocks, and the successive flows of any mesa may be somewhat different. However, the flows of this area are mostly higher in soda and potash content than the flows to the south, and they are mostly lower in lime content and dark minerals and commonly carry tridymite and biotite and, less commonly, hornblende in the gas cavities. The larger part of the rocks is prophyritic, with phenocrysts of feldspar as long as several centimeters and fewer smaller ones of quartz, olivine, and augite; some flows carry phenocrysts of biotite or hornblende. In the groundmass in all the flows the feldspar is less distinctly tabular, and some interstitial feldspar is more sodic, irregular or nearly equant, and in many flows these equant feldspars make up nearly all the groundmass. There seems to be a tendency for the flows in the extreme northwestern bodies to carry on the average more and larger phenocrysts, to be higher in soda and potash content, and to have only equant feldspar grains in the groundmass.

The flows in the extreme southern part of the Cochetopa and Saguache quadrangles megascopically resemble the quartz-rich porphyritic rocks to the west, and, although they carry no olivine, they carry hypersthene and hornblende. The groundmass contains much glass. These rocks carry no tridymite but have cristobalite in the gas cavities.

SOURCE OF MATERIAL

Although the rocks of the Hinsdale formation have been eroded to such an extent that only remnants of the formation remain in much of the area covered by these rocks, few intrusive bodies of these rocks have been found and few centers from which the flows came can be determined with certainty. The basalt porphyry stock a few miles south of Rio Grande Pyramid in the San Cristobal quadrangle has about the composition of the Hinsdale olivine andesite and is believed to be a source for some of the flows. Rio Grande Pyramid itself is a remarkable conical mountain made up entirely of olivine latite, but this material seems to have piled up locally and not to have spread over any large area. Intrusive olivine latite remarkably similar to the overlying flows of the Hinsdale are exposed under and in the Hinsdale flows in Dyer Gulch and adjoining areas in the central part of the Uncompahgre quadrangle. Small cinder cones associated with the Hinsdale, in no way adequate for the great lava flows of Hinsdale age, were found in several places, and small dikes of similar rock were found in a few places. The largest crater found forms Los Mogotes in the southern part of the Conejos quadrangle and thus was probably the source for at least part of the flows of the great mesa above which Los Mogotes rises.

In looking for the source of the lavas of the Hinsdale formation the following facts must be taken into account:

1. The latite-basalt of the Hinsdale formation is rarely overlain by younger rock, and its upper surface is characteristically a rather flat mesa except in a few places where volcanic cones rest on it. Individual flows are also thin, regular, and flat, except where they have evidently been tilted. In the New Mexico area, north of the Chama River, and in the adjoining parts of the Conejos quadrangle, the dipping mesas at the top of the Hinsdale are extensive and, except for the younger cones and some very low gentle undulations, are remarkably uniform. In the Del Norte area they have been greatly dissected and only scattered remnants remain, but the individual mesas are not uncommonly several miles across and seem to be nearly as uniform as those in New Mexico, though much more extensively eroded.

2. In the great New Mexico mesas the flows throughout the mesa and in all parts of the area, those interbedded with the gravels as well as those that underlie the mesa, are remarkably uniform in character. In the Colorado area the rocks of any mesa are likely to be of 1 or 2 closely related kinds, but the rocks of mesas nearby may be appreciably different.

3. In many of the isolated mesas of Colorado there seems to be some thickening of the flows in a more or less central part of the mesa and a gentle slope of the mesa from this part. Alpine and Cannibal Plateaus in the Uncompahgre quadrangle, the plateau east of Lost Trail Creek, and that east of Lake San Cristobal seem to show this very well.

On Alpine Plateau the presence of large-sized bodies of cross-cutting intrusive rocks that are identical in character with the neighboring flows shows clearly that this was the center for much, if not all, of the extensive basalt flows to the north. This is further substantiated by the fact that the individual flows, as well as the formation as a whole, become rapidly thinner away from the highest part of the plateau, until they attain their normal thickness of a few hundred feet. No intrusive bodies were found in the Cannibal Plateau area, but the abnormal local thickness of the formation at the crest of Cannibal Plateau and the rapid thinning to the east and northeast show that this was the center for most of the formation of this area. The mountain south of Cannibal Plateau is probably also a center for Hinsdale flows, though most of the flows have been removed by erosion except around the center. The source of the flows forming the mesas northeast of Spencer is not known.

In the San Cristobal quadrangle the body of andesite of the Hinsdale formation east of Lost Trail Creek is a gentle dome, and it is probably a low cone. A small cinder cone and some intrusive rock are present in the cliffs on the northeast border of this body. Some of the bodies of Hinsdale rocks seem to be clear-cut cones wtih much steeper slopes; such are Rio Grande Pyramid in the San Cristobal quadrangle and Green Ridge and Los Mogotes in the Conejos quadrangle.

Considering the above facts, it seems highly probable that the Hinsdale rocks of most of the Colorado area were erupted from scattered centers and formed a group of cones or domes. Most of these are low and gently sloping; but some had much steeper slopes, and they probably merged to form a nearly continuous plateau-like surface of basalt with low domes and some steeper peaks. Erosion on such a surface would tend to cut the canyons and gulches between the cones, leaving the central parts of the cones little modified.

A similar explanation may account for the great plateau of basalt in New Mexico, but this has many of the features, on a smaller scale, of the great basalt plateaus ascribed to fissure eruptions. If the flows were erupted from many fissures, it is remarkable that no large dikes or other cross-cutting intrusives were observed in the underlying sands and gravels, although these are well exposed in many miles of cliff and canyon exposures and are so soft and light in color that any dikes of basalt would stand out prominently.

Everything points to a great fluidity for the magma that gave rise to the flows and to eruptions of a great amount of magma at one impulse. Many flows only 20 to 50 feet thick are uniform in thickness for several miles in canyon sections and cover a regular, flat surface; consequently they must have retained their fluidity for a long time. Moreover, in many cliff exposures of the most favorable kind for showing intrusive bodies, none is present and no cone or other source of the flows can be found on the mesa surface. These facts indicate that the centers from which the lavas were extruded were widely scattered. Everything indicates that many, if not most, of the flows covered many square miles of surface and were nearly as flat and regular as sedimentary rocks.

CHEMICAL COMPOSITION

Eleven analyses have been made of rocks from the latite-basalt of the Hinsdale formation and these are listed in table 25, page 208. Analyses confirm the microscopic studies and show that the rocks range from basalt to latite. Ten of these analyses are plotted on a variation diagram in figure 48.

VOLCANIC ROCKS OF QUATERNARY AGE

LATITE OF RED MOUNTAIN IN THE CONEJOS QUADRANGLE

Red Mountain in the northwestern part of the Conejos quadrangle near La Jara Reservoir received its name from the striking beds of red scoria exposed on the north and west sides. The crater which erupted these rocks is located near the crest of Red Mountain and has been largely destroyed or modified by landslide and erosion. Flows of pyroxene latite extend eastward from the crater down the slopes for nearly 1,000 feet in altitude, reach the floor of the valley, and cross the valley just east of La Jara Reservoir. They are not found far to the west, north, and south of the crater, and they probably did not flow far in these directions, although erosion and landsliding may have removed any flows that spread in those directions. The ancient hills and valleys over which the lava spread are essentially those that existed during the Durango glacial stage and the terminal moraine of glacier of the Durango is present in La Jara valley. The moraine is probably younger than the latite of Red Mountain. The lava is therefore probably a little older than the Durango glaciation and is early Pleistocene in age.

The earliest eruption at Red Mountain seems to have produced pink or gray tuffs and red scoria and cinder beds. These beds of pyroclastic material are overlain by rather thin volcanic flows.

The normal flows of Red Mountain are a blue-gray, fine, even-grained, vesicular rock, with a few conspicuous quartz and orthoclase phenocrysts. The microscope shows a rock containing a few euhedral andesine crystals, and a large proportion of anhedral albite and orthoclase grains. Long slender needles of augite form about 10 percent of the rock, and minute grains of magnetite are conspicuously numerous. The rock is a pyroxene latite.

Red scoriaceous flows possess about the same mineral composition as the dark flows, but they usually contain large phenocrysts of iddingsite derived from olivine. The alteration products of olivine seem to be normally present in the quickly chilled rocks but they and fresh olivine are absent in those that cooled more slowly. It is probable that resorption was complete where cooling was slow. The mineralizers from the vent that have so completely oxidized the iron of the scoria probably altered the olivine to iddingsite.

A specimen collected 1.5 miles east of the crest of Red Mounatin represents a coarse-grained phase with a larger proportion of euhedral plagioclase, near labradorite in composition, and appreciable amounts of olivine. Thus, it has a basaltic composition.

The gray tuffs are composed of basaltic glass fragments and shards of bubble walls, with a smaller proportion of mineral grains.

BASALT OF RIO BRAZOS CANYON, NEW MEXICO

To the southwest of Red Mountain about 8 miles south of the Colorado-New Mexico State line in the basin of Rio Brazos, four cones of basaltic rock rest on pre-Cambrian rock in a valley cut below the basalt of the Hinsdale formation and Los Pinos gravel. The valley is of about the same age as the La Jara valley. The Rio Pinos has cut a narrow canyon in the broad valley that is about 1,000 feet deep near the cones. At least one flow from above, on the east rim of the canyon, cascaded into the canyon, flowed down it for many miles, and spread over a small area below the mouth of the canyon. Later erosion of the torrential stream has swept most of the basalt from the canyon, but in places remnants remain on the walls. Their position shows that erosion has reached very little below the base of the flow. These rocks are probably younger than the latite of Red Mountain and may be middle Quaternary.

TABLE 25.—*Analyses, norms, and modes of latite and basalt of the Hinsdale formation*

	1	*2*	*3*	*4*	*5*	*A*	*6*	*7*	*8* [1]	*9*	*10* [2]	*11* [3]
ANALYSES												
SiO_2	50.38	54.76	50.18	49.65	50.95	55.0	55.21	55.55	54.80	54.72	56.83	61.94
Al_2O_3	16.55	16.38	16.47	16.95	16.10	16.5	15.72	14.89	16.69	16.60	16.90	18.85
Fe_2O_3	1.45	4.66	8.92	2.11	6.01	4.8	4.56	4.28	5.18	3.81	6.85	3.04
FeO	9.78	4.88	2.60	8.54	4.23	3.1	4.58	4.22	2.73	4.11	.13	.86
MgO	7.54	4.96	6.98	7.44	7.02	4.0	4.17	3.90	3.61	2.88	2.67	.80
CaO	9.27	2.40	9.30	8.92	8.24	6.1	6.67	6.35	6.23	6.31	4.92	2.26
Na_2O	2.88	3.04	2.74	3.21	3.59	4.0	3.88	4.35	3.74	4.04	4.58	5.17
K_2O	.50	2.18	1.04	1.13	1.73	3.2	3.31	3.36	3.57	3.49	4.00	5.05
H_2O+	.44	.34	.35	.35	.61	.8	.13	.72	.37	.49	.40	.41
H_2O-	.18	.15	.08	.40	.05	-----	.61	.42	.55	.68	.38	-----
TiO_2	1.04	1.46	1.60	1.49	1.62	1.4	1.45	1.40	1.14	1.52	1.41	.83
P_2O_5	.12	tr	.29	.30	.13	.6	none	.98	.78	.77	.50	.32
MnO	.13	none	none	.13	.11	.08	.06	.12	.10	.09	.11	.04
CO_2	none	none	none	none	-----	-----	none	-----	tr	none	none	none
ZrO_2	none	-----	-----	-----	-----	-----	-----	-----	.07	none	none	-----
SO_3	-----	-----	-----	-----	-----	tr	-----	-----	-----	none	none	-----
S	-----	-----	-----	-----	-----	tr	-----	-----	.01	none	none	.04
Cr_2O_3	-----	-----	-----	-----	-----	.005	-----	-----	.005	.01	tr	-----
V_2O_3	-----	-----	-----	-----	-----	.03	-----	-----	.03	none	-----	-----
NiO	-----	-----	-----	-----	-----	tr	-----	-----	none	-----	-----	-----
BaO	none	-----	-----	-----	-----	.13	-----	.07	.17	.12	.12	.13
SrO	none	none	.03	-----	-----	.05	.04	.07	.04	.05	.06	.03
Total	100.26	100.21	100.58	100.62	100.39	99.8	100.39	100.68	99.83	99.69	99.86	99.77
NORMS												
Q	-----	6.90	3.78	-----	-----	-----	-----	2.92	4.50	3.36	3.54	6.48
or	2.78	12.79	6.12	6.67	10.01	-----	19.46	20.02	21.13	20.57	23.35	30.02
ab	24.63	25.68	23.06	27.25	30.39	-----	33.01	36.68	31.44	34.06	38.77	44.01
an	30.58	24.74	29.75	28.36	22.80	-----	15.57	11.12	18.38	16.69	13.90	10.56
di	12.09	9.48	12.10	11.53	13.45	-----	14.08	11.02	6.05	7.78	2.38	-----
hy	17.12	10.55	11.60	5.48	9.40	-----	5.72	6.58	6.20	5.46	5.60	2.00
ol	8.07	-----	-----	13.83	1.54	-----	-----	-----	-----	-----	-----	-----
mt	2.09	6.73	3.71	3.02	8.82	-----	6.73	6.26	5.80	5.57	-----	.70
il	1.98	2.89	3.04	2.89	2.89	-----	2.89	2.74	2.13	2.89	.61	1.60
hm	-----	-----	6.40	-----	-----	-----	-----	-----	1.28	-----	6.85	2.56
ap	.34	-----	.67	.67	.33	-----	-----	2.35	1.68	1.68	1.34	.66
Symbol	"III.5." 4.(4)5	II.(4)5. 3."4	I(III). 5.4.4	III(II). 5.3(4). 4	II(III). 5.3.4	-----	II.5.2 (3).(3) 4	II.5.2. '4	II.5.2 (3).3(4)	II.5.2 (3).(3) 4	II.5.2 (3).4	I".″5. 2.3(4)
	Auvergnose	Andose	Hessose	Comptonose	Andose	-----	Akerose	Akerose	Shoshonose	Akerose	Akerose	Pulaskose
MODES												
Quartz	-----	0.5	-----	-----	-----	-----	-----	-----	-----	0.5	0.5	-----
Orthoclase	-----	-----	7.5	-----	-----	-----	-----	-----	-----	-----	-----	5
Plagioclase	6	10	58	57	-----	-----	1	1	2	1	12	22
(An content)	(66)	(65)	(55)	(62)	-----	-----	(40)	(40)	(64)	(35)	(30)	(15)
Augite	-----	1	17	22	-----	-----	1	1	3	.5	1.5	2.5
Olivine	5	6	11	12	7	-----	-----	-----	3	.5	tr	-----
Biotite	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1	1.5
Magnetite	-----	-----	5	4	-----	-----	1	1	1	3	2	.5
Groundmass	89	82	0	5	93	-----	97	97	91	90	83	69

[1] F, 0.02. [2] Titanite, 2.74. [3] Corundum, 0.80.

NOTES TO TABLE 25

1. Basalt (N. M. 78). From crater of Buffalo Butte, N. Mex., about 15 miles south of Antonito, Colo. George Steiger, analyst, 1923.

2. Basalt (N. M. 213). From Ortiz Peak, N. Mex., about 30 miles south of Antonito, Colo. Phenocrysts of quartz, orthoclase, and cores of plagioclase are foreign. Glen W. Brown, analyst, 1920.

3. Instrusive basalt, crater of Los Mogotes (Con. 143). Southern part of the Conejos quadrangle. A rather dense, vinaceous-drab rock that has very many 0.5-mm-sized, fluidal plagioclase tablets. The rock has a diabasic texture, the plagioclase laths are chiefly less than 1 mm long, the augite is interstitial, and the augite and olivine are stained brown from deuteric oxidation. Glen W. Brown, analyst, 1920

4. Typical basalts of the dipping mesas of New Mexico, collected from railroad cut 4 miles south of Servilleta, N. Mex., in SW¼ sec. 20, T. 20 N., R. 10 E. (NM 402). The rock is deep neutral gray and has some vesicles. In the hand specimen a few grains of honey-yellow olivine can be seen. The texture is intersertal, with little glass. The olivine crystals are fresh and about 0.5 mm across. The plagioclase tablets are about 0.5 mm across. George Steiger, analyst 1923.

5. Typical olivine latite (Con. 813) of Los Mogotes area in the southern part of the Conejos quadrangle. From the cliff east of Mogote Peak. Neutral gray and rather dense. Much like the rock represented by analysis 2, but has a little less dark mineral and a little more alkalic feldspar. J. G. Fairchild, analyst, 1925.

A. Average composition of the basalt and latite of the Hinsdale formation as calculated from the individual analyses and the estimated distribution and thickness of the different types of rock in Colorado. To the south in New Mexico basalt makes up large areas.

6. Olivine latite (Con. 21) of Green Ridge, Conejos quadrangle. From northeast shoulder of Green Ridge, half way to the top. A highly vesicular black basalt. The few phenocrysts are about 0.5 mm across. The groundmass has much andesine in laths 0.1 mm across, some augite, a little magnetite, a little hypersthene, and some submicroscopic paste. Glen W. Brown, analyst, 1920.

7. Olivine latite, Green Ridge type. Same as rock represented by analysis 6. George Steiger, analyst, 1919.

8. Olivine latite (SC 1206). From near the middle of the San Cristobal quadrangle 1 mile southeast of turn in Lost Trail Creek, at an elevation of 12,100 ft. Deep quaker drab. Has small, flattened gas cavities. The phenocrysts are about 0.5 mm long, the olivine is partly altered to iddingsite, the groundmass is made up of abundant fluidal tablets of andesine about 0.5 mm long, smaller grains of pyroxene and magnetite, and interstitial albite-oligoclase, and probably orthoclase. Chase Palmer, analyst, 1913.

9. Quartz-olivine latite (Up. 23). Cannibal Plateau type. Neutral gray. Contains abundant vesicles most of which are small. Phenocrysts are about 1 mm in largest dimension, the olivine is in small part altered to iddingsite. The groundmass is made up largely of fluidal andesine tablets, about 0.1 mm long, and has some augite grains and magnetite and a small amount of submicroscopic material, probably albite-oligoclase and orthoclase. George Steiger, analyst, 1911.

10. Porphyritic latite (Up. 24). Alpine Plateau type. Quaker drab. Contains abundant small vesicles and some of the larger plagioclase phenocrysts are highly vesicular. The plagioclase phenocrysts are variable in size and some grains are as large as 20 mm long. The large feldspar grains are glomerophyric aggregates. The plagioclase is moderately zoned and has borders that are filled with glass (?). They have some intergrown orthoclase irregularly distributed and in part as large nearly-square patches. The augite is dark brown from oxidation of iron, and the smaller grains in the groundmass are nearly opaque. The biotite is much resorbed. The groundmass is made up of equant grains about 0.05 mm across. Oligoclase is the chief mineral, dark augite is common, biotite less common, and needles of apatite are abundant. The feldspar of the groundmass is variable in composition and little orthoclase could be recognized. George Steiger, analyst, 1911.

11. Latite. (LC 1116). Porphyritic type of Alpine Plateau. From the Lake City quadrangle, in Willow Creek at an altitude of 10,350 ft. Light quaker drab. Dense, contains abundant glomerophyric phenocrysts of feldspar as much as 20 mm across. Some of the feldspar crystals are 2 mm across. They have rounded, corroded outlines, have rounded cores of An_{51} sharply separated from the main feldspar which is somewhat zoned and averages An_{14}. This latter feldspar has irregularly intergrown orthoclase. The feldspars were separated with heavy liquid and are described in detail in the section on mineralogy. The percents of the various feldspars are:

Orthoclase	18
An_{10} (antiperthite)	60
An_{15}	5
An_{22} (varies somewhat)	9
An_{45} (core)	8

The augite and biotite grains are less than 1 mm across. The biotite has been much resorbed. The grains of the groundmass are chiefly less than 0.05 mm long and are chiefly stout, poorly formed albite tablets and interstitial orthoclase with some quartz, magnetite, augite, and biotite.

OLIVINE LATITE OF ARCHULETA MESA

Flows of dark basaltic rock form Archuleta Mesa, which is near the southwestern corner of Summitville quadrangle. They overlie weak Cretaceous and Eocene sediments and form cliffs, below which the slopes are gentle and strewn with blocks of lava. The lava mesa extends for some distance into New Mexico and has a total area of about 10 square miles.

The erosional surface over which the lavas flowed was mapped as a part of the San Juan peneplain by Atwood and Mather (1932, plate 1), and the lavas as Hinsdale. However, the lava is not like any known Hinsdale rock and the San Juan peneplain in this area must have been at least 1,000 feet higher in altitude than Archuleta Mesa. It is believed that the lavas rest on a younger surface and that they are of Quaternary age.

The fresh basalt of Archuleta Mesa is nearly black, but the weathered rock is lighter. In the fresh rock phenocrysts are inconspicuous but in the weathered rock the white plagioclase is easily seen. Phenocrysts make up about a third of the rock and most of them are less than 5 mm long. Thin tablets of bytownite (An_{74}) are the chief phenocrysts, augite is nearly as abundant, olivine, partly altered to iddingsite and serpentine, is rather abundant, and hypersthene, altered to bastite, is in small amount. The groundmass is made up of tablets of zoned plagioclase, averaging andesine-labradorite and about 0.2 mm long, some grains of augite and magnetite, a little biotite in irregular patches, and abundant interstitial material made up chiefly of alkalic feldspar, but with a little quartz. Texturally, the rock is rather different from the rocks of the Hinsdale basalt and latite to the north and east, but chemically it is much the same as the darker rocks of the Hinsdale in the Uncompahgre quadrangle. It would be classified as a latite or a quartz latite. There is about enough quartz in the groundmass to convert the olivine phenocrysts to hypersthene.

RHYOLITIC ASH NEAR DURANGO

Woolsey (1906) has described rhyolitic ash from the three following localities near Durango: on the west side of the Animas River, 2.5 miles north of Animas City; on the divide between Junction Creek and Dry Gulch, 2 miles west of Animas City Mountain; and on the Spencer ranch, 4 miles east of Durango on the Florida Mesa. The deposits have a thickness of 25 to 50 feet in the region south of Durango and a thickness of about 3 feet in the Florida Mesa area. Attempts have been made to utilize the material.

The tuff seems to be on the same terraces as the Florida gravel and it appears to rest on bedrock and to be overlain by some gravel. It probably is Durango or middle Pleistocene in age. Thus, the rhyolitic ash has about the same age as the latites of Archuleta Mesa and those near La Jara Reservoir.

INTRUSIVE ROCKS OF TERTIARY AGE

INTRODUCTION

Except in the extreme western part of the San Juan Mountains, bodies of Tertiary intrusive rock are remarkably few in number and small in size, considering the complexity, the great thickness, and the wide distribution of the extrusive rock. It is certain that during each period of igneous activity there were few centers of eruption, and that as they naturally were under the crests of the domes where the resistant volcanic rocks were thickest and most massive, they have been protected from erosion. The main streams developed on the flanks of the centers, and the centers were the crests. Most of the intervals of erosion between periods of eruptive activity were long enough to develop deep, steep-walled canyons but left broad mesas between the canyons. The postvolcanic activity also has reached only the canyon stage. The only mature topography was developed during the San Juan peneplaination, preceding the eruption of the lavas of the Hinsdale formation, and this seems not to have been a deep erosion.

The greatest part of the intrusive bodies fall into two groups: the laccoliths and stocks that intrude chiefly the sediments in the western part of the mountains, and the stocks and associated dikes of Conejos age that intrude the Conejos rocks in the eastern part of the mountains. Some intrusive bodies, mostly small, have been found that belong to almost every period of eruption, but many of these were so insignificant and superficial that they were not separated from the associated extrusive rocks.

All of the intrusive rocks that could, with reasonable assurance, be correlated in age with one of the volcanic formations have been described with the other rocks of that formation and will not be further described here. In the following pages only those intrusive rocks are described whose definite age within the Tertiary is unknown, and they are subdivided according to their petrographic character. On the geologic map all of the intrusive rocks are divided as follows:

Hinsdale age
Los Pinos age
Fisher age
Alboroto age
Sheep Mountain age
Conejos age
Beidell age
Rhyolites and granite porphyries
Quartz latites
Dark quartz latites and basalts
Stocks and laccoliths (granite to gabbro)
Lamprophyres and diabase
Lake Fork age
Paleocene or Late Cretaceous quartz monzonite porphyry

CRITERIA FOR DETERMINING THE AGE OF THE INTRUSIVE ROCKS

Although it is not always possible to determine the age of the intrusive rocks, the following considerations offer valuable evidence of their age and for most bodies fix the age within reasonable limits. This discussion applies primarily to the San Juan Mountains.

1. Obviously, an intrusive body is younger than the rocks it cuts. This establishes the earliest age of most of the intrusive bodies.

2. If the eroded surface of an intrusive rock is overlain by rocks of known position in the section, that establishes the latest age of the intrusive. This criterion can be applied to a few intrusive bodies, and is especially valuable where a more or less complete section of rocks is exposed in cliffs or steep slopes, as in the southwestern face of the mountains. Unfortunately, most of the intrusive rocks believed to be of Conejos age are in the broad, eastern strip of Conejos outcrops where the section is incomplete and the overlying rocks are at a distance from the main volcanic centers.

3. Criteria 1 and 2 can be used if related intrusive bodies offer the evidence, such as the dikes that radiate from the Summer Coon intrusive mass a few miles north of Del Norte.

4. If the altered or mineralized rocks, metamorphic zones, veins, and other aftereffects of intrusion affect rocks of known age, the earliest age of the intrusive body is established. If such bodies and zones are truncated by rocks that are not affected, the latest age for the intrusive body is established.

The following criteria offer less positive evidence, but in association with other evidence they may establish the age of an intrusive body.

5. Similarity of the rocks of an intrusive body to extrusive rocks of known age. Chemical, mineralogical, and textural similarity must be taken into account. Since the same rock types occur again and again in the geologic column, this criterion must be used with caution. In all respects the three dark quartz latite divisions of the Potosi volcanic series are much alike and chemically the Fisher rocks are much like the three Potosi quartz latites. The three rhyolite formations of the Potosi volcanic series are also made up of similar rocks. In general, textural features are more useful than chemical. It has been shown in the descriptions of the formations that the different flows and breccia

beds of a formation commonly show considerable differences in chemical and even mineral composition and have persistent and characteristic textural characters throughout. Some of their textural features are the abundance, size, shape, and character of the phenocrysts, as illustrated by the Fisher rocks, the texture of the groundmass, and vesicularity and minerals in the gas cavities, as in many of the latites of the Hinsdale formation. In such rocks as the Fisher quartz latite the phenocrysts are clearly intratelluric and seem to be characteristic of the magma. One would expect these features to persist with little modification in the small near-surface intrusive bodies, and even in larger stocks large phenocrysts might reasonably be expected.

6. In great dome or lenslike accumulations of volcanic rocks such as are most of the volcanic formations of the San Juan Mountains, the main intrusive bodies that served as centers of eruption are likely to be near the central, thicker part of the formation. Modification of the volcanic pile by later erosion must be taken into account. In applying this criterion it is reasonable to assume that the intrusive rocks of a center of eruption such as that of Embargo, northwest of Del Norte, are of Conejos age because they are near the center of the Conejos lens and are in an area where later dark rocks are practically absent in the section. Other evidence confirms this conclusion.

7. Two or more intrusive bodies may be so similar in their broader field characteristics or petrographic character as to leave little doubt of their close relationship. Any evidence as to the age of one may be reasonably applied to the other. Such are the 3 intrusive necks in the San Luis Hills, each of which consists of 3 kinds of rock and all 3 kinds are remarkably similar in all 3 necks.

Another illustration is the similarity of the Embargo center and many of the other centers of Conejos age to the Summer Coon center, with its central neck near granodiorite in composition and many large radiating dikes of quartz latite porphyry and small dikes of dark rocks.

8. If fragments of an intrusive body are found in clastic beds, the fragments are clearly older than the clastic bed.

In applying the above tests to the intrusive body, it must be remembered that some centers of eruption may have been sources of material for more than one formation, although no such complex centers have been observed. However, two or more intrusive bodies may happen to be geographically close together though not closely related genetically.

9. A few of the intrusive bodies, notably the laccolith north of Blanco Basin in the Summitville quadrangle, deformed the bordering rocks. It must be younger than the rocks that have been deformed.

10. The intrusive rocks of the La Plata and Rico Mountains are younger than the main part of the doming of the mountains and are therefore believed to belong to the Miocene volcanism.

INTRUSIVE RHYOLITES AND GRANITE PORPHYRIES

Intrusive bodies of rhyolite are not common in the San Cristobal quadrangle and adjoining area and none of the bodies is large, the largest being about one-half mile across in outcrop. Most of the bodies are dikes or stocks and some are very irregular. The rocks range in age from pre-Potosi to Hinsdale and are coarsely porphyritic to felsitic in texture.

The microgranite laccolith of Tomichi Dome in the northeastern part of the Cochetopa quadrangle is about 3 miles across and the granite porphyry stock, a few miles to the south, between Needle and Larkspur Creeks is somewhat smaller.

PORPHYRITIC RHYOLITE

One of the commonest types is a rather dense nearly white, flesh-colored, or pale-pink rhyolite porphyry that carries penocrysts of glassy sanidine and smoky quartz and a few of white plagioclase and dark biotite in a dull aphanitic groundmass. The phenocrysts commonly make up about one-third of the rock and are as long as 3 cm. The sanidine is commonly rounded from resorption and is more or less kaolinized and the quartz is embayed. Oligoclase is in small amount and in smaller crystals. The groundmass is commonly a fine granophyric intergrowth of quartz, orthoclase, and probably albite. Most of the dikes have a marked porphyritic texture in the center and a contact zone 3 to 4 feet wide of a dense, greenish felsite that carries a few quartz phenocrysts.

A stocklike body of this rock, with irregular boundaries, cuts the Treasure Mountain rhyolite and pre-Cambrian rocks in the northeastern corner of the Needle Mountains quadrangle and extends for a short distance into the San Cristobal quadrangle. Other dikes of this rock occur to the south on the ridge southwest of Bear Creek, and a dike of similar rock cuts the Silverton volcanic series and pre-Cambrian rocks in the south-central part of the Silverton quadrangle in Deer Park and Cunningham Gulches. This dike is from 20 to 30 feet wide, has been mapped for nearly 4 miles, and may continue for some distance farther to the east. It has a number of bends, some of them rather sharp.

This type of rhyolite also forms the rather large, irregular intrusive body mapped in the extreme western part of the San Cristobal quadrangle south of the Rio Grande between Bear and Starvation Gulches. It cuts

Treasure Mountain rhyolite. Some miles to the north it forms the bodies south and southwest of Wolf Mountain, which is south of Lake Fork of Gunnison River, where it cuts rocks of the Silverton volcanic series. North of Lake Fork, dikes of this type of rhyolite were found in Smelter Gulch, in the southwestern part of the Uncompahgre quadrangle, and in the Current Gulch, in the extreme northern part of the San Cristobal quadrangle. In the latter locality it cuts the Sunshine Peak rhyolite.

In the northeastern part of the San Cristobal quadrangle dikes of this type of rhyolite cut the Piedra and Fisher rocks. One dike crosses the ridge about three-quarters of a mile north of Painted Peak; another is present in the gulch to the west. A similar dike of much altered rock was found in the west fork of Rough Creek about 1.25 miles north-northwest of Painted Peak. Other dikes were found near the head of Miners Creek, west of the main fork of Mineral Creek and about a mile north of the Continental Divide, and elsewhere.

A somewhat similar rock, lacking the quartz phenocrysts, forms the small intrusive body in the extreme western part of the San Cristobal quadrangle north of the Rio Grande on the west side of Pole Creek near the trail to Minnie Gulch, and the body in the north-central part of the quadrangle on the ridge south of Red Mountain, which is west of Lake San Cristobal. The former of these cuts the Silverton volcanic series, the latter cuts Fisher quartz latite. The bodies of rhyolite porphyry near Creede, on the Creede quadrangle, are of this type without quartz phenocrists, and are probably of Alboroto age.

The large body of rhyolite in the northeastern part of the San Crisbtoal quadrangle, on the east side of the basin at the head of Rough Creek, cuts Piedra and Fisher rocks and is of the type without quartz phenocrysts and it has fewer and smaller phenocrysts and a fluidal texture.

A body of prophyritic rhyolite nearly 1 mile long and ⅛ mile across, cuts the Beidell and Conejos rocks in the basin of Lime Creek in the northern part of the Del Norte quadrangle, a few miles southwest of the old mining camp of Beidell. It is made up of a purple-drab to white rock which commonly has a platy fluidal structure and a glassy contact zone. The rock carries abundant phenocrysts as long as 3 mm of white plagioclase, glassy quartz, and sanidine, and black biotite in an aphanitic, rhyolitic groundmass.

FELSITIC RHYOLITES

Felsitic rhyolites have been found cutting the Mancos shale a few miles northeast of Razor Creek Dome north of the center of the Cochetopa quadrangle, and cutting the Conejos quartz latite a few miles to the south of this in Salt Trough Gulch. Similar rhyolites are mapped in the southwestern part of the Telluride quadrangle. Many felsitic dikes cut the Silverton rocks northeast of the center of the Silverton quadrangle, and felsite intrusive bodies were found in the northern part of the San Cristobal quadrangle and in other places. They occur as small irregular stocks, dikes, and sills. They are of uncertain age and are probably not all of the same age. Some cut only the sediments, others cut the Silverton or Potosi volcanic series.

Several small bodies of such rhyolite with few phenocrysts were found cutting rocks of the Silverton volcanic series and older rocks in the northeastern part of the San Cristobal quadrangle in the upper drainage area of the Lake Fork of Gunnison River (fig. 29). A large sill-like body is mapped under Whitecross Mountain; it extends into the Silverton quadrangle. This rock is dense and aphanitic and has many beautiful spherulites, some being 0.5 inch across. A somewhat similar rock forms the sill mapped just east of Lake San Cristobal in the north-central part of the San Cristobal quadrangle and adjoining parts of the Uncompahgre quadrangle.

A flesh-colored aphanitic rhyolite, dense, except for some lithophysae lined with minute crystals of quartz and orthoclase, forms the irregular body that intrudes the latites of the Treasure Mountain rhyolites and Sheep Mountain quartz latite just east of the mouth of Lost Trail Creek in the central part of the San Cristobal quadrangle. The rock consists of micrographic intergrowths of quartz and orthoclase and probably albite, with some biotite.

Several bodies of intrusive rhyolite and latite, much altered and of uncertain size and shape, were found in the basin at the head of Rough Creek in the northeastern part of the San Cristobal quadrangle, and similar bodies were found in the basin at the head of Mineral Creek. They cut Piedra rocks.

Three small, irregular plugs of rhyolite, the largest of which forms Prosser Rock and is about 0.25 mile across, intrude the Mancos shale near the forks of Razor Creek, a few miles northeast of Razor Creek Dome, northeast of the center of the Cochetopa quadrangle. A similar intrusive rhyolite cuts the Conejos in Salt Trough Gulch a few miles to the north. These bodies show irregular relations to the intruded Mancos shale. The rhyolite itself is greatly brecciated, and its fluidal banding is irregular.

This rhyolite is mostly dark red brown but part is nearly white. Much of it has a distinct fluidal banding caused by nearly white, porous streaks, and some has conspicuous spherulites. Glassy contact zones of obsidian or nearly colorless perlite are present, and in places the obsidian layers alternate with layers of

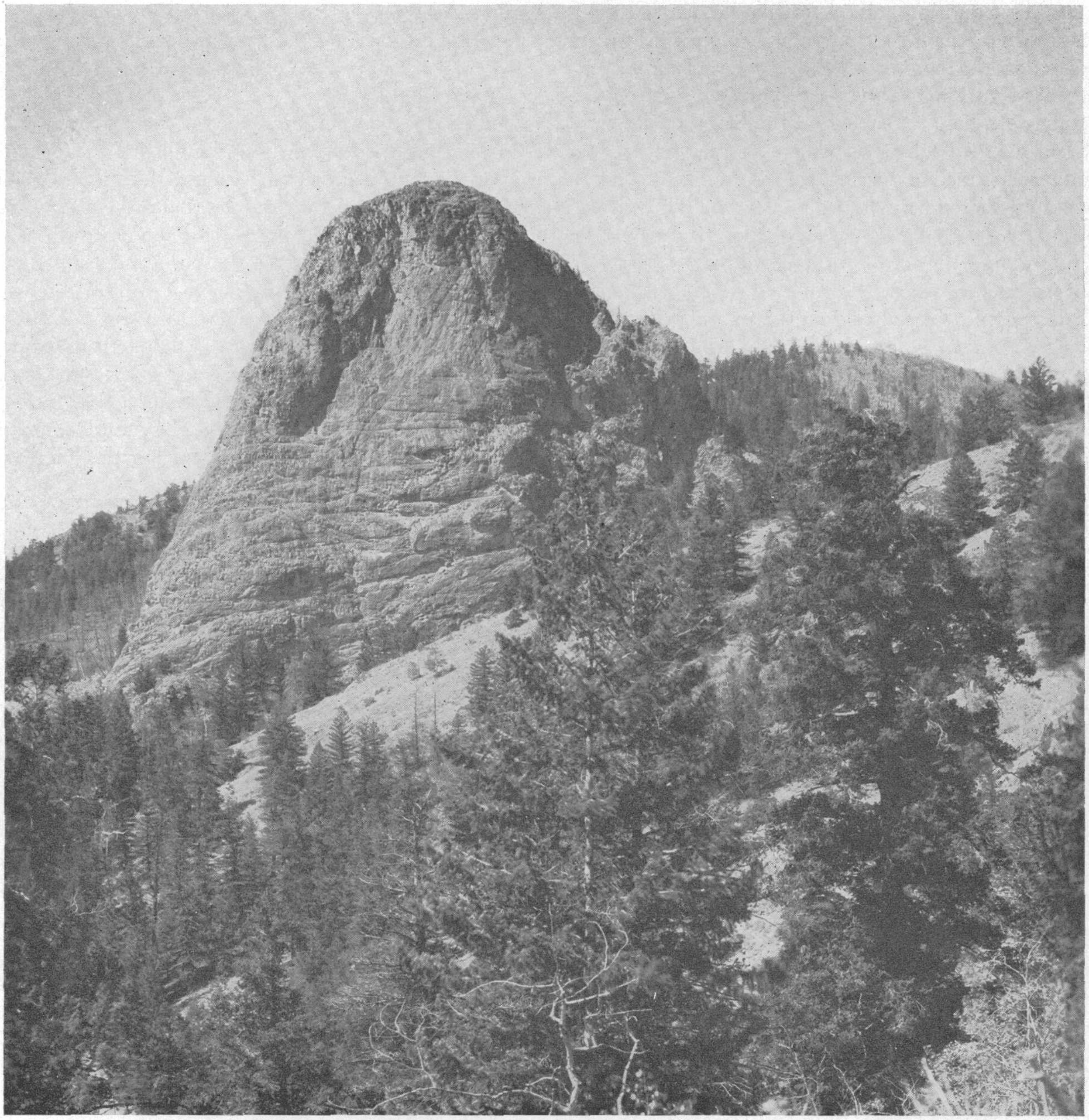

FIGURE 29.—Sugar Loaf, as seen from the second ridge to the east, is a rhyolite plug cutting the Eureka rhyolite, Lake City quadrangle.

spherulites. The rock is a felsite that carries only 10 to 15 percent of phenocrysts, mostly less than 2 mm across. The phenocrysts are mostly albite or oligoclase, and orthoclase, with a few of biotite, much resorbed. Some large sphene crystals are present. The groundmass is mostly crystalline but almost submicroscopic, and is no doubt rhyolitic in composition. The porous layers are more coarsely crystalline and much cristobalite and probably tridymite line the pores. Fragments of rhyolitic tuff are included in the felsite. Some of the rock resembles somewhat the cavernous tridymite rhyolite of the Alboroto to the north and west.

Two small plugs of rhyolite cut the Mancos shale just northwest of the railroad and southwest of Trout Lake in the southwestern part of the Telluride quadrangle. This rock is a dark gray, dense felsite, with a few small decomposed feldspar crystals and reddish-brown mica leaves. The mass of the rock is finely granular and cryptocrystalline. A breccia occupies most of the space in the plug nearest Trout Lake, but is cut by arms of the same rock in massive form.

Many dikes and intrucive sheetlike bodies of rhyolite cut the rocks of the Silverton volcanic series in the area northeast of the center of the Silverton quadrangle, west of the Animas River and between Eureka and California Gulches. All these bodies consist of a peculiar white to dull-gray felsite, usually with a very pronounced lamellar structure, and almost wholly without phenocrysts. In some places a zone of distinct spherulitic texture runs parallel to the contact zone, as along the Houghton Mountain dike. The weathered rock develops a pronounced platy cleavage. The microscopic texture is cryptocrystalline, granular, or in some specimens, spherulitic or poikilitic. Biotite blades rarely appear, and lime-soda feldspars are wholly lacking.

A sheet of closely related rhyolite but with slightly more biotite and plagioclase is mapped in Cinnamon Mountain across the Animas River a few miles to the east, where it intrudes the tuff of the Burns quartz latite.

GRANITE PORPHYRY OF ALPINE GULCH

Two large dikes, each more than 1 mile long and the widest about 0.25 mile wide, intrude the Sunshine Peak rhyolite in Alpine Gulch, about 7 miles east of the northwest corner of the San Cristobal quadrangle. The rock is pink and conspicuously porphyritic, with abundant well-formed phenocrysts of pink orthoclase, as long as 4 cm, and a few smaller crystals of andesine in a 0.5-mm-grained groundmass of quartz and feldspar, with some biotite and rarely augite. A few of the rocks contain pale-brown or pale-green hornblende, which is probably secondary after augite. The accessory minerals are apatite, magnetite, zircon, and sphene. There is some chlorite, epidote, calcite, and other secondary minerals.

The orthoclase crystals appear to be zoned, and they carry some intergrown albite in the outer zone or throughout. The groundmass is made up of interlocking grains or graphic intergrowths of microperthite and quartz.

An analysis of this granite porphyry from a dike in Alpine Gulch is given in table 21, column 59.

In some parts of the dikes the groundmass becomes coarser grained and the phenocrysts less conspicuous; in others the groundmass is finely microcrystalline. Scattered inclusions of an even-grained granite and of dark granodiorite porphyry are present.

GRANITE PORPHYRY OF NEEDLE CREEK

A large intrusive stock of granite porphyry forms the rough mountains between Needle and Larkspur Creeks in the eastern part of the Cochetopa quadrangle. It intrudes the Conejos quartz latite and in places the Mancos shale which is exposed only locally and near the stock. Its form as shown on the map is much generalized, but it is more than a mile long in a north-south direction and of considerable width. Where seen in the Needle Creek basin it rises as a steep, rugged, high mountain above the gentler slopes of breccia and flows of the Conejos. It forms light-colored rock outcrops with rounded boulders of disintegration. The rock where seen is uniform and is nearly white, with about 10 percent of phenocrysts of quartz about 5 mm across, nearly the same proportion of glassy sanidine in crystals 10 mm long, somewhat less of white plagioclase, and a few percent of biotite, in a fine-grained groundmass. The plagioclase is oligoclase and strongly zoned; the accessories are apatite, zircon, and magnetite, and the groundmass is a fine-grained aggregate of quartz and orthoclase and some plagioclase. Augite is present in some parts.

MICROGRANITE OF TOMICHI DOME

The most striking topographic feature of the Tomichi Creek basin which is in the northeastern part of the Cochetopa quadrangle, is Tomichi Dome, a symmetrical dome-shaped mountain rising out of the center of the basin more than 3,000 feet above the valley floor. It is about 11,460 feet in altitude and, except for many small, talus-covered areas, is well timbered with spruce. It is drained on the north and west by Hot Spring Creek and on the south and east by other tributaries of Tomichi Creek.

The mountain was formed by a laccolith of microgranite that constitutes most of the slopes above the 9,800-foot contour. The lower slopes on all sides of the dome are of Mancos shale, which has a general east-west strike and a southerly dip that averages about 8°. The laccolith has scarcely disturbed the sediments overlying its sides, and those that overlay its upper surface have been entirely removed by erosion. Such a smooth, symmetrical dome in these mountains could be the result only of the removal by erosion of a softer cover rock. If the body had been a lava flow, a plug, or a similar cross-cutting body, the upper surface would be a rugged, unsymmetrical mountain.

The main igneous mass of Tomichi Dome, which was mapped as Carboniferous limestone (?) by the Hayden survey, ranges from 1½ to 2 miles across, and rises on an average of 1,600 feet above the shale. In addition, near the laccolith and particularly west and northwest of it, there are many dikes and sills of greater or less size of similar rock. These bodies in places cause irregular and distinctive topography.

The microgranite forming Tomichi Dome is remarkable for its homogeneity. Except where surface waters have locally stained it to light brown, the rock is uniformly white, rather dense, and breaks easily with somewhat conchoidal fracture. It is even textured, with a few scattered phenocrysts of biotite a millimeter or so across, and a few crystals of smoky quartz, as much as 5 mm across, perhaps 1 or 2 occurring in a square foot. The granite is extremely fine grained and almost aphanitic, although under a lens the vitreous quartz grains and glistening cleavage faces of the feldspars can be distinguished in the more granular specimens.

The microscope shows that the prevalent type of the rock is seriate porphyritic. Individual grains average less than 0.1 mm and, aside from the phenocrysts, few crystals are as much as 0.4 mm across. The mineral composition of the rock may be represented as follows: quartz>orthoclase$\gtreqless$soda plagioclase>biotite>topaz>iron oxides>garnet. The orthoclase is commonly microperthitically intergrown with soda plagioclase and forms a matrix for the other minerals. The plagioclase is probably albite or albite-oligoclase. The relative proportion of the feldspar is not determinable from a study of thin sections, although it is believed that the granite is richer in soda than is common. The biotites range in size from minute specks when greatly magnified to phenocrysts more than 1 mm across, and are characteristically anhedral and ragged. Topaz is less abundant than biotite and occasionally occurs as millimeter-sized crystals poikilitically intergrown with quartz; it is probably secondary. Iron oxides, garnet, and perhaps zircon are present in accessory amounts.

Stark (1934) studied the heavy minerals in a specimen of rock from Tomichi Dome and found 0.289 percent of heavy minerals of which 69.88 percent was magnetite. Apatite was 3.77, ilmenite 8.49, sphene 6.60, hornblende 3.79, garnet 3.79, and topaz 61.32 percent of the heavy minerals exclusive of magnetite.

The rocks of the dikes and sills nearby are similar to the type described, although they are commonly of much finer grain, becoming in extreme cases microcryptocrystalline.

The great hot springs in Hot Spring Creek at the northern base of the dome are probably the dying phase of the igneous activity.

Stark and Behre (1936) studied Tomichi Dome and, although they recognized that the remarkably smooth, domelike form of the body favors a laccolithic origin, they concluded that the texture of the rock and lack of metamorphism of the sediments show that it is a flow.

We believe that Tomichi Dome is formed by a laccolith of rhyolite. The form of the dome is much smoother and more regular than that of a lava dome of rhyolite or of an erosional remnant of rhyolite. Moreover, the specimens of the rhyolite from Tomichi Dome that we collected are finely microgranular and are those characteristic of intrusive rhyolites rather than of effusive rhyolites. Stark and Behre say there is glass in the rock but we found none. They also consider the lack of recognizable contact phenomena as evidence that the dome is made of a lava flow. We did not see the contact of the rhyolite, but the contacts of rhyolite intrusive bodies, especially the bases of laccoliths, with shales, commonly show very little contact metamorphism.

QUARTZ LATITES

SAN CRISTOBAL QUADRANGLE

A dike of quartz latite porphyry cuts the Picayune quartz latite in the north-central part of the San Cristobal quadrangle, about a mile above Lake San Cristobal, a little west of the Lake Fork of Gunnison River. About a quarter of the rock consists of phenocrysts as long as 1 cm, chiefly of calcic andesine with some resorbed biotite. These are in a groundmass made up of feldspar laths in a spongelike intergrowth of quartz and orthoclase. The rock is much like some of the intrusive quartz latite bodies of Fisher age.

OURAY AREA

Many bodies of intrusive quartz latite cut the Potosi volcanic series and older rocks in the Ouray and adjoining quadrangles. They are probably of Potosi age but no close age correlation can be made.

One of the most important of these quartz latites is found chiefly in or near the basin of Difficulty Creek, in the south-central part of the Ouray quadrangle and in the Ouray folio was called the Difficulty Creek latite. The main mass is nearly a mile across, and several smaller masses are nearby. Several dikes radiate from the main central mass and extend outward for as much as 3 miles, cutting the San Juan tuff. The main mass has crosscutting relations to the south, but the fact that its base is approximately conformable with the bedding of the tuffs gives the mass the form of an asymmetric laccolith.

This quartz latite is rather uniform, though the dike rocks show some variety. The color is light gray or nearly white, in many places with a pink or purplish tinge. Phenocrysts make up only a small part of the rock and are chiefly oligoclase with very little orthoclase, and some biotite and quartz. Hornblende occurs with biotite in the rock of the summit west of the forks of Cow Creek and is common in several of the dikes of this region. The groundmass is felsitic and in the larger bodies is a microgranular aggregate of orthoclase and quartz containing a small amount of plagioclase and magnetite dust. Some of the smaller bodies are finer textured and trachytic or micrographic in texture. An analysis of this quartz latite is shown in table 26, column 1. It is a biotite-quartz latite rather near the rhyolites.

The type of quartz latite called the Cimarron Creek latite in the Ouray folio occurs in many dikes, sills, and irregular intrusive masses, for the most part intruding the San Juan tuff, but in part the Potosi rocks where it is not everywhere easily distinguishable from the flows. Some of the sheets or sills are traceable for several miles at approximately the same horizon. The masses range from a few feet to hundreds of feet in vertical dimensions. They are most abundant in the Cimarron Creek basin in the eastern part of the Ouray and adjoining parts of the Uncompahgre quadrangles, but they also occur to the south on the headwaters of Cow Creek and on the divide toward North Fork of Henson Creek. The most common phase of this quartz latite is a dark-gray, almost aphanitic rock with many small andesine or labradorite phenocrysts, 2 mm or less in cross section. Augite and hypersthene are the chief dark minerals but biotite is commonly present and hornblende is sometimes present. In some of the larger bodies the lower contact zone is a glassy flow breccia. The hypersthene is commonly altered but is fresh in the glassy rocks. The groundmass is cryptocrystalline and is made up of orthoclase and quartz and a small amount of augite, magnetite, and apatite. An analysis of this pyroxene-quartz latite is given in table 26, column 2. The analysis, together with the microscopic description, shows that this quartz latite is much nearer the andesites than is the Difficulty Creek latite.

A type of quartz latite called the American Flat latite in the Ouray folio intrudes the Henson tuff in the southeastern part of the Ouray quadrangle and adjoining parts of the Silverton and Uncompahgre quadrangles. The largest known body forms American Flat, on the Ouray-Silverton quadrangle line. Another body is present near Uncompahgre Peak in the Uncompahgre quadrangle, and some smaller bodies are mapped.

TABLE 26.—*Analyses and norms of intrusive latites of the Ouray quadrangle*

	1	2		1	2
	Analyses			*Norms*	
SiO_2	68.81	60.69	Q	24.60	16.38
TiO_2	.28	.73	or	23.91	18.90
Al_2O_3	15.54	15.90	ab	35.63	29.87
Fe_2O_3	1.78	4.52	an	8.06	18.07
FeO	.80	1.72	C	1.22	-------
MnO	.12	.13	di	------	3.24
MgO	.52	1.93	hy	1.30	3.30
CaO	2.43	5.23	mt	2.09	3.94
Na_2O	4.24	3.55	il	.61	1.37
K_2O	4.07	3.22	hm	.32	1.76
H_2O-	.50	.93	ap	.34	.67
H_2O+	.78	.96	*Symbol:*		
CO_2	.48	.27	*No. 1*	I.4.2.3(4) Lassenose-toscanose	
P_2O_5	.13	.31			
BaO	.13	.10	*No. 2*	(I)II.4''3.(3)4 Salic harzose-tonalose	
SrO	.04	.03			
Total	100.65	100.22			

1. Difficulty Creek latite. Difficulty Creek, Ouray quadrangle. George Steiger, analyst.
2. Cimarron Creek latite. Pinnacle Ridge, Ouray quadrangle. George Steiger, analyst.

The rock resembles some of the flows of the Alboroto rhyolite. It is a light- to dark-gray, fluidal, porphyritic rock with glistening biotite plates and carries many small, broken crystals of oligoclase, some of orthoclase, and considerable embayed quartz. The rock originally carried some crystals of hornblende but they have been completely resorbed and are now recognized only by their outline of magnetic grains and other residual products. The groundmass is a finely crystalline intergrowth of quartz and orthoclase. It should probably be classed as a rhyolite.

A hornblende-quartz latite forms the notable sheet in the east wall of the Amphitheater near Ouray in the Ouray quadrangle, reappears at the same level in the valley of Wildhorse Creek, and near the head of Cow Creek east of Wildhorse Peak. A few small bodies occur on either side of Cow Creek, and one north of North Fork of Henson Creek. The masses occur so nearly at one general level in the San Juan formation, and in one east-west zone, that they may be plausibly regarded as parts of one main intrusion with a few minor offshoots. The rock is dark gray or reddish and carries abundant phenocrysts of plagioclase, and some of hornblende, in part completely resorbed, in a quartz-orthoclase groundmass.

The quartz-biotite latite which forms the summit of Wildhorse Peak in the southeastern part of the Ouray quadrangle and two east-west ridges of jagged crestline to the northeast, has a different habit from the otherwise similar Difficulty Creek latite. It has a steeply northward-dipping fluidal banding. It cuts the San Juan tuff. The rock is reddish, pink, or dark gray. It is made up nearly half of well-formed phenocrysts, chief of which is andesine or labradorite, and biotite is rather abundant. The groundmass is rhyolitic and is mostly fine grained and in part glassy.

An augite-quartz latite of distinctive character forms an extensive sheet, cutting the San Juan tuff, in the southern part of the Ouray quadrangle, in the valley of Wildhorse Creek, and at the northwest base of Wildhorse Peak. It extends westward into Difficulty Creek and eastward into the head of Cow Creek. This rock is pink or gray and is rich in small phenocrysts of plagioclase and augite, with sporadic hornblende and biotite. Residual quartz phenocrysts surrounded by aureoles of oriented groundmass quartz are characteristic. The groundmass is mainly a patchy micropoikilitic intergrowth of quartz and orthoclase.

A dense altered rock, too fine textured and altered for accurate microscopic study but related to the quartz latites, was found in two small crosscutting bodies near Lake Lemore, a few miles north of Ouray in the Ouray quadrangle. Another somewhat larger body is present about a mile to the northeast, north of Dexter Creek. This quartz latite cuts the sediments.

MONTROSE QUADRANGLE

The small intrusive body near the creek bed a few miles north of Sneffels Peak in the south-central part of the Montrose quadrangle is a dense pale-greenish quartz latite porphyry that has about 30 percent of phenocrysts, about 2 mm across, in a rhyolitic groundmass. Andesine is the chief phenocryst; quartz and biotite, both much resorbed, are in small amount; and hornblende and augite were at one time present but the former was resorbed and the latter altered. Zircon, apatite, and magnetite are accessory, and chlorite, sericite, and calcite secondary.

SILVERTON QUADRANGLE

Many narrow dikes of a fine-grained porphyritic greenish-gray rock, now much altered, but apparently a quartz latite or rhyolite originally, cut the Picayune quartz latite in the Silverton quadrangle. They are so abundant within the Picayune area that they seemed related to the Picayune in time, but one of them was found to cut into the flow breccia of the Eureka rhyolite, and, at a point above the Bon Homme mine on the north spur of Handies Peak, one cuts through the intrusive quartz latite and the Burns quartz latite.

These rocks have many small, deeply embayed quartz crystals, and others of orthoclase and plagioclase, generally much broken, in a predominant groundmass that is cryptocrystalline and probably consists chiefly of quartz and orthoclase. Biotite was formerly present, but if other dark silicates were original constituents they have been replaced by epidote and chlorite.

A quartz latite, much like the Niagara Gulch latite of the Burns division of the Silverton volcanic series, cuts the Burns rock in the northeastern part of the Silverton quadrangle. A crosscutting mass of this rock in Hurricane Basin extends to the summits of the mountains on both sides, where it spreads out in sheet form in the upper tuffs of the Burns quartz latite. This rock differs from the Niagara Gulch latite (see p. 78) chiefly in the marked increase in the amount of biotite and in the somewhat more sodic character of the plagioclase, which is a soda-rich oligoclase. The rock contains some small phenocrysts of plagioclase, biotite, and hornblende. The felsitic gray or greenish-gray, predominant groundmass is cryptocrystalline and seldom exhibits the microlitic texture characteristic of the Niagara Gulch latite. The rock originally contained hornblende and in some places a little augite, but these minerals, as well as the greater part of the biotite, are entirely decomposed. The groundmass is probably rich in both orthoclase and quartz and the rock is a quartz latite.

The intrusive bodies on either side of Schafer basin, a few miles to the east of Hurricane basin, are nearly like the rock described in the preceding paragraph in composition but have a much more pronounced porphyritic texture with larger plagioclase phenocrysts and occasional orthoclase crystals an inch or more in diameter.

An intrusive mass about 2 miles long and 1 mile across caps the ridge between Bear Creek and the east fork of the Uncompahgre River, in the northern part of the Silverton quadrangle. It also is much like the Niagara Gulch latite of the Burns. It has a marked fluidal banding.

In addition to the larger bodies of intrusive quartz latites resembling the Burns quartz latites, there are many dikes and smaller bodies of such rock which have not been separated on the geologic maps. Several such dikes cut the San Juan tuff in the southwestern section of the Silverton quadrangle and many of them cut the Burns quartz latite in the mountains southeast of Silverton.

INTRUSIVE DARK QUARTZ LATITE AND BASALT

Dikes and other small bodies of dark quartz latitic rocks are abundant in many parts of the area, and they are generally so thickly clustered near the larger bodies as to leave little doubt of their close relation to the large intrusive masses. Such bodies have mostly been described in the preceding pages in connection with the descriptions of the intrusives of Conejos age, and later age. A few bodies of intrusive dark quartz latite are scattered here and there and show no obvious relation to any large intrusive mass. Not all of such bodies will be described, but only some of the larger or more conspicuous, and enough of the others to illustrate their character and occurrence. Bodies of this sort were found mainly in the San Cristobal, Ouray, Telluride, Silverton, and Uncompahgre quadrangles, chiefly because in much of these quadrangles many volcanic formations are present and erosion has removed much of them. Moreover, the geology was mapped in somewhat greater detail in these quadrangles.

Basalts and related pyroxene-quartz latite form a few small dikes in the southwestern part of the San Cristobal quadrangle and adjoining part of the Silverton quadrangle, and have rarely been found in other quadrangles. The small dike that cuts the Treasure Mountain rocks on the ridge near the head of the east fork of Ute Creek, 1 mile east of Lake Anna, in the west-central part of the San Cristobal quadrangle, is a fine even-grained black olivine andesite with a basaltic habit. It is made up mostly of oligoclase laths with about 30 percent of augite and some altered olivine and accessory magnetite and apatite. A dike of somewhat similar rock and resembling some of the flows of the latite and basalt of the Hinsdale formation, cuts the Conejos quartz latite in the west fork of the middle fork of Ute Creek, about 1.2 miles southwest of the hill having an altitude of 12,700 feet. The rock is dark ash gray, porous, and has a few inch-long crystals of glassy orthoclase, some resorbed quartz, and much augite and magnetite imbedded in a mass of oligoclase laths. The petrographic character and the freshness of these two dikes suggest a Hinsdale age but the evidence is very uncertain.

Another small dike at the head of the east fork of Ute Creek and about 0.2 miles south of Lake Anna cuts the pre-Cambrian rocks. It carries rather larger crystals of olivine and augite in a mass of plagioclase laths and glass. It is rich in dark minerals and is probably a basalt. It is fresh and may be of Hinsdale age.

In the western part of the San Cristobal quadrangle a dike of altered pyroxene andesite or basalt cuts the granite on the north side of the Rio Grande about 4 miles below the mouth of Bear Creek.

A dikelike body of olivine basalt lies between the granite and Piedra rocks about 2.5 miles south of Rio Grande Pyramid. Its relations to the adjoining rocks are uncertain. It is a black rock resembling in the hand specimen the tabular feldspar-pyroxene-quartz latite so common in the Potosi volcanic series. Phenocrysts make up about one-quarter of the rock. Those of labradorite somewhat exceed those of olivine, and biotite and magnetite are in smaller amount. The groundmass is made up of laths of sodic labradorite with some magnetite and grains of augite. The olivine is mostly altered to serpentine.

A few small dikes of pyroxene-quartz latite that resembles the tabular feldspar-pyroxene-quartz latite of the Potosi volcanic series but are much altered, cut the San Juan tuff and rocks of the Silverton volcanic series in a number of places. Several such dikes were found in the San Cristobal quadrangle, one north of the Rio Grande about 2 miles west of Lost Trail Creek, another north of the Rio Grande and near the western boundary of the quadrangle, and a third cuts the Picayune quartz latite in the extreme northwestern part of the quadrangle about 1.2 miles north of the mining camp of Whitecross.

Several small irregular intrusive bodies of pyroxene-quartz latites cut the pyroxene-quartz latite of the Silverton volcanic series in the western part of the San Cristobal quadrangle south of the Lake Fork of the Gunnison River in the basin at the head of Cataract Gulch and to the south. They may be of the same age as the rocks they intrude. They are dense black rocks much like the predominant rock of the pyroxene-quartz latite of the Silverton, and are made up about one-quarter of phenocrysts. Labradorite exceeds augite and hypersthene, and magnetite is in smaller amount. The groundmass is smoky and submicroscopic in texture.

One of the largest of the dark quartz latite intrusive bodies cuts the pre-Cambrian and Treasure Mountain rhyolite in the San Cristobal quadrangle, a few miles west of the center of the quadrangle, south of the Rio Grande, on both sides of Ute Creek, a few miles above its mouth. The body is about 1.5 miles long and 0.5 mile wide. The intrusive is everywhere considerably altered. The freshest rocks are gray to green or flesh colored. Megascopically they seem to be porphyritic, with a fine-grained groundmass, but the microscope shows that in spite of the large size of the body the groundmass is fine grained and the rock is a quartz latite porphyry. The rocks are made up about one-third of phenocrysts, many of them as long as 5 mm, chief of which is andesine; bright-green hornblende, much resorbed, is abundant; biotite is in moderate amount; and apatite, magnetite, and zircon are accessory. The groundmass is a fine spongelike intergrowth of orthoclase, albite, and quartz, and there may have been some pyroxene. In most of the specimens collected the hornblende is completely resorbed and only a skeleton of iron oxide remains. The rocks are all much altered and secondary quartz, calcite, a green faintly pleochroic, faintly birefracting chlorite, epidote, and sphene are present in variable amount.

Another large irregular or sheetlike quartz latite intrustion crops out as a number of isolated irregular bodies on the higher slopes of the basin at the head of the Lake Fork of the Gunnison River, mostly in the northeastern part of the Silverton quadrangle, but partly in the northwestern part of the San Cristobal quadrangle. The bodies are separated partly by faults and partly by erosion. They are distributed over an area about 4 miles by 3 miles, but much of the rock is so decomposed that it is impossible to determine whether it is all of one kind. So abundant are the tongues or inclusions of the Burns quartz latite tuffs and flows that it was impracticable with the poor exposures available to separate them all in detail and the intrusive body, as mapped, includes some of these bodies of Burns. The intrusive rock is much like the typical Picayune quartz latite but it is much younger in age, for it cuts the Burns quartz latite.

The rock is a green, porphyritic quartz latite, everywhere much altered. It is made up about one-third of phenocrysts of oligoclase or andesine as long as

5 mm, and some altered pyroxene in a very fine-grained groundmass that resembles that of a quartz latite and probably is made up of orthoclase, sodic plagioclase, and some quartz. The rock is much altered and secondary calcite, epidote, and chlorite are abundant.

All of the dikes mapped in the eastern part of the Telluride quadrangle and western zone of the Silverton quadrangle are of pyroxene-quartz latite, very similar in composition to the flows of the pyroxene-quartz latite of the Silverton volcanic series. In the Telluride quadrangle the small dikes in the vicinity of Sawpit, not shown on the map, belong to this group, as do the dikes around Lizard Head, and the one shown on the ridge south of Mount Wilson. In the Silverton quadrangle the many dikes in Richmond or Imogene basin, on Hayden Mountain, and elsewhere, belong here. None of these dikes cuts the Potosi rocks. A few inconspicuous dikes in Campbell Peak and Ruffner Mountain are hornblendic.

Intrusive andesite or quartz latite is widely distributed in the Ouray and Uncompahgre quadrangles. The largest body is the sheet cutting the Mancos shale in the basin of Nate Creek, a few miles north of the center of the Ouray quadrangle. Dikes are particularly abundant near Dike Ridge, east of the center of the quadrangle. Dikes are also present still farther east, near the boundary of the Ouray and Uncompahgre quadrangles, around the Difficulty Creek quartz latite mass, southeast of the center of the qudarangles, and other dikes are scattered through the area. These dikes cut the Alboroto and older rocks and many of them stand out as walls for miles, as seen in figure 30.

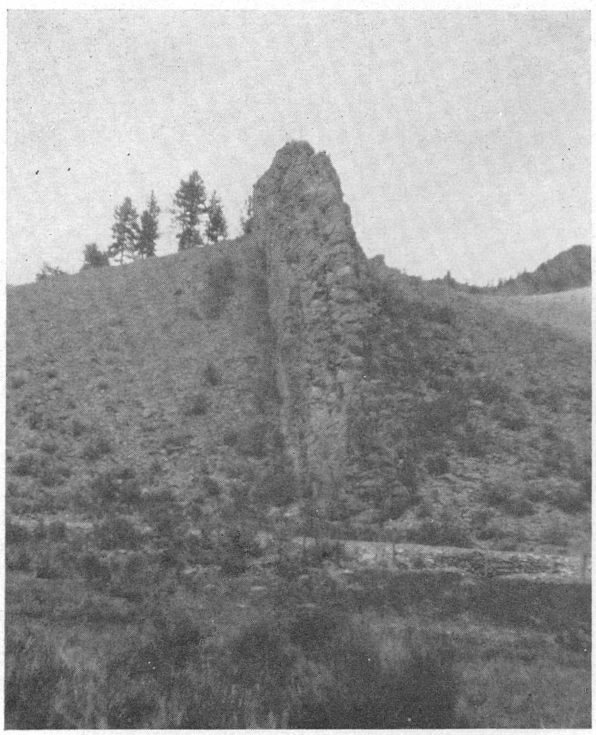

FIGURE 30.—A dike cutting Conejos quartz latite near Carnero Creek, Del Norte quadrangle.

These rocks are rich in dark minerals. The sheet in Nate Creek basin has brown hornblende with some biotite; most of the Dike Ridge rocks have hornblende and biotite, but at least one has chiefly augite; both augite and hypersthene are present in some of the Difficulty Creek dikes.

A small body of hornblende-quartz latite intrudes the Potosi rocks in the extreme northwestern corner of the Summitville quadrangle, near Turkey Creek, about one-quarter mile east of the western boundary of the quadrangle. It is a fine-grained rock containing, in percent, about 14 of hornblende phenocrysts, 8 of andesine, and 3 of magnetite, in a fine felted groundmass made up of andesine, a little orthoclase, and glass.

STOCKS, LACCOLITHS, AND RELATED INTRUSIVE BODIES, CHIEFLY IN THE WESTERN PART OF SAN JUAN MOUNTAINS

GENERAL CHARACTER

West of the San Cristobal and Uncompahgre quadrangles are a number of stocks, laccoliths, and related intrusive bodies that, for the most part, intrude the Mesozoic sediments and lie west of the western remnants of the effusive rocks; in part they also intrude the effusive rocks. Some of the stocks are several miles across and some of the laccoliths reach a thickness of 1,500 feet. The rocks of the stocks are nearly always granular; whereas those of the laccoliths and sheets are porphyritic. In composition they cover about the same range and are chiefly monzonites, diorites, and the corresponding porphyries, but include also granite, syenite, gabbro, and their porphyries.

A few of the stocks and laccoliths are rather uniform in character and are made up of a single rock type but many of the larger bodies differ greatly from place to place, in mineral composition, in chemical composition, and in texture. These variations in part have sharp contacts and are due to successive intrusions of different material, but in part the different rocks are gradational with indefinite and poorly defined contacts and they are probably due to the heterogeneity of a single magma. In most cases there is no apparent relation between the form of the intrusion nor the contacts with the intruded rock and the variations in the mass.

AGE

Several of these bodies intrude the San Juan tuff or the rocks of the Silverton volcanic series and a few intrude rocks as young as the Treasure Mountain rhyolite, but most of them are in areas where the volcanic rocks have been removed by erosion, and they are seen in contact only with Cretaceous and older rocks.

The age of the stocks and laccoliths of the La Plata and Rico Mountains cannot be determined with certainty, but the evidence available indicates that they are related to the volcanism that began in the middle Miocene. There was volcanism in the region during McDermott (Late Cretaceous) and Animas (Late Cretaceous and early Paleocene) times, and again beginning in the middle Miocene; but throughout most of the Eocene, all of the Oliogcene, and early Miocene no evidence of volcanism has been found. The intrusive rocks of the La Plata and Rico Mountains probably belong to one of the two periods of volcanism.

The intrusive bodies of the Rico and La Plata Mountains were emplaced after the main doming of the mountains but before the faulting (Cross, Spencer, and Purington, 1899, p. 10–11; Cross and Ransome, 1905, p. 8–9). The main doming of the mountains probably took place after the deposition of the Wasatch formation of Eocene age, and the intrusive rocks were emplaced before the development of the San Juan peneplain. They are therefore probably Miocene in age. For the most part there are few or no effusive rocks over these intrusive bodies, and the intruded rocks of the La Plata quadrangle are some miles from the nearest effusive rocks.

However, the western limit of the effusive rocks is erosional and the eastward-tilted volcanic plateau probably extended over the intrusive bodies in the Rico and La Plata Mountains, but the evidence is contradictory: There is no direct evidence that the stocks are the fillings of channels through which flows and tuffs were erupted; the absence of a succession of injections in most of the stocks, and the lack of many dikes of different kinds might be considered as evidence that these channels were not the vents for a complex succession of lava flows and eruptions. Yet, the fillings of most of the channels in other parts of the San Juan Mountains where eruptive rocks are abundant are nearly or just as simple as these in composition, even though most of them are surrounded by a complex of related dikes.

The relative ages of the different intrusive rocks in all parts of the San Juan Mountains are not clear, but throughout the mountains the stocks seem to be younger than the laccoliths and sheets.

GENERAL FORM OF THE INTRUSIVE BODIES AND THEIR RELATION TO THE INTRUDED ROCK

In the southwestern area, chiefly in the La Plata and Rico quadrangles, the intrusive bodies are thickly concentrated in two rudely circular areas. Outside these areas they are few. In the Rico group a relatively large stock occupies approximately the middle of the area, and the surrounding intrusive bodies are mostly laccoliths and sheets, but in the La Plata area there is no single, large stock in the middle, but smaller stocks of several kinds of rock are scattered through the area. Several of the laccoliths are larger than any of the stocks.

To the north and east, chiefly in the Telluride, Silverton, Ouray, and Montrose quadrangles, the intrusive bodies show no concentration around centers but seem to be scattered. Some of the large bodies throw out irregular arms and have a few neighboring sheets or dikes, but there is nothing that resembles the Rico and La Plata centers.

The tendency of the intrusive bodies to have the form of laccoliths and sheets, their irregular character and distribution, and their large size are probably due chiefly to the weak sediments which they intrude. In the Rico and La Plata areas, where the intruded rocks are chiefly thin sandstones and related rocks of the Dolores formation, the bodies are more abundant, thinner, and more sheetlike, but in the northern area and even in the western part of the La Plata area, where the intrusives cut the soft Mancos shale, the individual bodies are larger and thicker and there are many fewer sheets. In the sandstones the sheets probably branch out from a central stock in successive layers like the limbs of a fir tree, whereas in the soft shales the whole mass of intrusive accumulated in one great, thick lens.

There is no reason to believe that the larger number of intrusive centers in this western area is due to the character of the sediments underlying the volcanic rocks, but it is probably due to some deeper seated cause.

In much of the Needle Mountains, San Cristobal, Uncompahgre, and Cochetopa quadrangles, the volcanic rocks are underlain by pre-Cambrian rocks. In these areas intrusive rocks related to the volcanic effusions and cutting the pre-Cambrian rocks were found in many places. They are smaller and less closely spaced than the intrusive centers in the western area of sediments, and in form they are rather regular stocks.

In the area north of the San Juan volcanic rocks chiefly in the Cochetopa and Saguache quadrangles, the volcanic rocks are underlain by Cretaceous sedimentary rocks not very different from those of the western area, but in this area few intrusive bodies were found. The only large ones in this area are the large laccolith of microgranite that forms Tomichi Dome and the granite porphyry stock west of Needle Creek, both in the northern part of the Cochetopa quadrangle. The former intrudes the Mancos shale and it greatly resembles some of the laccoliths that intrude the Mancos shale in the Telluride quadrangle. Some miles farther north, in the Anthracite and Crested Butte quadrangles, somewhat similar laccoliths are exposed.

South of the volcanic rocks (flows) in the San Cristobal, Pagosa Springs, and Summitville quadrangles, the underlying rocks are chiefly Cretaceous and Tertiary sedimentary rocks. In this large area, few large intrusive bodies have been found. A medium-sized, irregular laccolith, with many associated sheets, intrudes the sediments of Jackson Mountain in the northwestern part of the Summitville quadrangle. This body has much similarity, through on a smaller scale, to the intrusive center of the Rico quadrangle. The intruded rocks are syenite porphyries and monzonite porphyries.

Some miles to the southeast, in the central part of the Summitville quadrangle, the Mancos shale is intruded by two rather large laccoliths without associated intrusives. Here the similarity to the laccoliths of the Telluride area is clear.

There is commonly great alteration around these intrusive bodies and much mineralization. Most of the mining camps of the western San Juan Mountains are situated near some of these bodies.

In places there is considerable contact metamorphism about the stocks. In the La Plata area, all through the strata of the Dolores formation near the intruded syenite there are abundant pyroxene, garnet, and probably idocrase; and small fractures in both the sedimentary and igneous rocks are commonly coated with scales of specular hematite. Some of the impure limestones have been transformed into granular masses of coarsely crystalline calcite, garnet, and pyroxene.

THE LA PLATA CENTER

A complex group of intrusive bodies lies chiefly in the northeastern part of the La Plata quadrangle but extend a short distance to the north into the Rico quadrangle and for some distance to the east into the Durango (Ignacio) quadrangle. The main part of these bodies is included in a roughly circular area about 11 miles in diameter, but some large bodies extend for several miles to the west. Within an area about 7 miles across, intrusive rock makes up a considerable part of the bedrock, but it becomes gradually less abundant to the north, west, and east. The individual bodies are mostly rather small and the largest outcrop is only a little more than a mile across. Some of the sills are several miles long. The complexity of the mass and the details of the distribution are shown on the geologic map (pl. 1), and in detail in the folios of the La Plata and Rico quadrangles.

Some of the intrusive bodies are stocks, dikes, and less regular crosscutting bodies, but many are sills or sheets which branch and coalesce in a complex manner. The largest stock forms Silver Mountain and is a little more than a mile across. These rocks intrude the sedimentary rocks as high stratigraphically as the Mancos shale but otherwise there is no direct evidence of their age. However, similar intrusive rocks some miles to the north in the Telluride quadrangle intrude the lower members of the San Juan tuff. That they probably belong to the Miocene volcanism has been shown in a preceding page. It seems highly probable that they were a source of some of the volcanic rock now largely or completely removed by erosion. The nearest outcrop of the effusive rocks of the San Juan Mountains is about 25 miles to the north-northeast in the Telluride quadrangle. The lack of a long succession of intrusive bodies of greatly varying character and the scarcity of dikes of varying composition seem to indicate that this center of eruption was not a vent over a long period of time, but it may have served as a vent during one of the volcanic periods of the San Juan area.

In the La Plata folio (Cross, Spencer, and Purington, 1899) the intrusive rocks of the La Plata center have been divided into five groups. The syenite, monzonite, and diorite occur chiefly as stocks, and the syenite porphyry and the granodiorite (diorite-monzonite) porphyry occur chiefly as sheets. The granodiorite porphyries were erupted first, the syenite porphyries second, and the diorite, monzonite, and syenite followed the porphyries. Their relative ages are not shown in the field, but judging from analogy with other areas the order was probably diorite, monzonite, and finally syenite. A few lamprophyric dikes are later than any of the larger intrusive bodies.

In the Durango quadrangle the sheets are more regular and of greater horizontal extent than those nearer the center of the La Plata quadrangle. In the Durango area most of the sheets are in the Dolores formation.

The dikes of Dike Ridge near the western border of the Durango quadrangle are of two kinds. The more notable are of diorite and connected with the small irregular stock of Lewis Peak. The other and older are of diorite porphyry.

THE RICO CENTER

The Rico center lies about 20 miles north of the La Plata center, in the northeastern part of the Rico quadrangle, and extends for a short distance to the east. The large monzonite stock near the town of Rico is probably the main vent filling and is roughly the geographic center of the intrusive bodies. The intrusive bodies are mostly rather small sheets, dikes, or less regular bodies and are confined to a roughly circular area about 5 miles across.

In the Telluride, Silverton, Ouray, and Montrose quadrangles, and in the Engineer Mountain quadrangle at a distance from the Rico center the intrusive bodies show no well-defined grouping around centers, but many bodies of different size are scattered through the area. They have the form of stocks, laccoliths, sheets, sills, and dikes and have about the same range in petrographic character as do the rocks of the Rico and La Plata centers.

GRANITE PORPHYRY

The granite porphyry of the Telluride quadrangle forms the body, bisected by Howard Fork, which is east of the center of the quadrangle above the town of Ophir. It is in some respects analogous to a laccolith, although somewhat irregular in its relations to the inclosing sediments.

Granite porphyry forms the laccolith in Deadwood Gulch in the southwestern part of the Silverton quadrangle, the long dike in Deerhorn Peak and Cunningham Gulch in the southern part of that quadrangle, and the body on the north side of Mill Creek in the western part of that quadrangle.

The Deadwood Gulch laccolith intrudes the Hermosa formation almost at its base. It is about a mile long and reaches a thickness of about 300 feet. The rock has both orthoclase and plagioclase phenocrysts, with biotite, in a gray dense groundmass consisting almost wholly of orthoclase and quartz. Some of the orthoclase crystals reach more than 1 centimeter in length.

A dike 15 to 20 feet wide, of similar rock, with a few small phenocrysts, cuts the schists of the canyon wall below the laccolith. It probably marks the channel through which the laccolithic magma ascended.

The body north of Mill Creek is more than half a mile in longest dimension. It cuts rocks of the Silverton volcanic series. It is much altered and now consists of quartz, orthoclase, and sericite. It contains conspicuous phenocrysts of quartz and orthoclase and may have had other minerals.

The rock of the body near Ophir in the Telluride quadrangle contains pink orthoclase crystals, some of which are half an inch long, and many smaller ones of white oligoclase, quartz, green hornblende, and brown mica, which lie in a groundmass consisting chiefly of orthoclase and quartz. The large orthoclase crystals especially characterize this rock.

RHYOLITE OF THE ENGINEER MOUNTAIN QUADRANGLE

The rock called quartz trachyte in the Engineer Mountain folio (Cross and Hole, 1910), which is now classed as a rhyolite, has been found only in that quadrangle where it is an intrusive rock that is comparable with the porphyries in all features of its occurrence. The large masses of Engineer and Graysill Mountains are thick sills or laccoliths intruded somewhat irregularly into the Cutler formation. Thin sills of the same rock penetrate the Rico formation and the upper part of the Hermosa formation in the valley of Cascade Creek. The uppermost bodies are in the Cretaceous Mancos shale or in the Dakota sandstone on Sliderock Ridge. The sill of Hermosa Ridge intrudes Dakota sandstone. The distribution is shown in the geologic map of the Engineer Mountain quadrangle (Cross and Hole, 1910).

This rhyolite is an ash-gray or light-pinkish rock exhibiting as a rule a few more or less tabular feldspar phenocrysts and minute black biotite flakes in an abundant groundmass. A trachytic habit is pronounced in the larger bodies. It is due to a rough parallelism of the feldspar tablets, a texture which is barely discernible in the groundmass. In the contact zones and in some other places fluidal texture is apparent. The rock of the smaller masses has generally the aspect of a felsite porphyry. Microscopic examination shows the rock to consist mainly of alkalic feldspars and a highly sodic plagioclase, with some quartz. These constituents make up more than 90 percent of the mass of all the different bodies. The other minerals observed are biotite, hornblende, augite, magnetite, apatite, and sphene. Of these, only the biotite is especially characteristic of the rock. The feldspar phenocrysts are mainly oligoclase or albite-oligoclase, though orthoclase and andesine occur less commonly. The groundmass feldspars are partly soda orthoclase and partly anorthoclase, which occur in prismoids or overlapping scales whose exact character is difficult to determine. Quartz occurs between these feldspars in minute, irregular interstitial particles as a cement. In some places the quartz is developed in anhedral grains more like that of the monzonite porphyry. Rarely, clusters of quartz grains make this mineral assume almost the role of a phenocryst, but such aggregates have not been anywhere recognized megascopically. The term "trachyte" was applied to this rock because its megascopic appearance and microscopic texture are, as a rule, typically trachytic—that is, the groundmass has a marked fluidal fabric and in many places the more or less tabular feldspar microlites are nearly parallel in position, causing a satiny sheen and making the texture megascopically distinct. Its mineral and chemical composition are those of a typical rhyolite. A specimen of fresh and typical rock from the southeast slope of Grayrock Peak has the chemical composition shown in table 27, column 13. The analysis confirms the microscopic determination. The absence of magnesia in the specimen analyzed indicates that the sample used for the analysis was poorer than most of the rock in biotite.

SYENITE PORPHYRY

The rocks mapped as syenite porphyry in the La Plata quadrangle and as monzonite porphyry in the

Rico quadrangle range from soda syenite porphyry to monzonite porphyry, and the monzonitic varieties are not very different from the monzonites belonging to the granodiorite porphyry. The syenite porphyries are younger than the granodiorite porphyries. The soda syenite porphyries make up only a small part of the intrusive rocks of the La Plata center, and the principal bodies are two small sills; the one on the southwest slope of Parrott Peak near the center of the La Plata quadrangle, the other on Jackson Ridge, a few miles to the north. A number of small sills and dikes are associated with the Jackson Ridge body, and a few small dikes of syenite porphyry were found on Helmet Peak, crossing Tirbircio Gulch near its mouth, in Deadwood Gulch, on Silver Mountain, in the southern part of the Rico quadrangle and the eastern part of the Durango (Ignacio) quadrangle. These smaller dikes are not shown on the geologic map. The syenite porphyries are everywhere so much decomposed that an accurate petrographic description is impossible. In all of them the phenocrysts are much subordinate to the groundmass. The phenocrysts are mainly plagioclase too much decomposed for accurate determination but probably rich in albite. Many have an oriented orthoclase rim. The dark minerals are scarce, and aegirine-augite is more common than hornblende; biotite is rare. The hornblende is generally olive green and exhibits resorption rims. Honey-yellow sphene is readily seen with the naked eye in some of the rock. The groundmass is trachytic and is composed of laminae or microlites, and in the narrower dikes the laminae are arranged so nearly parallel to the walls that a notable structure is produced. The groundmass is made up mostly of feldspar, which is so impregnated with pyritic dust as to obscure its character. It is probably an orthoclase rich in soda, or possibly in part anorthoclase. None of these rocks was fresh enough to warrant a chemical analysis but a determination of the alkalies on a specimen from Parrott Peak by W. F. Hillebrand gave 6.13 percent Na_2O and 4.68 percent K_2O.

Two long dikes of this rock (pyroxene monzonite porphyry) are mapped on the Rico quadrangle. One of these dikes crosses the Dolores River a short distance above the mouth of Bear Creek and has been traced for several miles up the valley of the latter stream. It appears to belong to the La Plata center of eruption. The other dike of similar rock crosses the head of Priest Gulch, and its course indicates that it is possibly connected with the Rico center. These rocks are much like the syenite porphyry of the La Plata area. They are much decomposed and the pyroxene is completely altered. The plagioclase phenocrysts are in about the same amount as the orthoclase of the groundmass.

Scattered through the Silverton quadrangle are several small bodies of syenite and quartz-poor granite prophyry that are characterized by their large orthoclase or anorthoclase crystals, some of which exceed an inch in length. In addition to the orthoclase phenocrysts, they contain some of soda-rich plagioclase, and usually both augite and biotite, which in some are abundant. The groundmass is dark, aphanitic, and predominates over the phenocrysts in most of the rocks. It consists mainly of scales or microlites of orthoclase, with a fine magnetite dust. There are some small particles of augite and biotite in the groundmass, together with apatite and sphene and a variable amount of quartz.

The small stock west of the center of the Silverton quadrangle, east of Summit, on the divide between Mineral and Red Mountain Creeks, has a predominant groundmass and only a few plagioclase crystals. The body a mile to the northeast, on Red Mountain No. 3, is similar. A partial analysis by George Steiger is shown in column 1.

	1	*2*
SiO_2	55. 54	60. 20
CaO	5. 38	3. 22
Na_2O	2. 72	3. 38
K_2O	5. 42	4. 71

The lime must be mostly in the pyroxene. Several small dikes of similar rock are present near the head of Red Mountain Creek.

Farther to the north, across Red Mountain Creek, at the head of Full Moon Gulch, there is a small stock that varies notably in texture, only a part of the rock possessing notably large orthoclase phenocrysts. The rock is much altered.

In the northeastern section of the Silverton quadrangle this prophyry appears in several bodies, one of the most notable being the cap rock of Engineer Mountain. This rock has many orthoclase crystals as long as 7 cm, and a number of quartz, plagioclase, biotite, and hornblende phenocrysts. The ferromagnesian minerals are resorbed to a large extent and are marked by ferritic material in small particles. The dark-gray groundmass is about equal to the phenocrysts in amount. A partial analysis by George Steiger is shown in column 2, above. This porphyry carries some inclusions of finely granular rock of nearly the same mineral composition, with less quartz and dark components. Fragments of this rock are found in fragmental beds at the base of the Potosi.

A small dike of this prophyry was observed on the ridge leading northwest from Engineer Mountain and another was found on the trail from California Gulch to Poughkeepsie Gulch, just east of the divide.

QUARTZ MONZONITE PORPHYRY

Quartz monzonite porphyry makes up most of the sheets north of the South Fork of Mineral Creek in the southwestern part of the Silverton quadrangle. It also forms the body a few miles to the north, north of the Middle Fork of Middle Creek and the body at the head of Bear Creek in the northern part of that quadrangle.

In the Silverton quadrangle, the porphyry between the South Fork and the main stem of Mineral Creek is a group of sheetlike bodies with irregular connections; it is mapped for several miles along the strike. It intrudes the San Juan tuff and the underlying sedimentary rocks. These porphyries are much like the quartz monzonite of the adjacent stock and they are probably closely related. However, no gradation from one to the other was found and in Snowslide Gulch at 9,900 feet altitude the finely granular monzonite was found sharply cutting the porphyry. In general the rock of these intrusive masses is a marked prophyry exhibiting many distinct feldspar crystals embedded in a felsitic, gray, even-grained groundmass. In some places there are large orthoclase phenocrysts, reaching an inch or more in length, as in the sheets in the Dolores formation, but commonly both feldspars are much smaller. Biotite and quartz occur variably as phneocrysts. The rock ranges in composition from granite porphyry almost free from plagioclase, as in the bed of the main fork near the northern limit of the porphyry, to quartz monzonite porphyry, such as the more common facies along the South Fork. In these latter rocks plagioclase is the more abundant in phenocrysts, although pinkish orthoclase tablets are usually present. The groundmass consists of quartz and orthoclase in all the rocks. The rock along the southern border of the valley of the South Fork commonly has a coarser grained groundmass than the rock farther north. The granite porphyry forming a ledge on the south bank of the South Fork, a little below the stream from the amphitheater under Bear Mountain, contains tufts of dark tourmaline resembling, to the naked eye, phenocrysts of a dark silicate.

The irregular intrusive body to the north, and north of Middle Fork, is a similar quartz monzonite porphyry. The biotite is completely decomposed and chlorite and epidote are abundant.

The intrusive body at the head of Bear Creek in the northern part of the quadrangle is less than a mile across. Related dikes are present to the north in the Ouray quadrangle. This rock intrudes the tuffs of the Treasure Mountain rhyolite of the Potosi volcanic series. The rock contains many labradorite phenocrysts, a few of which reach a centimeter across, much less glassy orthoclase of irregular size, but some of them as much as 2 cm long, embayed quartz crystals, and abundant fresh biotite tablets. Diopside and green hornblende are subordinate constituents, and both are much decomposed. Magnetite and particles of other dark minerals, such as chlorite, render the groundmass gray or greenish.

The rock of the dikes in Porphyry basin and on each side of the Middle Fork of Cimarron Creek contains phenocrysts of andesite or labradorite, and much hornblende and biotite in a matrix of quartz and orthoclase. Augite is locally present. An analysis of this rock is given in table 27, column 9.

The small bodies on the divide between Bear and Cow Creeks have unusually large phenocrysts, those of glassy orthoclase reaching 2 cm across. Biotite is conspicuous in this rock and augite was present but is now almost completely altered.

HORNBLENDIC QUARTZ MONZONITE PORPHYRY

By far the greater part of the smaller intrusive bodies about the monzonite stock of the Rico area are made up of hornblendic quartz monzonite porphyry which shows little variation in mineralogical or chemical composition but considerable variety in texture. The rock of the larger sheets and of many of the dikes is a distinct porphyry, generally light gray, with an even balance between phenocrysts and groundmass. Labradorite is the chief phenocryst, small crystals of hornblende are always present, and a few small, resorbed quartz crystals are present in a few places. The groundmass consists of orthoclase and quartz.

The plagioclase phenocrysts may be of nearly uniform size or they may differ greatly in size. In the sheet crossing Dolores Valley at Montelores, for example, the plagioclase phenocrysts are uniformly 2 to 3 mm in diameter. More commonly there are many crystals of 5 mm or more, but only a few reach a size of 1 cm in diameter.

THE CALICO PEAK PORPHYRY

The small stock, less than half a mile across, forming Calico Peak which is in the western part of the area of intrusive rocks of the Rico quadrangle, is an altered monzonite porphyry. Many dikes of a similar porphyry cut the sediments and the hornblende-quartz monzonite porphyry in the vicinity of Calico Peak. A single small sill of this rock was found between beds of the Dakota sandstone about 3 miles south-southwest of Calico Peak. The rock is everywhere much altered but the freshest is a porphyry characterized by large orthoclase phenocrysts in considerable abundance, many of them more than 1 inch long. Many smaller crystals of plagioclase, and augite, hornblende, or biotite, and rarely quartz are present. The groundmass has much plagioclase and little or no quartz. The rock is not much different in composition from the monzonite stock, but it is not fresh enough for accurate determination or for a chemical analysis. The stock of Calico Peak is mostly altered to an aggregate of alunite, kaolinite, and quartz, and some of the dikes in Johnny Bull Gulch are also much altered.

GRANODIORITE PORPHYRY

In the La Plata quadrangle granodiorite porphyry (diorite-monzonite of Cross) is the oldest of the intrusive rocks and forms by far the greatest part of the intrusive bodies that are exposed. It is commonly intruded as sheets or laccoliths but the bodies are locally crosscutting. The large mass of Silver Mountain is in places laccolithic but in others it is distinctly crosscutting. In many places the bodies form a complex ganglion. Most of the bodies of the central area are connected by irregular, narrow bodies or connecting sheets or dikelike bodies. The general character of the outcrops is shown on the geologic map of the La Plata quadrangle (Cross, Spencer, and Purington, 1899) as diorite-monzonite porphyry. The rocks are distinctly porphyritic and exhibit many crystals of white plagioclase and black hornblende embedded in a gray, dense-looking groundmass. Some folia of biotite are found, and a few rounded phenocrysts of quartz are present. The plagioclase is commonly much more abundant than the orthoclase, but in some rock the two feldspars are in about equal amount and in others orthoclase is in small amount. The plagioclase has the composition of andesine-labradorite and is found chiefly in the phenocrysts. In some rocks these crystals are of a uniform size, but in others they grade down to groundmass size. Hornblende is by far the chief dark mineral and in most of the rocks it is the only dark mineral. It occurs in crystals of various sizes and in somewhat various amounts. Biotite is in small amount. Augite is present in a few of the rocks and in a rock from the ridge between Shaw and Boren Gulches it is the only ferromagnesian mineral. The dark minerals are commonly in much less amount than the plagioclase, but they differ greatly in amount through they are always subordinate to the feldspar. The groundmass is made up of a granular mixture of orthoclase and quartz. The accessory minerals are magnetite, sphene, and apatite. The chemical composition of the rocks can be judged from an analysis of a typical specimen collected from a dike on the western slope of Deadwood Gulch and given in table 27, column 6.

GRANODIORITE AND MONZONITE PORPHYRY, FLAT TOP TYPE

The granodiorite porphyry (diorite of Cross) forms the large laccolith of Flat Top in the southwestern part of the Telluride quadrangle and adjoining part of the Engineer Mountain quadrangle, the two laccoliths of Gray Head and Whipple Mountain in the northwestern part of the Telluride and adjoining part of the Montrose quadrangle, and a number of small sheets, mostly near the three laccoliths. The Flat Top laccolith is the largest, having a maximum exposed thickness of about 1,500 feet, and the present remnant has a diameter of a little more than 3 miles. It must have lensed out rapidly, for it is not present across East Dolores River only a mile or so from the main mass, except to the northeast where it is represented by a thin sheet. This body is intruded between the Dakota sandstone and the Mancos shale. The Gray Head and Whipple Mountain laccoliths are somewhat smaller and less regular than the Flat Top body, and they are in the Mancos shale. The dipping sheetlike body near Dallas Divide, in the southwestern part of the Montrose quadrangle, is similar. The granodiorite porphyry contains phenocrysts or distinct crystals of andesine or labradorite, hornblende, biotite, and occasionally augite, in a gray groundmass of orthoclase, plagioclase, and quartz. The crystals are never very large. In the laccolithic masses the groundmass is so coarse and the phenocrysts are so small that the porphyritic structure is rather subordinate, but appears distinctly when thin sections of the rocks are studied under the microscope. In the thin adjacent sheets the groundmass is very fine grained, and hence contrasts with the phenocrysts embedded in it.

A specimen from the southeast slope of Last Dollar Mountain in the northern part of the Gray Head body is a light-gray porphyry that contains about 40 percent of phenocrysts about 5 mm in length, of which white oligoclase-andesine makes up about 25 percent of the rock, brown-green hornblende about 10, altered pyroxene 5, and sphene 2. Magnetite and apatite are accessory, and the groundmass is made up of fine-grained orthoclase and plagioclase. The rock is intermediate between a monzonite and a diorite. The middle sill a few miles northwest of Last Dollar Mountain is similar but has 10-mm phenocrysts, no augite phenocrysts, but has biotite and a little augite in the groundmass. These rocks are considerably altered; sericite, chloritic minerals, and calcite have developed.

The body of the Dallas Divide sheet is a light greenish-gray rock with about 20 percent of phenocrysts about 1 mm across. Andesine is the chief phenocryst, altered augite is nearly as abundant, and biotite is in small amount. The groundmass is chiefly sodic plagioclase, with some biotite and a little quartz. The feldspars are filled with secondary sericite and clinozoisite, and the rocks contain some chlorite, calcite, and epidote.

The small stocklike body in the cirque about a mile east of Mears Peak carries a few percent of plagioclase crystals, as much as 5 mm across, in a matrix made up mostly of stout plagioclase crystals 0.5 mm across, with about one-third interstitial quartz and orthoclase and a little augite and biotite. The large plagioclase crystals have large cores of andesine that are clouded with inclusions of the groundmass, a narrow irregular layer outside of this of clear labradorite, and a narrow outer layer of clear andesine grading to more sodic plagioclase. The plagioclase crystals of the groundmass have centers of calcic andesine and borders of oligoclase.

The mineralogic composition of these rocks does not vary greatly. Quartz is not abundant in any of them and is nearly lacking in the rock of Flat Top. Orthoclase is always so subordinate that the rocks are near the diorites.

ANDESITE

Capping Diamond Hill, east of Big Bear Creek, in the northwestern part of the Telluride quadrangle, is a thin sheet of a much-decomposed rock. In certain parts of it are many small cavities containing perfectly clear crystals of quartz, whence the local name of the hill. The rock is so highly impregnated with calcite and chlorite, and all its constituents are so much altered that its original character is uncertain, although it is designated andesite on the map of the quadrangle. It may be an intrusive sheet of porphyry, but, if so, it has undergone alteration in a manner not elsewhere observed among the intrusive sheets.

The irregular intrusive body cutting the sediments near the center of the Montrose quadrangle was originally a porphyry, but specimens collected from along the automobile road are completely altered to a mass of quartz and kaolin with calcite. The rock originally had some pyroxene phenocrysts.

On both sides of the ridge a few miles west of Last Dollar Mountain, in the west-central part of the Montrose quadrangle, the San Juan tuff is cut by many small dikes of andesite. Such dikes are abundant in the San Juan as far east as Sneffles Peak. The typical rock is red-brown and carries about 30 percent of phenocrysts of andesine about 1 mm across, and a few percent each of brown-green hornblende and augite in a finely crystalline groundmass made up chiefly of felted plagioclase laths. The rock may well be a quartz latite, rather than an andesite.

INCLUSIONS IN THE PORPHYRY

In the La Plata quadrangle many of the porphyry sheets and dikes are characterized by many inclusions of apparently foreign rocks, these inclusions differing greatly in abundance. Some sheets are spotted uniformly with inclusions. The small sheet in the northwestern branch of Cumberland basin contains the largest number of inclusions. These range from granitic rocks, or rocks of granitic composition and gneissic structure, to dark granular amphibole masses, or to schistose rocks consisting largely of hornblende. Similar inclusions are found also in the more mafic porphyries, and there is no observable relation between the size of the porphyry body and the size or number of inclusions which may be contained in it. Thus, some of the narrow lamprophyric dikes of Snowstorm Peak contain a great many inclusions of granite, or of amphibole rocks of the same types which occurs most commonly in the monzonite porphyries.

Considering the great number of fissures traversing the sedimentary formation, it is somewhat remarkable that fragments of these formations are so rare in the intrusive bodies. Apparently the granitic rocks, at least, represent the composition of the pre-Paleozoic floor upon which the sedimentary section of this region rests. From what is known of the pre-Cambrian complex in the Animas Valley, it must be considered that the amphibole inclusions may also be derived from this fundamental formation. At the same time inclusions rich in hornblende are so characteristic of dioritic masses almost everywhere that it is natural to infer that the fragments and the rock containing them are genetically related. Until samples of a large number of these inclusions have been collected and carefully studied, it will be impossible to affirm or deny such a relationship for the inclusions of the La Plata Mountains. The amphibolic fragments differ considerably in appearance. They are sometimes rather dense and schistose, but in certain dikes and sheets on the southwest face of Hesperus Peak a number of fragments were observed which, although several inches in diameter, consisted mainly of a single hornblende individual, as shown by the continuous cleavage. Pyroxenic masses occur in some of the sheets containing abundant inclusions, but they are nowhere so abundant as those characterized by hornblende.

Both railroad cuttings at the Ophir Loop in the Telluride quadrangle show the diorite-monzonite at that locality to be characterized by abundant inclusions of many varieties of rocks. The inclusions are most common at the level of the lower railroad cutting, where for nearly half a mile the diorite-porphyry is so crowded with them that they make up more than half the mass. This line of the railroad is within about 50 feet of the lower contact of the igneous mass, which is, however, not exposed. Apparently this is about the point at which the sheetlike arm extending westward toward Mount Wilson leaves the main stock of the Ophir Needles. No reason is apparent for the concentration here of such an enormous number of inclusions. The enclosing rock is a fine-grained hornblendic diorite-porphyry, showing distinct fluidal structure winding about the inclusions.

The inclusions of the Ophir Loop exposures present great variety in composition and structure and show such a complete gradation, even in the comparatively small part of the mass here visible, that the question of their origin becomes of great importance. The striking fact is that many of the inclusions are practically coarse-grained diorite, and that gradation seems to exist toward masses which are nearly pure segregations of each of the constituent minerals of the diorite. Further, nearly every mineral aggregation is found in both granular and in banded forms. The study of the great number of transition forms present makes it seem highly probable that all these rocks are most intimately associated in origin.

No detailed study of these inclusions has been made but the inclusions studied are: (1) a rock made up of labradorite with a little orthoclase; (2) aplitic granite porphyry; (3) gneissoid granite; (4) banded granitic gneiss; (5) mica granite gneiss; (6) various gneisses; (7) hornblende diorite; (8) diorite rich in magnetite; (9) banded rocks rich in augite, hornblende, or biotite; and (10) massive and schistose rocks made up mostly of hornblende. Brief descriptions of these rocks have been published in the Telluride folio (Cross and Purington, 1899, p. 7).

AUGITE SYENITE

Augite syenite was found only in the La Plata quadrangle near the town of La Plata where it forms two large irregular stocks. The largest mass, to the northwest of La Plata, is nearly 2 miles long and nearly ½ mile wide at its widest part. The body about 1 mile southeast of La Plata is a little more than 1 mile in length and in most parts much less than ½ mile across. Somewhat similar rocks but having a porphyritic texture occur as small sills, dikes, or less regular bodies in the La Plata intrusive complex. The quartz syenite porphyries, small bodies of which are scattered through the Silverton quadrangle, are also similar. These porphyritic rocks have already been described.

The syenite of the La Plata area is everywhere much altered. It is made up mostly of feldspar, with some augite that is mostly altered, and in places a little biotite and hornblende. Quartz is present in small amount. The accessories are like those in the monzonite, with sphene relatively abundant and magnetite in unusually small amount.

The feldspar is mostly orthoclase and microperthite in various proportions, but there is probably sodic plagioclase in some of the rocks. In general, anorthoclase tends to a development in large grains and rudely automorphic crystals surrounded by microperthite and orthoclase zones. The latter varieties are usually more abundant and, where a transition to porphyritic structure appears, they form the granular groundmass for anorthoclase phenocrysts. Aplitic facies in which quartz, orthoclase, and microperthite constitute nearly the whole mass were found in dikelike bodies confined to the stocks.

A chemical analysis of the freshest even-grained syenite, collected from the ridge between Tirbircio and Schurman Gulches, is shown in table 27, column 11. The rock was somewhat altered as is shown by the CO_2 present.

QUARTZ MONZONITE

Quartz monzonite forms the large stock in the southwestern part of the Silverton quadrangle and the great stock in the Telluride and Engineer Mountain quadrangles. Somewhat similar monzonites with less quartz form the central stock of the Rico center and one of the largest stocks of the La Plata center.

In the Silverton quadrangle quartz monzonite forms the great stock in the southwestern part, the two wide dikes some miles to the east and northeast of the stock and southeast of the Animas River, a small mapped dike in Edith Gulch, which is a little to the north of the dikes last named, and a few smaller dikes. The great stock has a length of about 5 miles and a width of 2 miles. As shown on the map, its boundaries are irregular in detail, there being many short apophyses and sharp angles at several places. The southern boundary is well exposed, but on the north the contact is rarely visible. The main stock cuts the San Juan tuff and the Eureka rhyolite and the dikes cut the Burns quartz latite. The chemical analyses show that the quartz monzonite of Sultan Mountain is much like the Niagara Gulch latite of the Burns quartz latite but it is nevertheless believed that the stock is of much later date than any of the lavas of similar composition now visible in the Silverton quadrangle.

In the southeastern part of the Telluride quadrangle and adjoining parts of the Engineer Mountain quadrangle, a large stock of quartz monzonite forms the high mountains, including Grizzly Peak. This stock is about 5 miles long and has a medium width of more than 3 miles. It sends some apophyses into the adjoining rocks but, on the whole, has no closely associated intrusive rocks. It intrudes the Jurassic and Cretaceous sedimentary rocks, the San Juan tuff, and the Treasure Mountain rhyolite.

The Telluride stock is made up prevailingly of a single rock type, a pinkish-gray, rather fine-grained quartz monzonite. The chief minerals, in order of abundance, are pinkish orthoclase, white andesine-labradorite, quartz, and the ferromagnesian minerals, of which biotite and augite are the most common, and hypersthene and pale green hornblende are less common. Magnetite and apatite are in small amount, and some allanite is present. The quartz and othoclase are partly in separate grains and partly intergrown. In places large orthoclase crystals include the other constituents. The augite, hornblende, and biotite are commonly intergrown. Rarely does the proportion of quartz and orthoclase increase enough to result in a granite facies or decrease enough to result in a dioritic rock. Local aplitic bands were observed.

The quartz monzonite of the Silverton area is much like that of the Telluride area. Augite is the most common dark constituent, and biotite and green hornblende are in various amounts. The variation to a granite was observed but not that to a diorite. Locally, the ferromagnesian minerals increase in amount, generally with accompanying fine grain, and a much darker and nearly aphanitic rock results. Many of these darker rocks are near the borders of the mass, but they are not everywhere present in the contact zone. There is in some places a gradation from the darker monzonite into the common facies, and in other places sharp contacts were seen. Complementary to the facies richer in darker silicates are small dikes of aplitic granite or quartz monzonite, almost free from augite or other ferromagnesian minerals. These dikes range in grain from very fine to coarse, and an irregular porphyritic texture is also commonly developed. The quartz monzonite becomes porphyritic in many places, resembling the intrusive porphyry sheets of the Mineral Creek area, as has been stated in describing these rocks.

About 4 miles east of the main stock there is a wide dike of monzonitic rock that is difficult to outline accurately because of the extensive alteration in this area and because of the cover. The rock of this dike ranges from an aplitic granite to monzonite porphyry, but the latter is greatly predominant. The texture also ranges from granular to porphyritic, the latter being the more common. The common rock of this mass is porphyritic, with a strong contrast between the phenocrysts and the groundmass, and it resembles the rock of the laccoliths. Usually the feldspar phenocrysts are of plagioclase, with finer phenocrysts of orthoclase, quartz, biotite, and in some specimens augite. Chlorite, calcite, epidote, sericite, and other secondary minerals are abundant.

The dike a few miles to the north of that described in the preceding paragraph is about 3 miles long and ½ mile wide. The rock is a quartz monzonite much like that of the Sultan Mountain stock in composition. Locally it ranges to a granite or aplite. It is commonly granular in texture or nearly so but has decidedly porphyritic facies in places. The smaller dikes are of about the same kind of rock.

Two analyses of the quartz monzonite are available, one rock from each of the large stocks. The analysis of a specimen from the Telluride stock from near the lake northwest of San Miguel Peak is given in table 27, column 12. That of a specimen from the Silverton stock collected at the eastern base of Sultan Mountain on the wagon road is shown in table 27, column 10. It is probable that the visible mass of the Silverton stock is somewhat richer in ferromagnesian minerals than the sample analyzed.

GRANODIORITE OF LAKE FORK OF GUNNISON RIVER

A body of granodiorite that tends toward a diorite crops out in the north-central part of the San Cristobal quadrangle on both sides of Lake Fork about 4 miles above Lake San Cristobal. It is about 2 miles long and more than ½ mile wide. It is separated from the granite on the south by a fault, and its relations to the Picayune andesites on the north and east are uncertain but it probably intrudes them. It was at first believed to be pre-Cambrian but its close similarity in form and petrographic character to other Tertiary intrusive rocks makes its position in the Tertiary seem highly probable.

The rock ranges from a quartz-bearing monzonite to a quartz diorite and the average is a granodiorite rather low in content of quartz. It tends to be porphyritic and has crystals of labradorite about 2 mm across in various amounts.

The composition of the average rock, in percent, is about:

Andesine-laboradorite	45
Orthoclase	22
Quartz	10
Pyroxene	15
Biotite	5
Magnetite	3
Total	100

Apatite and zircon are accessory, and epidote, chlorite, uralite, sericite, and calcite are secondary. The pyroxene is mostly augite, but some hypersthene, now largely altered, was present. The orthoclase poikilitically encloses the plagioclase and other minerals. The quartz is mostly intergrown with the orthoclase. The biotite and augite are in irregular grains, usually collected in nests, as if they had replaced an older mineral. The proportion of both quartz and orthoclase varies considerably, and parts of the rock are diorite, others are monzonite. Near the contact with the granite the rock has a fine-grained groundmass.

MONZONITE

Monzonite containing little quartz forms the large central stock which is west of the town of Rico in the Rico quadrangle. It is partly obscured by Quaternary cover but seems to be about 2 miles long and 1 mile across. A similar rock forms the long irregular stock of the La Plata quadrangle, within which are situated Mounts Moss and Babcock and Spiller Peaks. This stock is nearly 3 miles long and in most places is less than ½ mile across.

The rock of the La Plata area is medium fine and even grained, gray, often with a pinkish tone due to the abundant pink orthoclase. As a rule, orthoclase and andesine-labradorite are in about equal amount. The dark minerals are in somewhat less amount than in the diorite and are chiefly green augite, with various amounts of biotite and hornblende. The usual accessory minerals are present, with sphene relatively abundant and magnetite uncommonly subordinate. A small amount of interstitial quartz is of common occurrence. Locally the orthoclase is present in large individuals enclosing poikilitically the other minerals. In places the plagioclase has cores of calcic labradorite.

Locally, just south of Banded Mountain and again at the head of West Mancos, the proportion of andesine-labradorite increases in amount and the rock grades into the diorites. In these places the rock tends to be porphyritic, hornblende is more abundant than augite, and quartz is more abundant than in the common monzonite.

At several places aplitic veins or dikes were observed in the monzonite. These are almost wholly composed of orthoclase, microperthite, and quartz, with small amounts of hornblende or biotite. The rock which seems complementary to these was seen only on the slope east from Banded Mountain. Here some narrow dikes of a dark-green heavy rock were observed. The material of this dark dike is principally green augite and magnetite, with grains of orthoclase and plagioclase quite subordinate.

Occasionally the narrow veins traversing the monzonite have irregular cavities lined with crystals of alkalic feldspar and quartz, with other minerals, such as epidote, magnetite, hematite (specular iron), and apatite, in variable abundance. Apatite was found in one of these drusy veins in beautiful transparent green prisms, reaching nearly 0.5 inch in length and 0.2 inch across. Several such crystals were grouped on a surface 3 inches square.

The common monzonite of the Rico stock probably has a little more quartz than does that of the La Plata stock but they are otherwise similar. A sample of the very fresh monzonite from Babcock Peak, in the La Plata stock has the composition given in table 27, column 5.

DIORITE-MONZONITE

Three large irregular stocks with irregular sheetlike connections present in the western half of the Telluride quadrangle range in composition from granite to gabbro, but the average, as well as the commonest rock, is intermediate between a diorite and a monzonite. The largest body extends to the west beyond the boundary of the quadrangle. The largest of these forms Mount Wilson and Wilson and Gladstone Peaks, and is about 3 miles across. An irregular sheetlike connection extends to the east and connects with a somewhat smaller stock of Ophir Needles about 4 miles distant. A third elongated body lies south of and between the other two, and forms Black Fall. This body is nearly 4 miles long and less than 1 mile wide. These stocks intrude the Telluride conglomerate, and the San Juan tuff. They are not in contact with rocks younger than the San Juan tuff.

In the Mount Wilson stock the prevailing rock is diorite, tending toward monzonite, but quartz-bearing monzonite and granite occur locally. In the mass of Yellow Mountain and Ophir Needles a quartz-monzonite is conspicuous and probably exceeds the dioritic facies in amount. But the most mafic modification of this body is found in the Ophir Needles, especially in the upper part of the mountain. Here gabbro rich in the dark silicates occurs, either in the fine-grained dikelike bodies or in more irregular areas grading into other facies less abruptly. The texture of these rocks varies, but by far the greater part is moderately fine and even grained. Coarsely granular development is local. The rock in the stock is generally granular, and that in the sheetlike connections and the Black Face body is more or less distinctly porphyritic. The groundmass in both these rocks is much smaller in amount than the phenocrysts, but occasionally a few large conspicuous orthoclase crystals develop. Such a growth of orthoclase may also occur locally, even in the large stock of the Mount Wilson group.

The transitions observed between the many structural and mineralogical varieties occurring in these rock masses are usually so gradual that the several facies cannot be regarded as of distinctly different periods of intrusion, the later ones cutting the older in dike form. It seems more likely that the magma injected into these stocks was not homogeneous and that much of the existing variation in the rocks is due to original variation in the magma. There is no apparent regular relation of changes in composition to form of the masses, suggesting a differentiation within the magma after intrusion. An exception to this statement may be presented in the Black Face mass, where orthoclase and quartz are commonly found in veinlike or irregular areas, often intergrown as graphic granite, but yet showing zones of transition into diorite-monzonite of subordinate porphyritic structure. These seem to be due to segregations of residual magma rich in potash and silica, and are not limited to any particular parts of the exposed rock.

The chief minerals are andesine-labradorite, orthoclase, and augite. Quartz is present in some of the rocks, hypersthene is usually present, and biotite is common, but primary hornblende is present only in the strongly dioritic rocks. Uralite after pyroxene is present in many of the altered rocks. The plagioclase is andesine in some of the monzonites, and a calcic labradorite in some of the gabbros. The porphyritic structure is nowhere comparable to that so characteristic of the laccolithic bodies. A megapoikilitic texture is noticeable in the diorite-monzonite, especially in zones between monzonite and gabbro, as in Ophir Needles.

Several analyses would be required to represent these rock masses, and it is believed that the microscopic study shows the variations of the mass. However, a specimen from the dark granodiorite of Ophir Needles was analyzed with the results shown in table 27, column 3. The analyzed rock is dark gray, fine and even grained. Labradorite is the chief constituent, and hypersthene, augite, and biotite, in order of abundance, are present in considerable amount. Orthoclase and quartz are present in very subordinate amounts.

DIORITE

Diorite forms three irregular stocklike masses with associated dikes in the La Plata quadrangle. The largest mass lies west of the La Plata River, near its head, and extends from Diorite Peak to Basin Gulch. It underlies an area of nearly a square mile. Small stocks occur in Lewis Peak, less than 2 miles east of the main stock, and near the end of the ridge between Bedrock and Madden Gulches about 3 miles southwest of the main stock. Some irregular dikelike arms are sent out by all the stocks, and they are especially conspicuous around the Lewis Peak stock.

The diorites are dark-gray rocks with a granular texture and are made up chiefly of andesine-labradorite, with various amounts of orthoclase, a little quartz, augite, some hornblende and biotite, and accessory magnetite, sphene, and apatite. The augite is more abundant than hornblende or biotite except locally where hornblende is in great amount. Sphene is more abundant than usual in such rocks and magnetite less so. A chemical analysis was made of a specimen of this rock somewhat richer in orthoclase than usual; it is given in table 27, column 4. The specimen was collected from the southeastern part of the Diorite Peak mass from the little canyon of the La Plata River, north of the mouth of Basin Creek. The alkalies of this rock are not much different from those of the monzonite of Babcock Peak, but the magnesia and iron contents are decidedly higher. There is considerably more orthoclase in the rock than can be accounted for from the potash content; this indicates a considerable amount of the albite molecule in the orthoclase.

GRANODIORITES AND ASSOCIATED ROCKS OF THE STONY MOUNTAIN STOCK

An irregular stock of dark rocks several miles long and in places more than half a mile across cuts the Treasure Mountain rhyolites, the San Juan tuffs, and the older rocks in the northeastern part of Telluride quadrangle and adjoining parts of the Montrose quadrangle. It forms Stony Mountain and Mount Sneffels. Several smaller bodies of similar rock, mostly less than half a mile in longest outcrop, are present to the south on the ridge north of Ophir, and to the east of U. S. Grant Peak. Others were found to the west of the main stock.

Dings (1941) has mapped in detail and described the part of the Stony Mountain stock that is near Stony Mountain and the following description is taken from his paper. The stock is made up of four distinct intrusions. The oldest rock is a fine-grained diorite (or granodiorite) in which most of the grains are less than 0.7 mm in length. An analysis and mode of a typical specimen are given in table 27, column 7. The granodiorite grades locally into a hornblende monzonite (granodiorite) facies that has conspicuous hornblende blades as long as 4 mm. An analysis and mode of this rock are given in table 27, column 8.

The second injection, which makes up the greater part of the stock, is a gabbro or granogabbro which varies greatly in composition and texture and grades into a quartz monzonite facies. The most abundant minerals of the gabbro are labradorite (An_{53}) and augite. Quartz ranges from a trace to 9 percent, orthoclase from 4 to 27 percent. Hypersthene varies greatly in amount and is completely absent in some specimens. Biotite is commonly present. An analysis of the gabbro from the summit of Stony Mountain is given in table 27, column 2.

In Mount Sneffels, gabbroic phases are predominant, partly coarse grained, but with large amounts of a fine-grained, almost aphanitic type seen in the Ophir Needles area, of which an analysis has been given already. The commonest rock from Mount Sneffles is a coarse gray gabbro with 5- to 20-mm tablets of labradorite, biotite, and pyroxene. The feldspar is sodic labradorite and makes up about half the rock. Augite and hypersthene each makes up about 10 percent of the rock and biotite about 5 percent. There are some magnetite and apatite, and as much as 20 percent of interstitial orthoclase and 10 percent of quartz. For the most part the quartz and orthoclase together do not constitute more than 20 percent of the rocks. The rock might be called a granogabbro.

A dark gabbro-porphyry occurring in dikes is conspicuous on the southwest side of Mount Sneffels and at the pass on the south. This porphyry is characterized by thin plates of plagioclase, in part as calcic as bytownite, in more or less marked parallel arrangement. They seem dark themselves because of the great number of dusty inclusions they carry and because they lie in a dark aphanitic groundmass of the other minerals common in these rocks. An analysis of a specimen from the pass south of Mount Sneffels is shown in table 27, column 1.

The granogabbro grades into and in places is intruded by a medium- to fine-grained granodiorite (quartz monzonite facies) whose average mode in percent, is:

Quartz	18	Sericite, calcite, epidote, apatite, pyrite, biotite, hornblende, sphene, hematite, and leucoxene	14
Orthoclase	22		
Andesine	36		
Magnetite	3		
Chlorite	7	Total	100

The third intrusion of the stock is a fine-grained, dark greenish-black, rather uniform monzonite (Stony Mount diorite). Most of the grains are about 0.3 mm across. The mode of a typical specimen, in percent, is:

Quartz	4	Augite	15
Orthoclase	15	Magnetite	6
Plagioclase:		Chlorite	7
(An_{42})	41	Apatite, calcite, sericite, hematite, and pyrite	4
(An_{40})	4		
Biotite	3	Total	99

The biotite and augite are in various amounts, and where one is in large amount the other is in small amount.

A rhyolite with phenocrysts of quartz and orthoclase 2 mm across is believed by Dings (1941, p. 714) to be the last member of the stock. The phenocrysts of quartz and orthoclase together make up about 16 percent of the rock, and orthoclase is somewhat in excess of quartz. Biotite and hornblende make up about 5 percent of the rock. The groundmass is made up of anhedral grains of quartz and orthoclase.

Many dikes of andesite (quartz latite) related to the early diorite radiate from the stock. These rocks lack conspicuous phenocrysts and are made up of andesine, augite, and some hornblende and minor amounts of quartz and orthoclase. Later dikes of andesite and "dacite" are not radiating.

CHEMICAL ANALYSES

Eleven analyses of relatively fresh rock from the stocks and laccoliths of the western area have been made in the Geological Survey laboratory and have been published in the La Plata (Cross, Spencer, and Purington, 1899), Telluride (Cross and Purington, 1899), Silverton (Cross, Howe, and Ransome, 1901), Engineer Mountain (Cross and Hole, 1910), and Ouray (Cross, Howe, and Irving, 1907) folios. They are quoted in table 27, where they are arranged in order, from the gabbroic to the granitic. These analyses show the range of these large intrusive bodies. Two other analyses made for Dings are also listed.

INTRUSIVE ROCKS NEAR DURANGO

Many dikes, sills, and less regular intrusive bodies cut the pre-Cretaceous rocks in the northwestern quarter of the Ignacio quadrangle. Most of these are made up of gray to reddish-brown quartz latites that grade into dacites. The rocks carry abundant phenocrysts, which in most of the rocks are less than 3 mm long but in a few are much larger. Plagioclase, ranging from andesine to labradorite, constitutes the chief phenocrysts; green, zoned hornblende is in less amount, augite is common, and biotite is rare. The groundmass is made up of laths of sodic plagioclase in a fine-textured matrix of quartz and alkalic feldspar. In some rocks the matrix makes up much of the groundmass; in others it is in small amount. The rocks are nearly all much altered to carbonate, chlorite, epidote, and sericite. In a few of the rocks the groundmass is more coarsely crystalline and the rocks are granodiorite or microdiorites.

A few of the dikes are made up of a dark andesite or diabase that is made up of plagioclase (andesine or labradorite), much pyroxene, some hornblende, and rare biotite and olivine. They are much altered and contain uralitic, hornblende, serpentine, chlorite, epidote, sericite, and carbonate.

LAMPROPHYRES AND RELATED ROCKS

Dark intrusive rocks related to the lamprophyres have been found at many places. They intrude the sediments on the south and west of the volcanic mass, but they are nearly or quite absent in the main volcanic mass. Such rocks are fairly abundant in the Pagosa Springs quadrangle, and they are present in the Summitville, La Plata, Rico, Telluride, and Montrose quadrangles, and in the northwestern part of the Uncompahgre quadrangle. They are no doubt present in other quadrangles but have not been observed.

These lamprophyric rocks occur chiefly as dikes but also as sheets or less regular bodies. Most of the bodies are thin but one sheet in the La Plata quadrangle is about 150 feet thick. The width of most of the dikes is measured in feet rather than in tens of feet and some of them, notably some in the Pagosa Springs quadrangle, are several miles in length. They are

TABLE 27.—*Analyses and norms of stocks and laccoliths of the western part of the San Juan Mountains*

	1	*2*	*3*	*4*[1]	*5*[2]	*6*	*7*	*8*[3]	*9*[4]	*10*	*11*	*12*[2]	*13*
ANALYSES													
SiO_2	47.32	52.05	56.93	55.53	57.42	60.44	60.15	60.23	61.36	63.91	59.79	65.70	70.73
Al_2O_3	16.71	17.96	17.03	16.78	18.48	16.65	18.03	15.56	16.36	17.07	17.25	15.31	14.22
Fe_2O_3	6.92	4.09	3.67	4.06	3.74	2.31	2.73	3.20	3.59	4.39	3.60	2.54	1.59
FeO	5.94	6.33	4.54	3.35	2.10	3.09	3.27	3.08	1.45	1.51	1.59	1.62	.59
MgO	5.69	5.03	3.30	3.00	1.71	2.18	2.18	2.73	1.75	.81	1.24	1.62	none
CaO	8.51	8.64	6.51	6.96	6.84	4.22	5.78	4.21	3.59	4.47	3.77	2.56	.72
Na_2O	2.70	2.99	3.19	4.31	4.52	5.18	3.53	4.43	4.04	3.48	5.04	3.62	4.96
K_2O	2.02	1.61	2.58	3.57	3.71	2.71	2.76	3.42	3.64	3.74	5.05	4.62	5.57
H_2O+	.24	.97	.13	.09	.08	.36	.09	.10	1.34	-----	.19	.17	1.16
H_2O-	1.04		.45	.55	.28	1.07	.53	1.10	1.56	.33	.39	.42	.32
TiO_2	1.50	-----	1.03	.95	.86	.60	.65	.79	.51	-----	.67	.72	.34
P_2O_5	.96	.31	.44	.47	.36	.29	-----	.34	.36	.21	.35	.33	.03
MnO	.08	.43	.10	.16	.09	.13	-----	.14	.07	-----	.20	-----	.11
CO_2	-----	-----	-----	.09	-----	.48	.19	.44	.64	-----	.72	-----	-----
ZrO_2	-----	-----	-----	-----	-----	-----	-----	.00	-----	-----	-----	-----	.04
SO_3	.19	-----	-----	-----	-----	-----	-----	-----	-----	-----	.04	.12	-----
BaO	.07	-----	.08	.13	.15	.12	-----	.11	.12	-----	.14	.12	.01
SrO	.06	-----	.06	.11	.08	.11	-----	-----	.12	-----	.11	.03	-----
Total	99.95	100.41	100.04	100.17	100.45	99.96	99.89	99.92	100.51	99.92	100.34	99.53	100.29
NORMS													
Q	0.84	1.50	10.80	1.50	3.96	7.98	13.26	9.84	16.98	19.74	3.30	19.92	19.56
or	11.68	9.45	15.01	21.13	21.68	16.12	16.68	20.02	21.13	21.68	30.58	27.24	33.36
ab	22.53	25.15	26.20	36.16	37.73	44.02	29.34	37.20	34.06	29.34	42.44	30.39	41.92
an	27.80	30.86	25.02	15.85	19.46	13.90	25.02	12.79	10.84	20.29	9.45	11.12	.00
C	-----	-----	-----	-----	-----	-----	-----	-----	1.84	-----	-----	.31	1.51
di	6.16	8.44	3.59	12.79	9.07	4.05	3.16	5.31	-----	-----	5.83	-----	-----
hy	14.04	17.43	10.27	3.03	.10	6.58	6.34	6.12	4.40	2.00	.40	4.10	-----
mt	9.98	6.03	5.34	5.80	4.64	3.25	3.94	4.64	3.48	4.87	3.94	3.02	.93
il	2.89	-----	1.98	1.82	1.67	1.22	1.22	1.52	.91	-----	1.22	1.37	.61
hm	-----	-----	-----	-----	.48	-----	-----	-----	1.28	1.12	.91	.32	.96
ap	2.35	.67	1.01	1.01	1.01	.67	-----	.67	1.01	.67	.67	.67	-----
SYMBOLS													
	II(III).5. 3(4).''4 Andose	(II''.5.3 (4).4 Hessose	II.4(5).3. (3)4 Tonalose	II.5.2(3). (3)4 Akerose	''II.5.(2) 3.(3)4 Andose	''II.(4)5. 2.4 Akerose	(I)II.4(5) 3.(3)4 Tonalose	''II.(4)5. 2.''4 Akerose	I(II).4.2 (3).4 Lassenose	I''.4''3.3'' Amiatose	(I)II.5.2. 3(4) Monzonose	I''.4.2.3 Toscanose	I.4.1.''3 Liparose

[1] FeS_2, 0.04; V_2O_3, 0.02. [2] Cl, 0.03. [3] Cl, 0.03; F, 0.00; S, 0.01; Cr_2O_3, 0.00. [4] Leucite, 1.50.

1. Gabbro porphyry. From near Mount Sneffels, Telluride, Colo. Analyzed by H. N. Stokes. Described on p. 231.

2. Gabbro. From summit of Stony Mountain in the Telluride quadrangle. Analyzed by L. G. Eakins. Described on p. 230.

3. Granodiorite. From Ophir Needles, Telluride quadrangle. Analyzed by H. N. Stokes. Described on p. 230.

4. Monzonite facies of diorite mass of Diorite Peak, La Plata quadrangle. From the little canyon of La Plata River not far above the mouth of Basin Creek. Analyzed by W. F. Hillebrand. Described on p. 230. Contains trace of Li_2O.

5. Monzonite. From Babcock Peak, La Plata quadrangle. Analyzed by H. N. Stokes. Described on p. 229.

6. Granodiorite porphyry. From Deadwood Gulch, La Plata quadrangle. Analyzed by W. F. Hillebrand. Described on p. 226.

7. Granodiorite (Governor diorite of Dings). From the northeastern part of the Telluride quadrangle, 290 ft due west of the Summit of Stony Mountain at an altitude of 12,510 ft. Mode by Dings (1941, p. 704), in percent by weight, is:

Quartz	8	Magnetite	4
Orthoclase	15	Chlorite	7
An_{42}	41	Biotite, hypersthene, apatite, calcite, hematite, sphene, and sericite	5
An_{57} (intratelluric)	10		
Augite	9		

Analyzed by R. B. Ellestad.

8. Hornblende granodiorite (monzonite). From Stony Mountain in the northeastern part of the Telluride quadrangle. The mode by Dings, in percent by weight, is:

Quartz	8	Augite	4
Orthoclase	19	Magnetite	6
An_{44}	31	Chlorite, epidote, calcite, pyrite, sphene, apatite, hematite, and sericite	13
An_{57} (intratelluric)	8		
Hornblende	11		

Analyzed by R. B. Ellestad.

9. Granodiorite porphyry. From the large dike in the east border of the Ouray quadrangle on the east side of Porphyry basin. Analyzed by George Steiger. Described on p. 224.

10. Granodiorite. From the east base of Sultan Mountain in the Silverton quadrangle. Analyzed by L. G. Eakins. Described on p. 228.

11. Syenite. Ridge between Tirbircio and Schurman Gulches in the La Plata quadrangle. Analyzed by H. N. Stokes. Described on p. 227.

12. Quartz monzonite. From near San Miguel Peak, Telluride quadrangle. Analyzed by H. N. Stokes. Described on p. 228.

13. Rhyolite (quartz trachyte of Engineer Mountain folio) from southeast slope of Grayrock Peak. Analyzed by George Steiger. Described on p. 222.

rather hard rocks, as compared to the intruded sediments, and they stand up as conspicuous dark-colored walls in the soft light-colored sediments.

These rocks intrude chiefly the sediments but in the western area they cut some of the intrusive rocks. Their age is uncertain but they seem to be late in the volcanic sequence.

The rocks are chiefly vogesites but minette, kersantite, and camptonite are represented. The lamprophyres are commonly much altered and in some places too much so for accurate description or classification. Some diabase dikes that intrude the sediments are believed to be related bodies and will be described with the lamprophyres.

VOGESITE

The vogesites carry large amounts of hornblende and pyroxene and have orthoclase as the predominant feldspar. They have various amounts of plagioclase and some have olivine and other minerals. Most of the rocks are much altered, the pyroxene to chlorite, the feldspar to sericite, analcime, calcite, and other minerals, and the olivine altered to serpentine or iddingsite.

The thin sheet in the north part of the La Plata quadrangle about 2 miles east of the center line of the quadrangle, on the North Fork of West Mancos River, north of Hesperus Peak, intrudes above the Dakota sandstone. It is a greenish-gray aphanitic rock, with many small biotite leaves megascopically present and showing parallel streaks of the feldspathic constituents. The microscope shows augite and orthoclase to be the chief constituents, the former predominating. There is no hornblende in this rock, and the biotite is present only in the leaves which are visible to the naked eye. The augite appears in small rounded pale-green prisms. This rock is considerably altered, chlorite, calcite, and muscovite being the chief secondary products.

The dike in the eastern part of the La Plata quadrangle, a few miles north of the center of the quadrangle, on the divide at the head of the La Plata River, is a hornblende-augite vogesite, richer in dark minerals than the rock described in the preceding paragraph. Hornblende decidedly predominates over augite. It is, indeed, the only conspicuous megascopic constituent, occurring in prisms as long as 1 cm, most of them rather slender, but a few short and stout. Augite is also quantitatively important in the rock, as shown by the microscope, but occurs uniformly in small grains. The matrix for the larger hornblende prisms is composed mainly of feldspar, with minute grains of augite and magnetite. Feldspar is chiefly orthoclase, in irregular grains. Decomposition products of augite, chlorite, calcite, and other minerals greatly obscure the feldspars. There is a little magnetite in the rock, and some of it is titaniferous.

The sheet or thin laccolith occurring in the Morrison formation in one of the knolls on Indian Trail Ridge, near the northeast corner of the La Plata quadrangle as shown by the map, is the largest mass of lamprophyric character in the mapped area. It lies in a nearly horizontal position, conformable with the strata inclosing it, and has a thickness of about 150 feet. The mass is not homogeneous in character, but exhibits important differences in composition in zones parallel to the upper and lower contacts respectively. The inner part of this body is a fine-grained, evenly granular, grayish-green rock in which the feldspars nearly equal the mafic minerals in amount. These two classes of minerals are so distinct in the rock that the role of each is clear. Of the dark minerals, augite is far more important than hornblende, which occurs only in a few short prisms. Biotite was also formerly present in subordinate quantity. There is little magnetite present in the rock. The feldspars are so much sericitized and obscured that their character is not certain. Some soda-lime feldspar is undoubtedly present, but orthoclase is greatly predominant. The transitions toward the contact zone are gradual. The feldspar decreases and both augite and hornblende increase in amount, but variably. Hornblende tends to appear in larger crystals of prismatic form, and augite ranges down to minute grains that mingle with the feldspar to form a groundmass which is much more distinct as seen under the microscope than it appears to the naked eye. Chlorite, epidote, and calcite as decomposition products obscure the feldspars and make the contact facies seem much more mafic than it actually is. As the amount of augite and hornblende increases, the feldspar becomes more and more predominantly orthoclase. In the contact zone, several feet wide, feldspar has become much subordinate and its composition is uncertain, for it is greatly obscured by the finer particles of augite and the alteration products of the dark silicates. A part of the rock is characterized by hornblende phenocrysts, which may exceed 1 cm in length, but the adjoining zones are likely to be almost entirely augitic rocks. The rocks of this mass seem more nearly related to vogesite than to any other recognized types of lamprophyres.

On the ridge north of the mass just described is a small irregular dike of a dark porphyry crowded with hornblende and augite phenocrysts, the former being much more conspicuous. As situated, this dike seems to represent the channel through which the magma of the adjacent laccolith ascended, but the rock is much richer in dark silicates than is the laccolith. Its feldsspars are confined to the subordinate groundmass, and a plagioclase in microlites is more abundant than the presumable orthoclase of the irregular intersitial grains. The decomposition of augite and feldspar is considerable. An analysis is shown in table 28, column 2. The rock is a camptonite.

In the Rico quadrangle, and especially in the Rico Mountains, several small dikes of olivine-bearing augite vogesite are known; no other mafic dikes were found elsewhere. Most of the rocks are much altered. The ferromagnesian silicates greatly predominate, common greenish augite being the most constant and abundant, with variable amounts of olivine, reddish-brown biotite, brown hornblende, and some magnetite. The feldspar is chiefly orthoclase. Analcime may be present in some of the rocks. The habit of the freshest rocks is decidedly basaltic, through the abundance and form of development of augite and olivine.

In the west-central part of the Telluride quadrangle, on the ridge running east from Gladstone Peak and in Bilk basin are narrow dikes of an ash-gray rock with black semivitreous contact zones. It resembles the vogesites of the Rico quadrangle and cuts the Cretaceous sedimentary rocks and the diorite-monzonite stock. The centers of the larger dikes contain much augite and dark-brown hornblende, with some olivine, in a colorless base, which consists largely of delicate interlocking, branching crystals of orthoclase. The contact zones are dark glass, with augite crystals alone.

MINETTE

Minettes, rocks related to the vogesites but carrying abundant biotite, were found only in the Telluride quadrangle. In the ridge running southeast from Gladstone Peak, in the Mount Wilson group, in the west-central part of the Telluride quadrangle, are two narrow dikes of a dense blackish rock cutting Cretaceous strata. These contain abundant augite and brown biotite, with a few decomposed olivine crystals, in a smoky-brown glassy base with cryptocrystalline spots. It is believed that this glassy base must be rich in potash and that the rock belongs with the minettes on account of the prevailing character of similar dikes in adjacent districts.

CAMPTONITE

Camptonites, lamprophyres made up chiefly of augite or hornblende and plagioclase, or all three, are common in the area. Most of those studied are augite-hornblende camptonites, but the sheet in the northwestern part of the Uncompahgre quadrangle is an olivine-augite camptonite and that in the southwestern part of the San Cristobal quadrangle is an augite camptonite. Many of the dikes in the Engineer Mountain quadrangle have augite as the predominant dark mineral.

A few miles southwest of the center of the Telluride quadrangle the small lenticular plug to which Black Face owes its name is composed of a dense black rock in which the naked eye can detect only a few minute particles of feldspar and dark grains of augite. The microscope shows much augite, brown hornblende, plagioclase in microlites, orthoclase in irregular grains, and a dust of magnetite. An analysis of this rock is shown in table 28, column 1.

Near the east border of the La Plata quadrangle, about 4 miles north of the center line of the quadrangle, near the summit of Snowstorm Peak there are several small dikes of a strongly marked porphyry with many hornblende phenocrysts in a dark or greenish aphanitic groundmass. The hornblende crystals range from 1 cm in length downward, but most of them are megascopically visible. Augite is also present, but in much smaller grains than hornblende. Possibly it is nearly equal to the hornblende in amount. The rock is megascopically similar to the vogesite described from the Indian Trail Ridge, but its feldspar is chiefly a soda-lime species in microlitic form with subordinate granular orthoclase. An analysis of the freshest rock obtained—from the dike just south of the summit—is shown in table 28, column 3.

Rocks similar to this type occur on the southewest slope of Lewis Peak and in the saddle between Snowstorm and Cumberland Peaks. Certain zones of the laccolithic mass of Indian Trail Ridge are also of this type.

In the Engineer Mountain quadrangle camptonite dikes occur principally on the eastern slope of the Rico Mountains and in the valley of the North Fork of Hermosa Creek. The dikes crossing the broad ridge southeast of Grayrock Peak also belong to this group. The rocks in some dikes of this group contain a small amount of orthoclase and quartz and in certain rocks the orthoclase becomes sufficiently abundant to place them almost in a monzonite group of lamprophyres.

A large sheet of camptonite cuts the Mancos shale near the western boundary of the Uncompahgre quadrangle and about 6 miles south of the north boundary of the quadrangle, mostly in the drainage area of Stumpy Creek, a branch of Little Cimarron Creek. The body was followed for about 2 miles. The rock is greenish gray and has the appearance of a 2-mm-grained gabbro. It is made up about one-third of phenocrysts as much as 5 mm across, of which labradorite is the chief, augite is nearly as abundant, and olivine, altered to serpentine or iddingsite, is in considerable amount. The groundmass is made up mostly of andesine, with considerable augite and some biotite and magnetite in a matrix of an unknown mineral that is now altered to analcime, and natrolite. The biotite is late. There is much secondary fibrous or platy serpentine or chlorite.

A lamprophyre collected from a dike in the southwestern part of the Summitville quadrangle, near the old village of Rio Blanco, is a dark greenish-gray, even-granular, millimeter-grained augite camptonite. The microscope shows the following approximate composition, in weight percent:

Albite-oligoclase	61
Augite in slender needles	23
Biotite	9
Magnetite	5
Apatite	2
Total	100

The rock is much altered, the augite is almost completely changed to chlorite and calcite, and the plagioclase is greatly altered to secondary calcite.

AUGITE KERSANTITE

Augite kersantite, a lamprophyre made up chiefly of augite, biotite, and plagioclase, was found only in the La Plata and Engineer Mountain quadrangles. In the La Plata quadrqangle it forms the sheet above the Dakota sandstone, about 6 miles east-southeast of the northwest corner of the quadrangle, and a small dike on the west side of Deadwood Gulch, a few miles east of the center of the quadrangle. In the Engineer Mountain quadrangle a single dike of an altered biotite-rich lamprophyre, probably a kersantite, was found in a small western tributary that enters Cascade Creek at an altitude of 9,850 feet.

MONCHIQUITE

In the northwestern part of the Engineer Mountain quadrangle, clearly clustered about and in places cutting the intrusive rhyolite of the area, are many small dikes of monchiquite, many of them less than a foot across. They are dense black rocks which show some crystals of augite in a strongly predominant vitreous groundmass.

Microscopic study shows that augite and olivine are abundant in a groundmass of brown hornblende, augite, and occasional brown biotite, with magnetite and apatite, all of which are embedded in an isotropic base, brownish as a rule, but in some slides colorless. The augite is pale green and in all these rocks it is more abundant than hornblende or biotite. Olivine occurs only in phenocrysts and is more extensively altered than the other minerals.

A small dike of monchiquite cuts the pre-Cambrian Vallecito conglomerate in the southwestern part of the San Cristobal quadrangle in Cave basin. The rock is dense, black, and aphanitic. It contains about 50 percent of crystals about 0.5 mm long, of which augite with hourglass structure is the chief, olivine is abundant, brown hornblende less so, and magnetite is in small amount. The groundmass is isotropic and is probably analcime. In patches the groundmass contains abundant spraylike skeleton crystals of alkalic feldspar, and in these parts augite is abundant and hornblende lacking. There are some secondary natrolite and calcite.

The small dike mapped north of the sheet of Dallas Divide in the southwestern part of the Montrose quadrangle is made of a dense, dark-gray rock showing a few crystals of augite. The microscope shows about 10 percent of augite in crystals of variable size, about the same amount of brown hornblende in small needles, and a few altered labradorite grains in an isotropic matrix which has an index of refraction averaging 1.506. There are streaks of birefracting material. The rock is probably related to the monchiquites though the isotropic groundmass is probably not analcime.

DIABASE

Diabase dikes, related to the lamprophyres, cut the sediments and older rocks in a number of places. Such rocks have been described from the Ouray quadrangle and they are abundant in the Summitville quadrangle and adjoining areas. The diabases are dense, dark rocks, characterized by bytownite, augite, olivine, and magnetite, with secondary hornblende, chlorite, serpentine, calcite, and other minerals. An especially conspicuous dike cuts the sediments near Dyke, about 10 miles west-southwest of Pagosa Springs, near the center of the Pagosa Springs quadrangle. Another dike was found in Turkey Creek about 600 feet above the main road of the San Juan River in the northwestern part of the Summitville quadrangle. This dike cuts the Mancos shales and was followed for more than a mile. The rock is half-millimeter-grained and carries about 50 percent of labradorite, about 30 percent augite, and smaller amounts of altered olivine and magnetite. The augite is much altered to calcite.

The dikes that cut the Cretaceous and Tertiary sedimentary rocks in the southern part of the Summitville and Pagosa Springs quadrangles were mapped by Mr. J. H. Gardner, to whom we are indebted for the mapping and the specimens. Most of the dikes are from 1 to 6 feet wide; the most easterly dike in the basin of Montezuma Creek is 24 feet wide. These dikes are composed of fine-grained rocks with much secondary carbonate, serpentine or a chloritic mineral, and some analcime or other zeolites. They range in composition from andesite to diabase. The dike 1¼ miles west of the junction of Montezuma Creek and the San Juan River contains some altered olivine, some augite, abundant prisms of pale-brown hornblende, in part growing about the augite, late biotite, and abundant tablets of plagioclase. The plagioclase averages andesine in composition and has broad outer zones of oligoclase. Magnetite grains and apatite needles are abundant. There is some interstitial analcime. The most westerly dike of those north of Montezuma Creek is similar, but is more altered.

The western of the two dikes south of Kearns and east of the railroad to Pagosa Springs is similar, but has no olivine, has a feldspar with the composition of labradorite and has a little interstitial quartz and orthoclase. The prominent dike, 10 feet across, that makes the long mapped ridge at the head of Coyote Creek and north of the road between Chama and Pagosa Springs, in the Summitville quadrangle, is similar to the rock just described.

A specimen from a small dike cutting the Pictured Cliffs sandstone about 2½ miles south of Durango, collected by J. B. Reeside, Jr., is a black vitreous basalt. It contains some small crystals of olivine and augite which are embedded in a glass that contains some trichites.

A small dike cutting the volcanic rocks near the north boundary and center line of the Uncompahgre quadrangle, a little north of the saddle at the head of Middle Creek, is made up of a diabase with abundant 3-mm phenocrysts. The rock has about the following composition:

Bytownite	20
Augite	27
Magnetite	7
Some altered olivine	---
Groundmass	46
Total	100+

The groundmass was probably originally glassy but is now made up largely of secondary serpentine.

A diabase dike is exposed for a quarter of a mile in the west-central part of the Ouray quadrangle, east of Uncompahgre River, nearly opposite the mouth of Coal Creek, where it intrudes the Mesozoic rocks. It is from 6 to 8 feet wide. It is fine grained, has an aplitic texture, and is made up of labradorite, augite, and magnetite.

A dike of plagioclase basalt, probably related to the diabase dikes, cuts the sediments in the northwestern part of the Telluride quadrangle near the mouth of Big Bear Creek. It has abundant fresh olivine crystals and a holocrystalline groundmass consisting of augite, olivine, labradorite, magnetite, and a little biotite.

CHEMICAL COMPOSITION

The lamprophyres are mostly too greatly altered for satisfactory chemical study. However, three analyses have been made and are listed in table 28. One of these is on a relatively fresh rock but the other two are much altered as is shown by the high content of carbon dioxide and water.

TABLE 28.—*Chemical analyses of lamprophyres*

	1	*2*	*3*
SiO_2	55. 65	43. 98	47. 25
TiO_2	. 90	1. 18	1. 22
Al_2O_3	17. 04	13. 30	15. 14
Fe_2O_3	2. 81	3. 67	5. 05
FeO	5. 17	6. 92	4. 95
MnO	. 20	. 22	. 17
MgO	3. 42	7. 03	6. 87
CaO	6. 82	10. 66	9. 98
Na_2O	3. 27	2. 15	2. 39
K_2O	2. 29	1. 64	2. 60
H_2O-	. 46	. 42	. 40
H_2O+	1. 49	1. 52	2. 12
CO_2	------	6. 46	1. 87
P_2O_5	. 37	. 32	. 25
NiO	------	. 03	. 02
FeS_2	. 00	. 54	-------
BaO	. 08	. 06	. 08
SrO	. 05	. 05	. 05
V_2O_3	------	------	. 05
Total	100. 02	100. 15	100. 46

NORM OF NO. 1

Q	7. 92	an	25. 02	mt	3. 94
or	13. 34	di	4. 76	il	1. 67
ab	27. 77	hy	12. 48	ap	1. 01

Symbol II.(4)5.3."4 Tonalose-andose

1. Camptonite. From Black Face, Telluride quadrangle. Analyzed by W. F. Hillebrand. Described on p. 234.
2. Camptonite. From Indian Trail Ridge, La Plata quadrangle. Analyzed by W. F. Hillebrand. Described on p. 233.
3. Camptonite. From just south of the summit of Snowstorm Peak, La Plata quadrangle. Analyzed by W. F. Hillebrand. Described on p. 234.

STRUCTURE

GENERAL STATEMENT

Geological sections across the area are shown in plate 2.

Little of the complicated structural history of the pre-Cambrian has been determined. There were several periods of metamorphism and batholithic intrusion. In the Needle Mountains mass most of the contacts between units are either faults or intrusive contacts. A single thrust fault has been mapped, and it is younger than the Twilight and older than the Eolus granite. The many normal faults are post-Eolus and they tend to be tangential to the Needle Mountains mass.

The Paleozoic section has no angular unconformity. In most of the area the Triassic overlies the Paleozoic with apparent conformity, but near Ouray there is an angular unconformity at the base of the Triassic.

Northwest of the San Juan region this unconformity is widespread and in places the Triassic directly overlies the pre-Cambrian. Likewise, in the western part of the area the Jurassic overlies the Triassic with apparent conformity but in the southern part of the area, in and near the drainage of the Piedra River, the Triassic and older rocks were greatly deformed and peneplaned before the deposition of the Jurassic. A less pronounced unconformity is near Ouray and north and east of Ouray where the Jurassic directly overlies the pre-Cambrian.

After the deposition of most of the Cretaceous rocks and before the Oligocene (?) there took place one of the great deformations of the area. The Needle Mountains were elevated more than 11,000 feet; other areas were less deformed, and many great faults were formed. The age of this deformation is not accurately placed and part of it may have taken place as early as pre-McDermott but most of it was probably post-Eocene. Most of the faults formed at this time are steeply dipping normal faults, but the Crookton fault in the Chochetopa quadrangle is a thrust fault. It is characteristic of the faults of this period that the rocks near the fault on the downthrown side dip steeply away from the fault. In places this steep dip extends as far as 1,000 feet from the fault.

During the eruption of the San Juan tuff and Silverton volcanic series, the volcanic mountains remained above the general level of erosion, but after the Silverton eruptions they subsided several thousand feet and were reduced to a mature surface before Potosi time.

During the eruption of the great mass of Potosi and Fisher rocks, the central part of the volcanic mountains remained above the level of erosion by an amount equal, or nearly equal, to the thickness of the volcanic rocks, but along the margins of the mass, especially the southern and southeastern margins, the land must have subsided by an amount nearly equal to the thickness of the volcanic rocks (several thousand feet). Following the Fisher eruption the central area subsided several thousand feet, while the bordering areas remained nearly stable or were somewhat elevated. The San Juan peneplain was cut on these deformed rocks.

Beginning after the eruption of the Hinsdale formation, which was near the end of the Tertiary, the mountains were again elevated and deformed. Since the beginning of the volcanism the Needle Mountains mass has been elevated about 14,000 feet. This makes the elevation of the Needle Mountains since Cretaceous time more than 25,000 feet. Most of the volcanic area has been elevated several thousand feet. Gentle synclines on this deformed surface are occupied by Tomiche Creek and Gunnison River, Saguache Creek, and the Rio Grande.

In several small areas the volcanic rocks are broken by a complex of faults and locally by a few scattered faults. Most of the faults are younger than the San Juan peneplain; a few are older. The faulting tends to form graben and horsts, most of which are small. The faults bounding the graben in the northestern part of the San Cristobal quadrangle tend to grade into monoclines in which most of the tilting is in the rocks on the upthrown sides of the faults, and toward the faults or graben. In places the rocks within the graben dip away from the fault.

Except for the graben just described, for a large part of these faults the beds on the downthrown side dip moderately into the fault for a distance of several miles in some places. In some blocks, bounded by faults, this dip is due to tilting of the block, but in others it is due to bending of the rocks. In some of the faults, most or all of the displacement is due to this tilting and the rocks beyond the hinge line have about the same elevation as the rocks on the opposite side of the fault zone. It is characteristic of the faults and fault zones that they displace the rocks only locally. On the two sides of the zones of faulting the rocks are nearly horizontal and at almost the same elevation. The displacement in the fault zones commonly decreases rapidly either by branch faults or by the bending or tilting of the rocks on the downthrown sides of the faults.

The general character of the successive deformations from the beginning of the Paleozoic to the present time are shown in figure 31, which is a generalized north-south section through the Needle Mountains. This section was selected because it shows the maximum known deformation and yields sufficient data to furnish reliable sections. Figure 31*A* shows the position of the base of the Paleozoic with relation to sea level at different stages in the deformation. It shows that about half the 25,000-foot total elevation of the Needle Mountains since Cretaceous time took place after the beginning of volcanism. Figure 31*B* shows diagrammatic north-south sections across the Needle Mountains at different stages in the history of the area.

In the description to follow, the structures formed in pre-Cambrian time will be discussed first, followed successively by the later structures in order of age. In a general way in each group the structures of the northern part of the mountains will be described first, followed by those to the south. Because the structure of the western area has been described in detail in the published folios and other papers, only brief outlines of the structures in that area will be included.

DEFORMATION IN PRE-CAMBRIAN TIME

The ancient schists and gneisses and the highly metamorphic rocks of the Gunnison River basin are for the

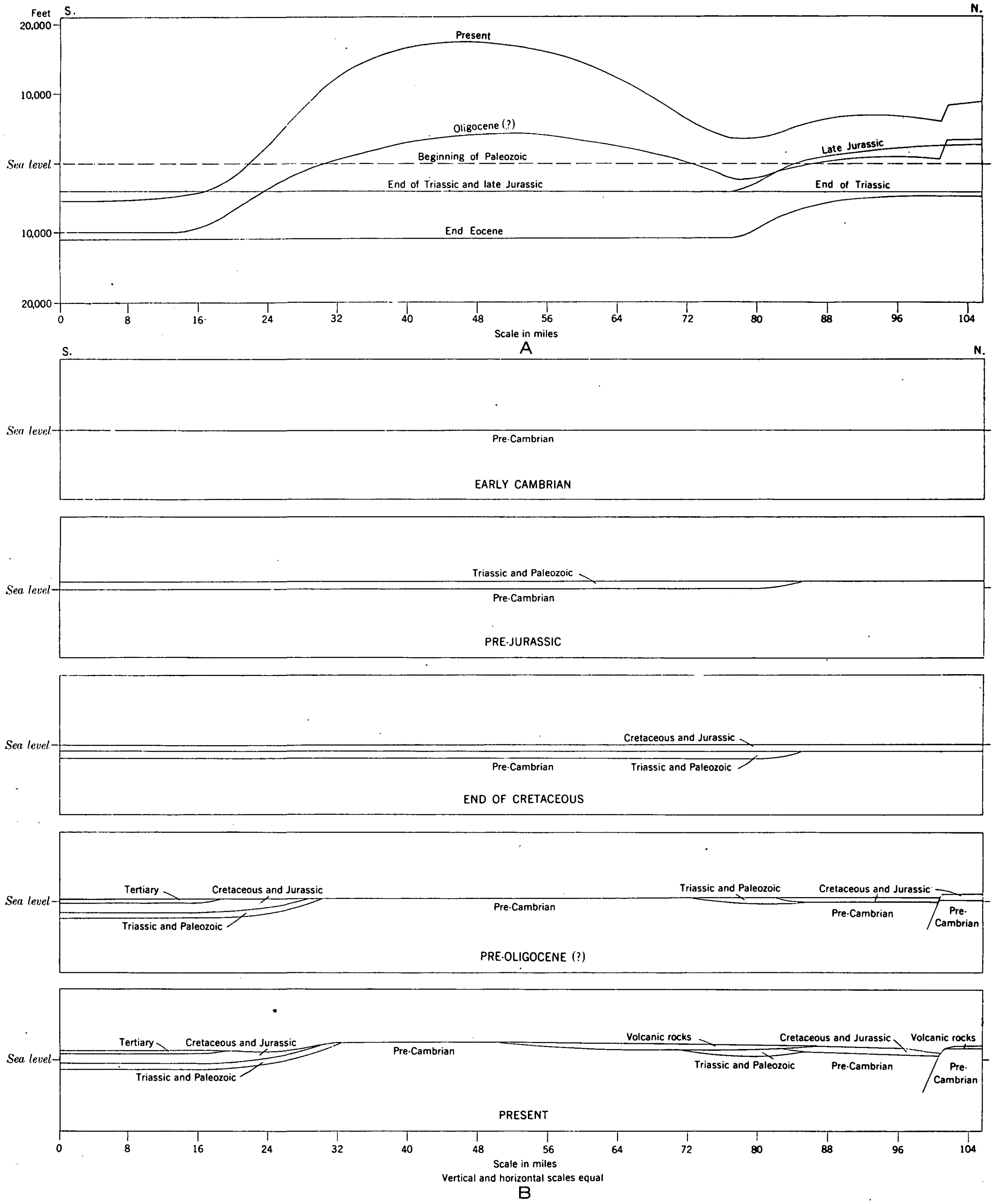

FIGURE 31.—Structural evolution of the Needle Mountains as seen in a general north-south section. Part *A* shows the movement of the base of the Paleozoic rocks in reference to sea level. Part *B*, structural sections.

most part well banded or laminated, but these features are metamorphic in origin and only rarely can bedding or other original features be recognized. In the following description the structure refers to the structure of the schistosity. In all of these bodies there are local faulting and folding, especially near intrusive bodies. Only the general structure will be considered in this report.

In the Gunnison River area the general strike in the western part of the mass of schists and gneisses is about north or east of north and the dip steep (about $70° \pm$) to the west. Except for local northeast strikes near the body of Vernal Mesa granite, this attitude continues eastward to Curicanti Needle where there is an abrupt change in attitude, probably due to a fault. East of this the strike is west or northwest and the dip steep and south.

In the small body of these rocks near Rico the strike is about east–west and the dip vertical.

The larger body in the southern part of the basin of the Animas River strikes about east–west and dips steeply to moderately south. Farther north, in the eastern part of the Engineer Mountain quadrangle the strike averages about northeast and the dips are steep to the southeast. In the southern part of the body in the Needle Mountains quadrangle the strike is north–south and the beds are nearly vertical, and in the northern part of the body the strikes are east–west and the beds are nearly vertical.

In the strip to the north, along the border of the Silverton and Needle Mountains quadrangles the strikes average about east–west, and the dips vertical or steep to the south. Locally the beds are flat.

These data show that the schists are much folded and that there is no uniform regional structure. Probably strikes in the northwest quadrant and steep south-westerly dips are more common than others.

The schistosity of the Irving greenstone commonly strikes nearly north–south and is vertical or dips steeply to the west.

The bedding of the Vallecito conglomerate is easily seen in many places. The strike and dip of the body in the basin of Los Pinos River both vary greatly, but the average strike is north and the dips are from 20° to 80° east.

The quartzite of the Uncompahgre formation has several interlayered beds of schist, and these have been mapped in the Needle Mountains and San Cristobal quadrangles and are shown on the quadrangle maps, but not on the small scale map of the San Juan region. In the southeastern part of the body the beds strike about north-south. To the northwest the strike turns toward the west, and in the western part it is about east-west. Thus the beds crop out as a quadrant of a circle. In detail, the structure is complicated by strike faults and some cross faults. In the extreme western part of the mass the dips are nearly vertical and the structure is complicated by faulting, but the main part of the mass in the Needle Mountains quadrangle is a rather broad anticline with several smaller synclines and anticlines on its northern flank.

In the San Cristobal quadrangle near the western border, the anticline is less marked. South of Mt. Oso the dips are 30° to 45° north. Near Mt. Oso they steepen to 70°, and this steep dip continues nearly to the boundary line of La Plata and San Juan Counties, where the beds flatten and are locally horizontal. Farther north they again turn down and dip 30° to 45° north, with some nearly horizontal dips in places. In the southern part of this body, in the San Cristobal quadrangle, the beds dip steeply to the southwest in the eastern part of the mass, and steeply to the northeast in the western part.

A few faults of the region are truncated by Paleozoic rocks and are certainly pre-Cambrian; others do not come into contact with Paleozoic rocks but are believed to be pre-Cambrian from general consideration; still others displace Paleozoic rocks with small or moderate displacement and are believed to have displaced the pre-Cambrian rocks by a large amount. There are probably many faults in the pre-Cambrian rocks that have not been mapped.

In the Needle Mountains area the east-west fault zone at the northern border of the quartzite of the Uncompahgre formation is pre-Elbert. It probably has a large displacement. The several faults to the south, in the Uncompahgre, are probably pre-Cambrian. The fault at the south boundary of this mass of quartzite of the Uncompahgre is a thrust fault with a rather low dip to the north. It is younger than the Twilight granite and older than the Eolus granite. The long north-trending fault, which throughout most of its length is west of Vallecito Creek, separates the Eolus granite from the quartzite of the Uncompahgre and the Irving greenstone. This fault displaces the Paleozoic sediments but the major part of the displacement is believed to have taken place in pre-Cambrian time. At its southern end it appears to pass beneath the Cambrian beds. The fault that is east of the one just described and that separates the Irving greenstone from the Vallecito conglomerate is clearly pre-Cambrian.

The irregular group of faults that separates the small body of Vallecito conglomerate from the Irving greenstone near the southwestern corner of the San Cristobal quadrangle is pre-Cambrian. The two faults to the south, beyond the Paleozoic, are no doubt related to the group just described. The longer fault, against which the two faults just mentioned end, between Vallecito

Creek and Lake Fork displaces the Paleozoic rocks but in its northern part it branches and the west branch cuts the Paleozoic rocks; whereas the eastern branch is overlain by the Paleozoic. The west branch has a dip of 65° west. Just north of the Los Pinos River the Vallecito has a marked change in structure on the two sides of the fault. On the west side the dip is about 70° W. and on the east side it is about 35° E.

The north-south fault that is just east of Lake Fork and bounds the Eolus granite on the west is pre-Cambrian, and that bounding the Irving greenstone on the north is probably pre-Cambrian. South of the hill having an altitude of 12,915 feet this fault dips 42° to the southwest. Near this fault the Irving greenstone is brecciated and cut by quartz veinlets. For about 100 feet from the fault it is schistose, with the laminations parallel to the fault plane.

The main faults in this body of pre-Cambrian rocks in the Needle Mountains seem to form a semicircle about the eastern half of the mountains, as does the structure of the Uncompahgre quartzite. The thrust fault is pre-Eolus granite; the others as far as can be determined are post-Eolus. Many of the faults were reopened after the deposition of the Paleozoic rocks.

The pre-Cambrian rocks have been deformed many times. During each of the periods of metamorphism they must have been greatly deformed. The older schists and gneisses are greatly metamorphosed and completely recrystallized so that it is commonly impossible to determine their original character. The River Portal mica schist of the Gunnison River area is somewhat less metamorphosed; the Irving greenstone, the rocks of the Uncompahgre formation, and some of the gneissoid granitic rocks are only mildly metamorphosed; and the younger granitic rocks are either only slightly metamorphosed or not metamorphosed. There was probably deformation associated with each of the many successive intrusions of granitic rocks. There are two recognizable ages of faulting—the pre-Eolus thrust faulting and the post-Eolus normal faulting. In addition, the pre-Cambrian rocks have been deformed by all the later movements of the crust.

MOVEMENTS DURING THE PALEOZOIC

During late pre-Cambrian or possibly Early Cambrian time, the whole of the San Juan region, as far as evidence is available, was an area of considerable relief. By Late Cambrian (Ignacio) time erosion had reduced the surface to a flat plane with a maximum relief of only a few hundred feet at most, as indicated by the wide distribution of the relatively thin Ignacio quartzite. In Late Cambrian time the land was depressed beneath the sea, at least in the western part of the region.

No angular unconformity has been found within the Paleozoic rocks although the area was elevated and depressed a number of times, perhaps as follows:

1. The lack of Ordovician and Silurian strata and the absence of the Cambrian in places, indicates some movement between Cambrian and Devonian.
2. The deep weathering of the upper part of the Leadville limestone indicates elevation and depression between early Mississippian and Pennsylvanian times.
3. The terrestial red beds of the Permian (?) (Cutler) overlying the marine deposits of Pennsylvanian and Permian (?) age (Hermosa and Rico) show elevation during the Permian.

In the Anthracite quadrangle, only 20 miles north of the Uncompahgre quadrangle (Emmons, Cross, and Eldridge, 1894, p. 6), the conglomerate of the Maroon formation of Carboniferous and Permian age overlies older Carboniferous and pre-Cambrian rocks with angular unconformity.

In the northeastern part of the San Juan Mountains, in the Kerber Creek area, Cambrian and Silurian rocks are absent.

DEFORMATION PRECEDING THE DEPOSITION OF THE TRIASSIC AND JURASSIC(?) DOLORES FORMATION

In most parts of the region the Triassic and Jurassic (?) Dolores formation seems to rest conformably on the Permian (?) (Cutler and Rico), but east of Ouray the base of the Dolores cuts across the whole of the Cutler, and the Dolores locally lies on the Hermosa formation (Pennsylvanian). In the Black Canyon of the Gunnison, a few miles northwest of the mapped area, the Triassic and Jurassic (?) overlie the pre-Cambrian and are in turn overlain by the Jurassic. In canyons cutting the Uncompahgre plateau, about 20 miles northwest of Ouray, the Triassic and Jurassic (?) directly overlie the pre-Cambrian throughout a large area. Dane (1931) concluded that the Uncompahgre Plateau was situated along the west margin of a landmass which extended southeast into New Mexico during Pennsylvanian, Permian, and Early Triassic time. Such a landmass would have covered much of the San Juan Mountains. In the area included on the map of the San Juan region the only place where the Triassic and Jurassic (?) rest with angular unconformity on the older rocks is near Ouray. Near Ouray the critical area where the Jurassic cuts across the formations from Triassic and Jurassic (?) to pre-Cambrian is covered by younger rocks. In the Black Canyon and the Uncompahgre plateau the removal of the Paleozoic rocks took place before the Triassic but, to the east, in the drainage of the Gunnison River the pre-Cambrian everywhere directly underlies the Jurassic. It is possible that in this area, as to the west, the main deformation and erosion of the Paleozoic rocks took place before the Triassic, and that the Triassic either was not deposited or was removed by erosion before the deposition of the Jurassic Morrison formation. However, in the southern part of the mountains, in the drainage of the Piedra River, exposures are sufficient to show that the Triassic and Jurassic (?) rest with angular unconformity on the Permian (?) Cutler formation, and that the Paleozoic and Triassic and Jurassic (?) rocks were sharply folded and beveled to a smooth surface before the deposition of the Late Jurassic formations, which transgress all the rocks from pre-Cambrian to Triassic. It seems probable, therefore, that a great deformation in the San Juan region took place after the Triassic.

In the Sangre de Cristo Range, east of the San Juan Mountains, Burbank and Goddard (1932) found Permian conglomerate overlapping the Carboniferous, and locally resting on the pre-Cambrian. In the San Juan region there is no evidence of intense, widespread deformation either in the Paleozoic or at the end of the Paleozoic. Of course, in much of the eastern part of the San Juan area such deformations could not be detected from the rock outcrops.

DEFORMATION AFTER THE DEPOSITION OF THE DOLORES FORMATION

In the western part of the mountains the late Jurassic Entrada sandstone overlies the Triassic and Jurassic (?) Dolores formation with apparent conformity and the only indications of an unconformity between the two formations are the somewhat variable thickness of the Dolores, which becomes thinner toward the east, and the presence in places of shallow stream channels at the top of the Dolores.

In the basin of Cow Creek, northeast of Ouray, the Morrison formation rests on the Cutler formation and there is an angular unconformity. Rocks younger than Triassic underlie the area for many miles to the north and east of Ouray. About 30 miles north of Ouray, north of the Black Canyon of the Gunnison, the Jurassic Morrison formation directly overlie the pre-Cambrian and for 60 miles to the east on both sides of the Gunnison River it overlies a smooth surface cut on pre-Cambrian rocks. West of Tomichi Creek it is faulted against the pre-Cambrian, and it was not found east of this fault. In the Crested Butte quadrangle, which lies about 20 miles north of the eastern part of the Uncompahgre quadrangle, the Jurassic Morrision formation rests unconformably on the Carboniferous (Eldridge, in Emmons, Cross, and Eldridge, 1894).

In most parts of southwestern Colorado the Jurassic seems to rest conformably on the Triassic and Jurassic (?) but in the canyon of Leon Creek, south of Naturita, the Jurassic is mapped (Burbank, Lovering, Goddard, and Eckle, 1935) as directly overlying the Carboniferous.

In the southwestern part of the San Juan Mountains the Jurassic Entrada sandstone seems to rest conformably on the Triassic and Jurassic(?) Dolores formation for 50 miles east-west, but near Vallecito the Dolores is thin and a few miles farther east it is absent. In the canyon of the Piedra River the pre-Jurassic rocks are folded into three synclines and anticlines and are broken by a fault; the Entrada overlies a surface cut across the bevelled edges of the Dolores and the whole Paleozoic section and locally the Entrada rests directly on the pre-Cambrian (Cross and Larsen, 1914). The Jurassic and older beds are covered in all of the mapped area east of this, but just south of the southwest corner of the Conejos quadrangle in a railroad cut north of Wolf Creek the Jurassic is exposed but the rocks underlying it were not seen.

The base of the Jurassic, therefore, seems to overlie one of the greatest unconformities of the area. After the deposition of the Triassic and Jurassic (?) sedimentary rock the crust was folded to form a high mountain mass whose western border followed a nearly north-south direction across the mountains. Since the sedimentary rocks are not exposed in the central part of the mountains, no certain conclusion can be drawn about the structure in that area. The erosion of the crust over much of the mountain mass must have been greater than the thickness of the Triassic and Paleozoic rocks, at least 4,000 feet. Before the deposition of the Jurassic beds the mountain mass was levelled by erosion to a smooth plain.

DEFORMATION DURING CRETACEOUS AND EARLY TERTIARY TIMES

INTRODUCTION

Where the Cretaceous overlies the Jurassic the Cretaceous units, except the uppermost formation, are in conformable succession. However, during or preceding McDermott time there were eruptions of volcanic rocks in the San Juan region, and there must have been an elevated landmass nearby, for the conglomerates of the McDermott formation contain pebbles of volcanic and other rocks.

There was some elevation and deformation at the end of the Cretaceous. Volcanic mountains were still present during Animas time. After the deposition of the Animas formation there were erosion and some deformation. During Paleocene time mountains existed of sufficient elevation to maintain the glaciers which furnished the Ridgway till. The deformations of Cretaceous time can be recognized only on the southern flanks of the mountains where relatively undeformed

Tertiary rocks are present. A much greater deformation took place in the main mountain dome. In the western part of the mountains the Telluride conglomerate underlies the San Juan tuff with apparent conformity and overlies a rather smooth surface that has been cut on deformed rocks that range in age from pre-Cambrian to Cretaceous. The Telluride is thick in the western part of the area but it becomes thinner toward the east and finally pinches out. It was probably derived from a mountain mass to the east.

The Blanco Basin formation in the southern part of the mountains underlies the Conejos quartz latite rather regularly, and it overlies a rather smooth surface cut in somewhat deformed Cretaceous and, locally, pre-Cambrian or Animas rocks.

The Paleocene and Eocene beds are present within 10 or 15 miles south of the main mountain front. They dip away from the mountains, and their northern limit is due to erosion. They probably once covered much of the southern part of the mountains. If that is true, they must have been folded with the older rocks and removed by erosion before the deposition of the Blanco Basin formation. This would require a considerable amount of the deformation to have been post-Wasatch and probably early Miocene or Oligocene.

However, it is probable that some of the deformation preceded the deposition of the Animas formation and the deformation continued with interruptions throughout the early Tertiary time.

The prevolcanic rocks are confined to the western half of the mapped area, a strip along the northern part, and a triangle north of the south boundary. The pre-Miocene structure in a large area in the central and eastern part of the mountains is therefore unknown.

The Telluride conglomerate and the Blanco Basin formation were deposited on surfaces that were smooth and nearly flat or dipped gently away from the mountains. The surface beneath the San Juan tuff or the Lake Fork quartz latite where the Telluride is absent was a mature surface of little relief. That at the base of Conejos quartz latite where the Blanco Basin formation is absent was a mature surface of moderate relief. The general pre-Miocene surface can therefore be reconstructed by making the surface beneath the Telluride and Blanco Basin or the San Juan, Lake Fork, or Conejos a smooth surface, nearly flat or dipping gently away from the mountains.

THE CIMARRON FAULT

In the Gunnison River basin in the northern part of the area, the great Cimarron fault can be easily recognized from the automobile road or train near Cimarron, where deep canyons and high mountains cut in pre-Cambrian rocks are north of the fault, and gentle slopes underlain by the Mancos shale are south. The fault, which has been described by Hunter (1925, p. 88–91), is easily followed west of Fitzpatrick Mesa, and in this western area it commonly separates pre-Cambrian rocks from the Mancos shale. The shale is commonly upturned near the fault. East of Fitzpatrick Mesa the fault is in most places overlain by younger rocks. The volcanic rocks are not commonly displaced by the fault but in the canyon of Blue Creek movement on a parallel fault nearby has displaced the volcanic rocks about 300 feet in the opposite direction from the displacement of the older fault. The fault is again situated in the Lake Fork where Mancos shale is faulted against the pre-Cambrian. East of the Lake Fork the fault is covered. It must pass near Powderhorn postoffice and from there turn to the southwest up the valley of Cebolla Creek. South of Powderhorn are two small outcrops of Morrison formation; the southern body overlies the pre-Cambrian rocks at an altitude of 8,300 feet, and the northern body is surrounded by Alboroto rhyolite and has an altitude of 8,000 feet. Across Powderhorn Valley, about 3 miles to the northeast, the flat-lying Morrison beds overlie the pre-Cambrian at an altitude of 9,700 feet.

The fault has therefore been followed for nearly 40 miles. The displacement of the fault cannot be accurately measured, but it must be more than 2,500 feet near Cimarron and near Powderhorn the base of the Morrison formation on the two sides of Powderhorn valley has a difference in altitude of 1,400 feet. In few places was the actual fault plane seen, but it seems to be somewhat irregular and to dip steeply to the south.

The two small faults east of Powderhorn are probably branches of the large Cimarron fault.

The small fault three quarters of a mile southwest of Iola seems to be a reverse fault. A nearly horizontal bed of sandstone of the Morrison formation underlies the lower slopes; the pre-Cambrian underlies the upper slopes. Next to the fault the sandstone is traversed by a network of veinlets and forms a low ridge. The La Plata scarp shows a smooth slickensided, striated surface.

THE CROOKTON FAULT

The Crookton fault (Stark and Behre, 1936, p. 106–107) is another great fault that separates the pre-Cambrian from the Mesozoic rocks. According to Stark and Behre, the fault is a thrust and dips not less than 45°. In the southern part of the fault the Morrison formation is commonly next to the fault, but to the north the Dakota sandstone is commonly next to it. The sandstones west of the fault are everywhere upturned steeply and locally they are overturned (fig. 32). The amount of movement on the fault is uncertain.

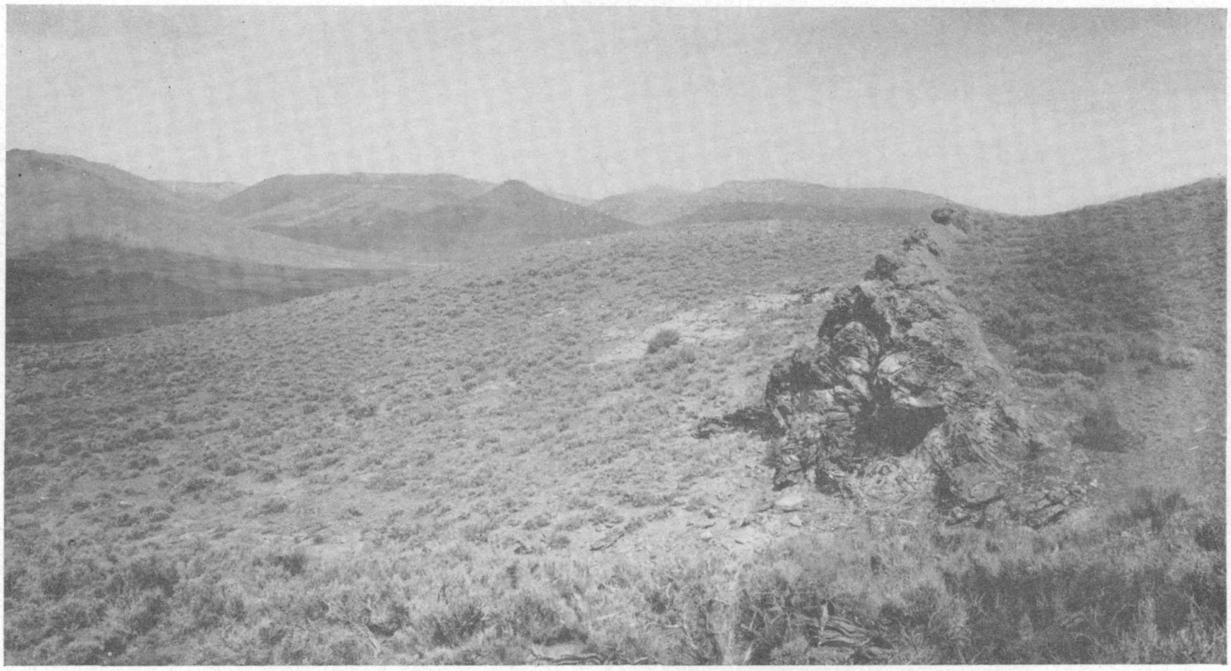

FIGURE 32.—The Crookton fault in the northern part of the Cochetopa quadrangle, as seen looking south from a point south of Tomichi Dome. The Morrison formation, forming the ridge, is faulted and upturned against pre-Cambrian rocks to the left.

During the early Tertiary deformation the whole area of Cretaceous and older rocks was divided into three segments by these two great faults. In the eastern segment, east of the Crookton fault, the volcanic rocks are underlain by pre-Cambrian rocks and some small faulted bodies of Paleozoic rocks. In the segment between the Crookton and Cimarron faults the volcanic rocks overlie Mancos shale in the eastern part and Morrison or pre-Cambrian rocks to the west. In the eastern part of this segment, east of the end of the Cimarron fault, the beds probably dipped gently to the south, but in and north of the Uncompahgre quadrangle the beds dipped gently northward away from the fault. As they do south of the Gunnison River, the San Juan and Lake Fork rest on the pre-Cambrian, but north of the river and north of the Uncompahgre quadrangle, the San Juan tuff rests on successively higher formation of the Cretaceous.

THE NEEDLE MOUNTAINS DOME

The large area south of the Cimarron fault was a great dome whose highest elevations were in and north of the Needle Mountains. Two small domes in the Rico and La Plata Mountains were on the southwestern flank of the main dome, and the great Uncompahgre Plateau, to the northwest of Ouray, may have been a large dome. The sedimentary beds dipped away from the Needle Mountains dome to the south, west, and north. The eastern border of the dome is covered by volcanic rocks. The central part of this dome is about 100 miles across, in a north-northeast direction from Durango to the Gunnison River. It may include much of the mountains to the east.

In general, the area of steep dips is bounded on the southeast by Weminuche Creek; thence it runs westward from the mouth of Weminuche Creek to the south slopes of the La Plata Mountains, turns rather abruptly northward along the west slopes of the La Plata and Rico Mountains a few miles west of Telluride, and northwestward to a point a few miles north of Ouray. Beyond the area of steep dips to the south, west, and northwest, the dips are gentle and away from the mountains. How much of the gentle dips are prevolcanic is not certain.

The height of this great prevolcanic dome was probably much more than 10,000 feet.

In the Needle Mountains dome there has been some faulting, much of it having been renewed along pre-Cambrian fault planes. There is some tendency for the major faults to be tangential to the dome and for the smaller faults on the outer flanks of the dome to be radial. This may be largely due to the position of the pre-Cambrian faults, for much of the Tertiary faulting was by renewed movement along pre-Cambrian faults.

Near the faults the beds on the downthrown side commonly dip at considerable angles away from the faults, but in some places they are vertical or overturned; and along some of the faults the beds on the upthrown side dip steeply into the fault. This is well shown near some of the faults east of Vallecito Creek and along the fault that crosses Weminuche Creek.

The Hermosa formation south of the east-west fault near the head of Red Creek commonly dips steeply away from the fault and is locally nearly vertical or overturned. On the north side of this fault the Ouray and Elbert turn down sharply toward the fault. The fault in Weminuche Creek is nearly vertical or dips steeply to the east. The fault is somewhat irregular in outcrop because of the softness of the beds involved. Near Weminuche Creek 1,000 feet of sedimentary strata next to the fault are nearly vertical or locally overturned. Southwest of Weminuche Creek the beds dip away from the fault, commonly at angles of 50° or more.

LA PLATA AND RICO DOMES

The La Plata dome is about 12 miles across and in it Upper Carboniferous rocks are exposed. Its central part must have been elevated about 4,000 feet above its general surroundings on the south and west.

The Rico dome is smaller than the La Plata dome and in it Paleozoic and early Mesozoic rocks make up most of the exposures. A small body of pre-Cambrian rocks, bounded by faults, is present near the center of the dome. The Rico dome is on the western flank and the La Plata dome is on the southwestern flank of the large Needle Mountain dome; the domes tend to coalesce in areas in which the beds are at high altitudes (see cross sections, plate 2).

The Rico and La Plata domes are associated with faulting, and many sills, small laccoliths, and plugs of intrusive rock are present in the dome. The age of these intrusive rocks is uncertain but they are believed to be younger than the formation of the dome. They are older than the faulting.

THE SOUTHEASTERN AREA

The area southwest of the volcanic rocks, southeast of the Weminuche Creek fault, seems to have been an area that was little deformed. In the basin of Coal Creek northeast of Pagosa Springs the Animas formation is folded and faulted between Cretaceous beds.

South of the southern part of the San Juan region and south of the Conejos quadrangle, a rather narrow arm of high mountains projects southward from the San Juan Mountains and extends for many miles into New Mexico. The core of the mountain range is made up of pre-Cambrian rocks overlain by volcanic rocks. Small outcrops of pre-Cambrian rocks are present as far north as the Conejos River. The west flank of these mountains is steep and, according to Darton (1928, p. 178), steeply dipping Cretaceous rocks, faulted against the pre-Cambrian, form the west slope. In a railroad cut northwest of Wolf Creek, and a short distance south of the south boundary of the Conejos quadrangle, Mancos shale strikes N. 20° W. and dips 23° west. Its beveled edges are overlain by flat-lying sandstone of the Blanco Basin formation.

SUMMARY

A major deformation of the area took place after the Cretaceous; it probably began near the end of the Cretaceous and continued through Eocene time. The major part of the movement probably took place after the deposition of the Eocene beds and probably in early Miocene or Oligocene time. The deformation formed great domes with steep slopes and some large faults. The Needle Mountains dome was elevated 10,000 feet or more. Its southern, western, and northern slopes are well shown by the distribution and structure of the sedimentary rocks but its eastern slopes are covered by volcanic rocks, and it may have extended for many miles across the central part of the mountains.

The block north of the Cimmarron fault must have been elevated more than 6,000 feet, and that to the south of the fault was from 1,500 to 2,700 feet lower. In the northeastern part of the area, east of the Crookton fault, was another high area, and in the southeastern part of the area, east of the Chama River and extending into New Mexico, was another. The great area in the central part of the mountains, extending to the San Luis Valley, is covered by younger rocks, but the structure of the Cretaceous in the southern part of the mountains indicates that this area was elevated.

STRUCTURES THAT DEFORMED THE VOLCANIC ROCKS

INTRODUCTION

To determine the detailed structure of the volcanic rocks would require a much more detailed study than we have made. Mapping on a larger scale and the making of many more subdivisions of the volcanic formations would have been necessary. On the other hand, to determine the broader structure requires the study of a large area. The methods commonly used in the study of the structure of sedimentary rocks can be applied to the volcanic rocks to only a limited extent. Many of the volcanic units are locally several thousand feet thick, they change rapidly and irregularly in thickness from place to place, and are locally absent. Some of them were deposited on surfaces characterized by deep canyons of erosion. Some of the formations, particularly the rhyolitic rocks, are well layered. The layers were originally nearly horizontal, but in few places can local structures be accurately measured with confidence. However, where the rocks are exposed in the walls of deep canyons and can be followed for miles, the general structure of the rocks can commonly be determined with assurance. In places a particular flow or tuff bed can be recognized in an area a few miles across, rarely in an area a few tens of miles across. The structure is best shown by mapping the formations and determining the layering wherever possible. In this way the broader structures have been determined. In general, the rocks are nearly flat and rarely do they dip at angles greater than 5°. These steeper dips are local and are nearly always associated with faulting.

Local deformation probably took place many times during the volcanic eruptions, and larger scale deformation has taken place at least three times, each time following the eruption of one of the main groups of volcanic rocks; that is, preceding an interval during which few volcanic eruptions took place. The chief evidence for the first two deformations is the fact that for one group of eruptions deep canyons were cut in the older rocks during intervals between the eruptions of members of that group, and the next younger group of rocks was deposited on a mature erosional surface cut on the older group at an elevation much higher than the bottom of the older canyons that were cut during the accumulation of the older rocks.

The conclusion is reached that after the eruptions of the Silverton volcanic series the northwestern part of the area, where the Silverton and San Juan rocks are present, was depressed several thousand feet. Erosion reduced the area to a rather mature surface before the Potosi volcanic series was erupted.

During the long time in which the Potosi and Fisher rocks were erupted the central part of the mountains was built up and maintained as a high plateau or dome. There was some local faulting, but so far as known no widespread depression or elevation of the area. The borders of the area of volcanic rocks, notably in and near the Conejos quadrangle, seem to have been progressively depressed during the volcanic eruptions so that its surface remained about base level throughout Potosi and Fisher time. The total depression of this bordering area was several thousand feet.

Following the eruptions of the Fisher quartz latite the central area was depressed several thousand feet and the border area was little disturbed. The San Juan peneplain was then cut and the eruptions of the Hinsdale formation were spread over the peneplain.

Beginning in late Pliocene and continuing into the Pleistocene the area was elevated to an asymmetric, deformed dome. The highest part of the dome was in the Needle Mountains where the base of the volcanic rocks was at an altitude of more than 14,000 feet and the base of the Potosi volcanic series may have been several thousand feet higher. The lowest part in the mapped area is along the eastern border where the base of the Potosi is estimated to be at an altitude of 5,000 feet. The crest of the dome was in general near the western border of the mapped area and the slopes to the west were probably relatively steep. The general character of the deformation is shown by the contour map of the base of the volcanic rocks (pl. 4). The slopes are steep on the south, east, and north sides of the Needle Mountains dome to altitudes 4,000 to 5,000 feet below the crest. To the east they are undulating to within about 10 miles of the San Luis Valley, and then they dip gently to the east and the beds pass beneath the San Luis Valley. There are synclines along the Gunnison and Saguache Rivers and the Rio Grande.

Faults are not numerous in the volcanic rocks except in a few small areas where they are very numerous. Most of the faults are only a few miles long, but some have displacements as great as 3,000 feet. The fault zones are commonly only a few miles across and not many miles long. The rocks on the two sides of some of the fault zones are nearly flat and are at about the same altitude, showing that the disturbance was confined to the fault zone. Graben and horsts are common. Commonly, the beds on the downthrown side of the faults dip into the faults for a mile or so from the fault and much of the displacement is accounted for by this dip. In the graben in the northeastern part of the San Cristobal quadrangle the rocks on the upthrown side of the faults dip into the faults and locally the faults become monoclines.

THE SURFACE AT THE BASE OF THE VOLCANIC ROCKS

The mountains elevated by the deformation that followed the Eocene were eroded to an area of low relief before the deposition of the Telluride conglomerate and the Blanco Basin formation. In the western part of the San Juan region the Telluride conglomerate was deposited on this surface. This conglomerate is about 800 feet thick near the western border of the Telluride quadrangle. It becomes thinner to the east and pinches out near the eastern borders of the Ouray and Silverton quadrangles in a distance of about 30 miles. The San Juan tuff overlies the Telluride with apparent conformity, although local stream channels were eroded in the Telluride before the deposition of the San Juan.

In the southwestern front of the San Juan Mountains the Blanco Basin formation overlies a rather regular surface cut on the Eocene and older rocks for a distance of 60 miles. It is overlain regularly by the Conejos quartz latite.

In the central and northern part of the mountains the volcanic rocks directly overlie Cretaceous or older rocks. In this area the volcanic rocks were spread over a surface of low relief, especially where the San Juan tuff is present.

At the present time the base of the volcanic rocks is above 13,000 feet in altitude in the western part of the

Telluride quadrangle, and it has probably been eroded from the still higher peaks of the Needle Mountains. On the eastern side of the mountains near the San Luis Valley the base of the volcanic rocks is well below 7,500 feet, probably below 5,000 feet. It is certain that by far the greater part of the relief of this surface at the base of the volcanic rocks is due to deformation of the volcanic rocks.

To show the deformation of the surface on which the volcanic rocks were laid down, that surface has been contoured in plate 4. No attempt was made to show the smaller undulations or to indicate faults that have only locally displaced the surface. In the northern and northwestern part of the mountains and in a strip along the southwestern base of the mountains the base of the volcanic rocks is exposed in many places, but in the central part of the mountains and west of the San Luis Valley the base of the volcanic rocks is not reached, and its position has been determined by estimating the thickness of the volcanic rocks below the lowest exposures. The error resutling from this estimate is fairly large; in places probably several thousand feet.

STRUCTURE OF THE SURFACE AT THE BASE OF THE VOLCANIC ROCKS

The general character of the surface at the base of the volcanic rocks is shown in plate 4. Some of the minor irregularities shown on this contour map of the surface are due to the imperfect nature of the data and some to the fact that the original surface had some relief. However, the main features brought out by the map are well supported by reliable data.

The surface has been elevated to a dome in the Needle Mountains area where it must have had a maximum altitude of more than 14,000 feet. It slopes away from this dome in all directions and in a distance of 20 or 30 miles has an altitude of 9,000 feet, beyond which it slopes gently away from the dome with many local undulations. Near the eastern border of the mountains, west of the San Luis Valley, the surface dips gently to the east and reaches an estimated altitude of 5,000 feet at the edge of the valley.

The great dome of the western area has approximately the form of an isosceles triangle with rounded corners and is about 60 miles on each side. The highest part of this dome is in the Needle Mountains. In the Mt. Wilson area the surface is well exposed at an altitude of 13,200 feet and west of the Needle Mountains the La Plata and Rico Mountains were probably smaller domes on the flanks of the main dome.

On the north and east good exposures show that the structural surface dips rather steeply away from the center of the dome. A syncline in this surface lies between Silverton and Telluride and separates Mt. Wilson from the Needle Mountains. Under Mt. Wilson the base of the Telluride conglomerate, which conformably underlies the volcanic rocks, is at an altitude of approximately 12,000 feet, with about 1,500 feet of Mancos shale underlying it. To the west the volcanic rocks are not known. On the western slopes of the topographic dome the Cretaceous sediments dip to the west, and about 25 miles west of Mt. Wilson the base of the Mesaverde group is at an altitude of about 9,200 feet. It is reasonably certain that the base of the volcanic rocks must have dipped to the west on the west slope of the dome and at an inclination not very different from the slope of the present surface. On the south slope of the dome no volcanic rocks are exposed. The slope of the prevolcanic surface must have been relatively steep on this slope down to an altitude of about 9,000 feet near Durango and beyond that the surface must have been nearly flat or have sloped gently to the south.

North of the dome and southeast of Silverton the surface drops 3,000 feet in 4 miles. North of Silverton is a large, relatively flat area. Farther north there is some undulation, and the domes and troughs indicated on the map are an interpretation of rather scanty data.

In the northern part of the mountains, Gunnison River and Tomiche Creek are in a gentle syncline, and north of these the surface rises more than 2,000 feet and is at an altitude of 10,300 feet in the West Elk Mountains. To the south the slopes rise more steeply to an altitude of about 10,000 feet at the crest of an anticline.

Near the center of the mountains there is mapped a deep basin, estimated to reach as low as 5,000 feet in altitude. In this area the base of the volcanic rocks is nowhere exposed and the structure is not proved.

On the eastern flanks of the mountains the volcanic rocks dip gently beneath the San Luis Valley, and the base of these rocks must dip from an estimated 7,000 feet to 5,000 feet at the border of the valley. This structure extends for many miles south into New Mexico, and to the north it extends nearly to Saguache.

Along the southwestern border of the mountains, the volcanic rocks overlie the Blanco Basin formation with apparent conformity and the surface at the base of the volcanic rocks has a fairly uniform altitude of about 9,500 feet. It seems to dip to the northeast. Southwest of the mountain front the altitude of the surface was probably uniform for many miles, for Cretaceous and Eocene sedimentary beds underlie the hills and mesas of this area, many of which exceed 8,000 feet in altitude. West of the Chama River in northern New Mexico outliers of the volcanic rocks are shown by Darton (1929) as much as 18 miles southwest of the base of the volcanic rocks near the Chama River, and their base is at an altitude of 8,000 to 9,000 feet. The original volcanic dome probably extended for some miles in this direction but likely with decreasing thickness. It was probably made up largely of bedded volcanic sands and gravels.

The deformation of the surface at the base of the volcanic rocks is not the result of a single movement of the earth's crust, but of several, as will be shown in the following pages.

RELIEF OF SURFACE OVER WHICH THE SAN JUAN AND VARIOUS FORMATIONS OF THE SILVERTON VOLCANIC SERIES WERE SPREAD

In the Telluride and Montrose quadrangles and most of the Silverton quadrangle the San Juan tuff overlies a smooth surface of the Telluride conglomerate. To the east, except in the area of the Lake Fork volcano, the San Juan overlies a mature or old-age erosional surface underlain by pre-Cambrian or Mesozoic rocks. This surface sloped toward the west.

The base of the Silverton volcanic series is irregular and locally the Silverton rocks rest on a great thickness of San Juan tuff, but nearby it is directly on older rocks. At the time the Silverton eruptions began the land surface must have had much relief and canyons several thousand feet deep. In places the Eureka rhyolite overlies the Picayune quartz latite irregularly; in others the rocks of the two formations are interlayered. The Burns quartz latite was spread over an irregular surface of erosion and in places it overlies the Eureka or Picayune, in others the San Juan tuff. The dark pyroxene-quartz latite of the Silverton was erupted on a surface of erosion that had a relief of several thousand feet. It directly overlies the older formation of the Silverton volcanic series, the San Juan tuff, and the pre-Cambrian.

DEFORMATION FOLLOWING THE ERUPTION OF THE SILVERTON VOLCANIC SERIES

The canyons eroded in the San Juan tuff before the eruption of the Silverton volcanic series and the canyons cut several times during the Silverton eruptions show that during San Juan and Silverton times the volcanic rocks rose as high mountains several thousand feet above the base level of erosion of the area. In the northwestern part of the San Juan Mountains, where the San Juan and Silverton rocks are present, only remnants of the Potosi volcanic series remain and these cap the crests of the high ridges. They overlie a rather smooth surface of erosion that is made up of rocks from pre-Cambrian to Silverton in age and that is several thousand feet higher than the bottom of the canyons that were formed before and during the Silverton eruptions. It therefore is evident that this area must have been depressed several thousand feet after the Silverton eruptions, and eroded to a mature surface before Potosi time. So far as known, this depression was chiefly west of the Uncompahgre and San Cristobal quadrangles.

Since the field work for this report was completed, Burbank (1933, 1935, 1938, 1940, 1941, 1947) and others have described the Silverton and Lake City calderas. Burbank (1938) describes the Silverton caldera briefly as follows:

> The Silverton caldera is located in the San Juan Mountains of southwestern Colorado near the western edge of the Tertiary volcanic field that covers an area of over 3,000 square miles in the State of Colorado.
>
> The Silverton volcanic series with which the caldera is associated is one of the older series of the San Juan volcanic field, and is of Miocene age. The series has a maximum thickness of at least 3,000 feet, covers an area of about 1,000 square miles, and has a volume of about 250 cubic miles.
>
> Structurally, the caldera is located near the edges of two ancestral uplifts of the San Juan Mountains. The uplift as it now exists was first outlined in late Paleozoic time. After renewal of sedimentation in the Mesozoic, this uplift was rejuvenated and much enlarged during late Cretaceous and early Tertiary time.
>
> The Silverton caldera, which appears to be one of the eruptive centers of the Silverton series, is a downfaulted or collapsed block of volcanic rocks about 8 miles in diameter. The central collapsed block is surrounded by radial fissures and dikes, and by radial and concentric intrusive axes.
>
> As seen in plan, the structure of the caldera presents a remarkable symmetry, not only in the shape of the central collapsed block, but also in the focal concentration of the dikes and fracture systems towards this center. The pattern of this structure obviously is not inherited, but was produced by some igneous bodies acting over a large area of the crust and probably from considerable depth, as otherwise the lack of homogeneity in the shallow crust would have caused greater distortion of the fracture pattern.
>
> The caldera is located on the northwest flank of the compound pre-Tertiary uplift without apparent relation to, or without control inherited from, the structural framework of the pre-Tertiary formations. The fact that the radial intrusive axes extend much farther towards the west than towards the east, and also the fact that the dikes and fissures are much more continuous westward, suggests that the magma lay shallower in the crust in this direction. Hence the magma may have risen obliquely from great depth beneath the more central parts of the San Juan mountain block and migrated toward the plateaus. Finally at a certain critical level the pressure of the magma became sufficient to fracture the overlying crust or to permit invasion by stoping. The flanks of the two ancestral uplifts may have provided zones of weakness of or shearing that assisted in the upward migration of the magma.
>
> This widespread melting of the deep crustal zones was more or less coincident with the continental uplift of the mountain and plateau country as a whole, which was initiated during early Tertiary but which was much accelerated during middle and later Tertiary time. It is interesting to note that throughout the entire range of Paleozoic and Mesozoic time, this region, except for local mountain groups, lay beneath or close to sea level, and that there had been very little igneous activity prior to the end of Cretaceous time.

FOLDING IN THE POTOSI VOLCANIC SERIES AND YOUNGER ROCKS

Along the eastern base of the mountains the Treasure Mountain rhyolite, Los Pinos gravel, and Hinsdale formations were spread over surfaces of little relief, the formations were regularly layered, and they dip regularly toward the east. In the southern part of this area the dips are fairly regular for 20 miles and average 150 feet to the mile. Locally, in the northern part of the Conejos quadrangle near Alamosa Creek they dip 450 feet to the mile, and in the Del Norte quadrangle they dip for at least 10 miles at 250 feet to the mile.

The broader structures observed in the volcanic rocks conform in a general way to the structure indicated by the contour map of the base of the volcanic rocks. In the northern part of the area is a gentle syncline whose axis is followed by the Gunnison River and Tomiche Creek. Another syncline is approximately followed by Saguache Creek and a third is followed by the Rio Grande. The latter syncline has steeper slopes on the north side of the river than on the south side. In general the volcanic rocks dip away from the Needle Mountains dome. The faulting and structures near the faults will be discussed in a later section.

RELIEF OF SURFACE OVER WHICH THE VARIOUS FORMATIONS OF THE POTOSI VOLCANIC SERIES AND THE YOUNGER ROCKS WERE SPREAD

In most places the base of the Potosi volcanic series was laid down on a surface of low relief. About the Needle Mountains the Potosi appears to have been spread against a mountain mass. In the eastern part of the mountains near Saguache, and in the San Luis Hills east of Conejos, the Potosi was spread around hills and mountains of older volcanic rocks. In the western area, where the Silverton volcanic series is exposed, the Conejos quartz latite is absent and the Treasure Mountain rhyolite overlies a somewhat smoother surface cut on Silverton and San Juan rocks. In the Uncompahgre quadrangle the Alboroto rhyolite overlies a surface of moderate relief cut on the San Juan tuff and older rocks. In the Cochetopa quadrangle the Conejos or the Alboroto overlie a similar surface of moderate relief cut on prevolcanic rocks. Along the southwestern front of the mountains the Conejos overlies the Blanco Basin formation regularly.

The surfaces over which the subdivisions of the Potosi volcanic series were spread varied in different parts of the mountains. In general these surfaces had small or moderate relief near the borders of the volcanic pile, but in the central part of the mass the surfaces on which the Treasure Mountain, Alboroto, and Piedra rhyolite were laid down were characterized by canyons several thousand feet deep.

In a rather narrow strip along the southeastern border of the volcanic rocks, each of the subdivisions of the Potosi volcanic series appears to have been laid down on surfaces of small or moderate relief. In the southern part of the Summitville quadrangle and all of the Conejos quadrangle the Treasure Mountain rhyolite was laid down on a regular surface of the Conejos quartz latite; the Los Pinos gravel and Hinsdale formation were also deposited on rather smooth surfaces. The relations are well shown in the cliffs on both sides of the Conejos River. In the Del Norte quadrangle most of the surfaces over which the formations of the Potosi were spread were rather smooth surfaces, but the Sheep Mountain quartz latite, where the Treasure Mountain rhyolite is absent, filled in a topography that had canyons more than 1,000 feet deep.

In the Cochetopa quadrangle, the Alboroto and Piedra rhyolites were erupted on surfaces with much relief. In the canyon of Chochetopa Creek the base of the Piedra is about 4,000 feet below the tops of the mountains on either side (Sawtooth Mountain and Razor Creek dome) which are made up of Conejos rocks. In the Uncompahgre quadrangle, except in the southeast corner, the Piedra appears to overlie a fairly smooth surface of the Alboroto.

In the central part of the mountains, including the southeastern part of the Uncompahgre quadrangle, the eastern part of the San Cristobal quadrangle, the Cochetopa and Creede quadrangles, and the northeastern part of the Summitville quadrangle, the Treasure Mountain, Alboroto, and Piedra rhyolite were erupted on surfaces of much relief, with canyons about as deep as the present canyons of the area.

The Creede formation was deposited in a valley that was deeper than the present valley of the Rio Grande.

The Fisher quartz latite was erupted on a surface underlain by rocks ranging in age from pyroxene-quartz latite of the Silverton volcanic series to Creede, and it everywhere overlies an erosion surface that had canyons several thousand feet deep.

The Los Pinos gravel, which is probably of about the same age as the Fisher quartz latite is confined to the Conejos and Summitville quadrangles, and it was laid down on a smooth, flat surface of Treasure Mountain rhyolite.

The Hinsdale formation was deposited on the San Juan peneplain.

DEFORMATION DURING THE ERUPTION OF THE POTOSI, CREEDE, AND FISHER ROCKS

The data given in the preceding section show that the central part of the volcanic area must have remained nearly stationary during Potosi and Fisher time, and the great thickness of volcanic rocks must have risen above the general base level of the area by an amount approximately equal to the thickness of the volcanic rocks, whereas the borders of the volcanic pile, especially in the southwestern part and in the Conejos quadrangle, must have been depressed by an amount approximately equal to the thickness of the volcanic rocks of that area, which aggregates several thousand feet.

DEFORMATION PRECEDING THE EROSION OF THE SAN JUAN PENEPLAIN

To account for the position of the San Juan peneplain, following the eruption of the Fisher quartz latite the central part of the volcanic mountains must have been depressed several thousand feet and the extreme borders of the volcanic area must have remained nearly stationary or have been elevated.

DEFORMATION FOLLOWING THE ERUPTIONS OF THE HINSDALE FORMATION

After the depression that followed the Fisher eruptions, the San Juan region was reduced by erosion to a peneplain—the San Juan peneplain (Atwood and Mather, 1932, p. 21–25). The Hinsdale rocks were erupted on this peneplain, and following their eruptions the area was deformed and domed to form the present mountain mass. This deformation probably began in late Pliocene and continued into Pleistocene. Atwood and Mather (1932) have described this deformation and only the general features will be discussed here.

The highest part of the peneplain is in the western part of the area in and near the Needle Mountains, where the altitude of the peneplain is above 13,000 feet, and the lowest part is under the San Luis Valley, where the altitude is below 7,000 feet.

The high part of the surface, which is in the western area, is made up of several domes, and the surface slopes away from this high area in all directions. To the north it dips to the Gunnison River where it has an altitude of about 9,000 feet. To the east it dips to a broad, undulating plateau with a surface commonly between 11,000 feet and 12,500 feet in altitude. In the eastern part of the mountains, west of the San Luis Valley, this plateau dips gently to the east from an altitude of 12,000 feet to an altitude of 8,000 feet at the border of the valley where it passes beneath the fill of the valley. South of the mountains erosion has removed much of the surface and the structure is not clear.

There are three gentle synclines on the surface, one is followed by the Gunnison River, another by the Saguache, and a third by the Rio Grande.

The San Juan peneplain has been deformed in much the same way as the base of the volcanic rocks but somewhat less intensely, and most of the deformation of the volcanic rocks took place after the San Juan peneplain was formed.

Atwood and Mather (1932) show the San Juan peneplain on the southern flanks of the San Juan Mountains between Chama and Pagosa Springs as dipping rather steeply from the crest of the range southward and beneath the basalt of Archuleta Mesa. This was done on the assumption that the basalt of Archuleta Mesa is Hinsdale in age, but it is now believed to be Quaternary. The base of the volcanic rocks and the underlying sediments of this area on both sides of the boundary between New Mexico and Colorado has certainly not been tilted greatly but is nearly flat. Near the boundary between the two States the San Juan peneplain after its final deformation must have been much above the present surface and must have been completely destroyed by erosion.

FAULTING

Faults are rather difficult to discern in the volcanic rocks, because many of the formations are uniform from top to bottom and are more than 1,000 feet thick. Layering of the rocks is much poorer and less regular than in sediments, and only a few layers are visible. Only the Treasure Mountain, Piedra, and Hinsdale formations show much regular layering. Moreover, all of the normal contacts between members are somewhat irregular, and some of the contacts are extremely irregular and in many places simulate faults. Exposures are commonly excellent but the faults and contacts tend to be in valleys or other topographic breaks and tend to be covered with talus and soil. However, it is believed that most of the large faults have been located and shown on the map. No attempt was made to map small faults with 100 feet or less of displacement.

Faults are scattered in all parts of the volcanic rocks, but there are many faults in an area, 20 miles in an east-west direction and 10 miles north-south, lying south of the center of the mapped area, and on all sides of the corner at which the San Cristobal, Creede, Pagosa Springs, and Summitville quadrangles meet. A somewhat smaller area of faulting lies in and near the head of the Lake Fork of the Gunnison River in the northwestern part of the San Cristobal quadrangle. The only long fault or fault zone in the volcanic rocks is about 30 miles long, and extends nearly across the eastern part of the San Cristobal quadrangle from Williams Creek on the south to Spring Creek on the north. Most of the faults are less than 10 miles long.

Most of the faults that cut the volcanic rocks either bound or are associated with horsts or graben, and the beds on all sides of the relatively small disturbed zone are nearly flat and have not been displaced by the faulting.

The age of only a few of the faults can be determined. The fault west of the West Fork of the San Juan River cuts the Alboroto rhyolite and Huerto quartz latite but is overlain by the Piedra rhyolite. The fault in the head of Beaver Creek a few miles to the east of the one just described and apparently connecting with it, cuts the Piedra but is overlain by the Fisher quartz latite. The north-south fault in the southwestern part of the Saguache quadrangle cuts the Piedra but does not appear to displace the Hinsdale formation. The faults near Creede cut the Potosi volcanic series and Creede formation and the Fisher quartz latite. The faults west of Summitville cut the Fisher. The two faults bounding the graben in the northeastern part of the San Cristobal quadrangle cut the Hinsdale. The fault in the eastern part of the Creede quadrangle, east of the village of South Fork, cuts the Hinsdale.

HEAD OF LAKE FORK OF THE GUNNISON RIVER

Southwest of Lake City the oval body of Sunshine Peak rhyolite is bounded on the south, west, and north by a group of curved faults that dropped down the rhyolite and associated rocks. On the south and southwest, pre-Cambrian granite lies south and west of the faults. On the north, rocks of the Silverton volcanic series lie to the north of the faults. This fault zone probably has a large but uncertain displacement which decreases to the east at both ends.

North of the Lake Fork the fault is paralleled by a trench and dips steeply to the south. A group of faults with a general northwesterly strike extends for about 8 miles southwest of this oval fault zone (Cross, Howe, and Ransome 1905, p. 23-24). North of Cottonwood Creek faults separate the volcanic rocks from the granite and have broken the volcanic rocks into strips and blocks. Near some of the faults the volcanic rocks on the downthrown side dip at considerable angles into the faults. This is especially true in the block north of Cottonwood Creek where the base of the Burns quartz latite dips more than 1,500 feet down the slope toward the fault in a distance of 1.5 miles. A large part of the displacement along this fault must be represented by the dip of the rocks.

GRABEN IN NORTHEASTERN PART OF SAN CRISTOBAL QUADRANGLE

A graben on both sides of the Rio Grande in the eastern part of the San Cristobal quadrangle has a length of 20 miles and a width of 1 to 4 miles (fig. 33). The bordering fault and monocline on the east has a displacement of more than 1,000 feet near Lake Santa Maria, and the displacement may be as large at the head of Spring Creek. However, the fault was not located north of the head of Spring Creek.

In places along the break the displacement is taken up largely or entirely by tilting of the rocks. Northwest of Bennett Creek the lavas appear to dip down from the mesa at the crest to the valley. There may be some small breaks but there is no large fault. In other places the displacement is largely due to faulting.

The displacement on the west of this downthrown block dies out to the north in Deep Creek. Just south of South Clear Creek the displacement is more than 1,000 feet and is due to faulting (fig. 34, section *a–a′*), but less than a mile to the south in Spring Creek (section *b–b′*) the displacement is due to tilting of the lavas. The slopes on both sides of Spring Creek are nearly dip slopes and the lavas dip toward Spring Creek from both sides. The flat mesa at an altitude of 10,600+ feet 2 miles west of Spring Creek turns down toward the east, and slopes are dip slopes to Spring Creek. The lava descended about 1,400 feet from the top of the mesa to the creek bed. South of the Rio Grande the rocks on the upthrown side are flat, but those on the downthrown side are tilted steeply to the northwest away from the fault (fig. 34, section *c–c′*). Just south of the Rio Grande the dip is steeper than the slopes and the Huerto quartz latite is against the fault on the upper slopes and the overlying Piedra rhyolite is on the lower slopes. The beds flatten again in the valley of the Rio Grande.

In its wider parts, the block between the faults tends to be a syncline; elsewhere it dips to the southwest, away from the eastern fault. The displacement between the rocks on the two sides of the graben is small.

Three generalized sections across the graben are shown in figure 34. The first section (*a–a′*) extends from north of Bennett Creek southwest to the south of South Clear Creek. It shows the rocks on the east side of the eastern fault bending toward the fault, thus making the displacement chiefly by bending of the beds—a monocline. The second section (*b–b′*) crosses Spring Creek and Lakemans Fishponds.

It shows the rocks west of the western fault bending down toward the fault and forming a faulted monocline west of Spring Creek. The third section (*c–c′*) runs northeast from the ridge northwest of Woodfern Creek. It shows the rocks within the graben, near the western fault, tilted away from the fault.

The depression of the graben is about 2,000 feet.

At the time of the faulting the land surface must have been near the crests of the present bordering mesas, and the faulting and folding of the rocks now exposed took place at shallow depth—probably less than 2,000 feet.

As indicated by the names, there are large springs and marshes along the faults in Spring Creek north of the Rio Grande along the west fault, and also along the east fault in the other creek called Spring Creek.

THE FAULT IN WILLIAMS CREEK

South of the graben of Lake Santa Maria a fault (No. 1 on pl. 1) that is probably older than the graben,

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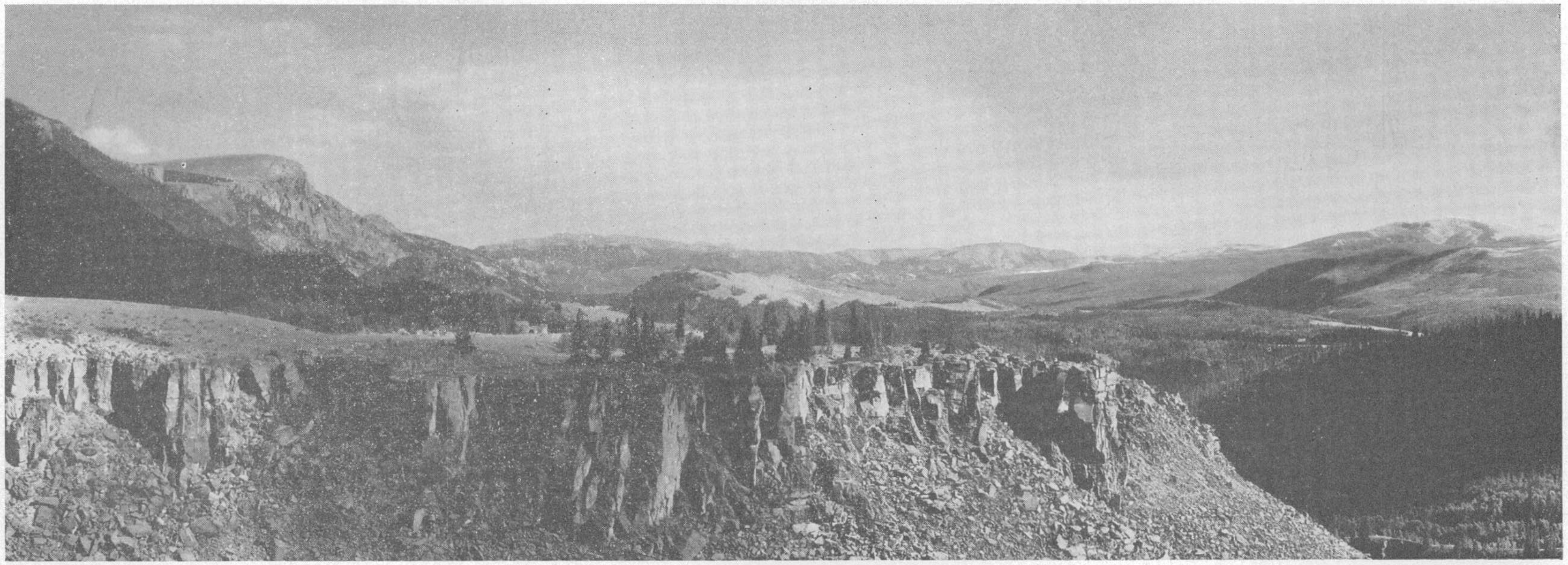

FIGURE 33.—The graben of Clear Creek, San Cristobal quadrangle, as viewed southward from Clear Creek Falls. Bristol Head is in the left background. The gap in which Lake Santa Maria lies is to the right of Bristol Head. Flows of rhyolite dipping west are west of Lake Santa Maria. The lower area is the downthrown block, and the steep slopes on both sides are the bordering masses. Photograph by J. W. Greig.

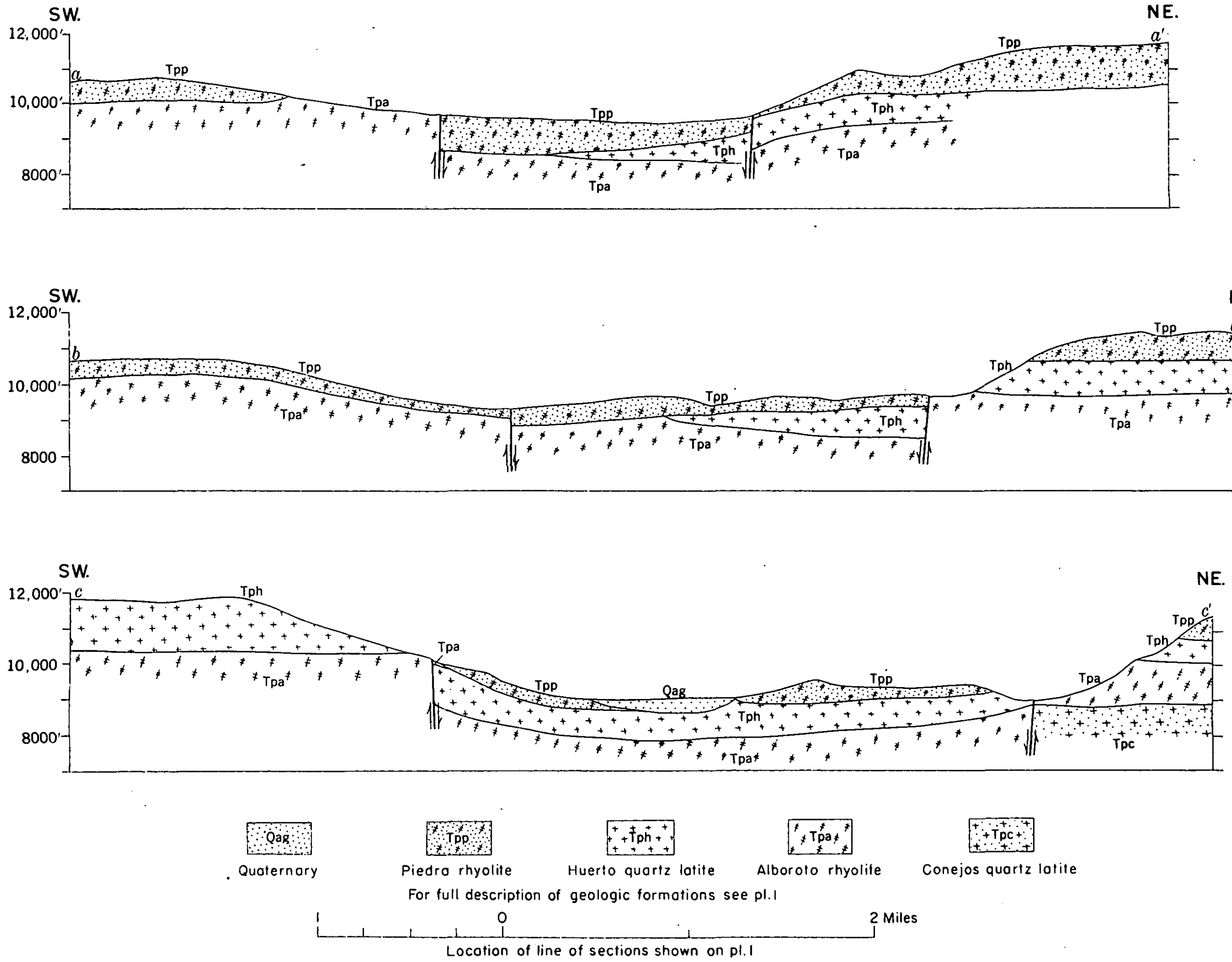

FIGURE 34.—Sections across the graben of Lake Santa Maria.

extends up Trout Creek and to the mouth of Williams Creek for a distance of about 13 miles. The rocks southeast of the fault have been downthrown, and the displacement is large over the exposed length of the fault. Near the mouth of Williams Creek where the Alboroto rhyolite is on the southwest side of the fault, the displacement is more than 2,500 feet and a few miles to the northeast where the Huerto quartz latite is next to the fault the displacement is more than 3,000 feet. In most of this area, a large part of the displacement is due to the fact that the rocks on the downthrown side dip steeply into the fault, thus increasing the displacement at the fault. The fault plane is nearly vertical. Where the Huerto is against the fault the tilting that is within 1.5 miles of the fault accounts for about 1,500 feet of the displacement. The fault may continue to the southwest in the sediments but with much diminished displacement because several branch faults on the downthrown side take up most of the displacement. The base of the Conejos quartz latite at the San Cristobal quadrangle boundary on the downthrown side of the projected line of the fault has about the same altitude as that on the upthrown side of the fault. Only 2 miles southeast of this great fault the base of the volcanic rocks is at about the same altitude as it is northwest of the fault though it dips northeast toward the fault zone. This fault cuts Piedra rocks.

The faulting northwest of the main fault in Williams Creek is complex and on too small a scale to show on the geologic map. A rough sketch map of this fault complex is shown in figure 35. The slopes in the area are steep and the exposures are excellent. The east-west fault on the south is well exposed, is nearly vertical, and has little fault breccia along it. The fault bounding the block on the north is well exposed along most of its course. It strikes N. 33° W. and dips 32° NE. at an altitude of 9,000 feet, and at 10,300 feet it strikes N. 70° W. and dips moderately to the north. It is a reverse fault and has several inches of comminuted material along it. The throw of the beds

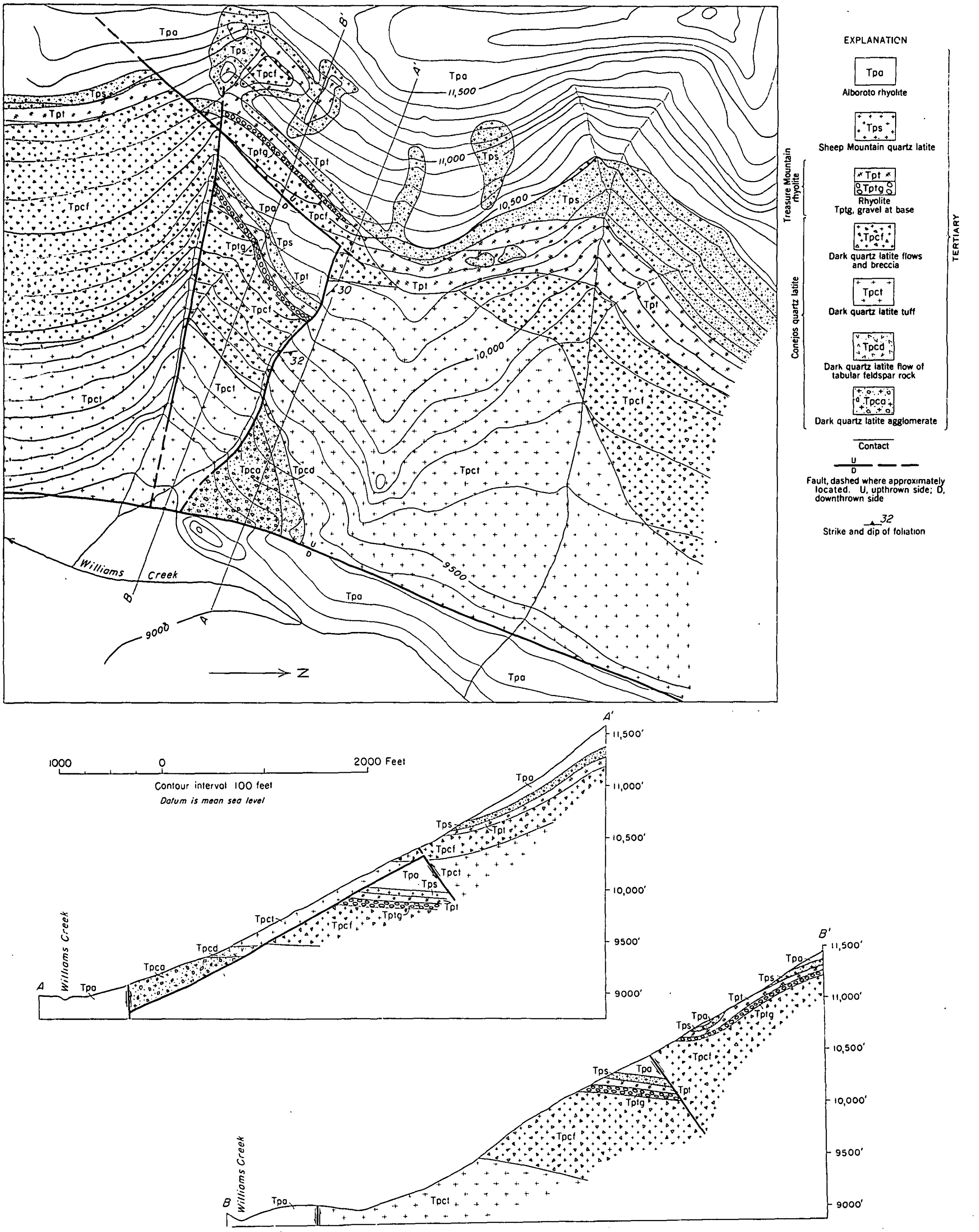

FIGURE 35.—Sketch map and cross sections of area west of Williams Creek, southeastern part of San Cristobal quadrangle, showing thrust fault. Arrows indicate general direction of the movement of the block.

appears to be about 800± feet. The fault on the west is not so well exposed. The beds west of this fault dip rather steeply, as much as 45°, into the fault. The block between the four faults is probably a small block that dropped down several hundred feet during the movement on the main Williams Creek fault. The rocks west and north of this block collapsed because their support was removed.

THE FAULTING EAST OF WILLIAMS CREEK

The main faults of this area bound two horsts, elongated in a northwest direction. There is a small elevated faulted block, several tilted blocks, and some other faults. The faults bounding the horsts are characterized by many angular changes in direction.

Most of the faults of this area cut the Huerto quartz latite and some cut the Piedra rhyolite; the fault in Beaver Creek in the Summitville quadrangle cuts the Piedra but not the Fisher quartz latite, and the fault near the southwest corner of the Summitville quadrangle cuts the Alboroto rhyolite but not the Piedra. Most of the faults are probably post-Piedra and pre-Fisher but the horst in the southwestern part of the Summitville quadrangle is pre-Piedra.

The larger and western horst extends from Middle Fork in the San Cristobal quadrangle, southeast across the Pagosa Springs quadrangle, and for a short distance into the Summitville quadrangle, for a total distance of about 12 miles. In its northern part it is only about a mile across and has rather definite bounding faults and few faults within it. It widens to about 4 miles in its southern part and near its southern end it breaks up into a complex of faults. This strip has been elevated more than 2,000 feet in its northwestern part and less in its wider, southeastern part. The irregular curved fault bounding the horst on the northeast (No. 12 on pl. 1) is nearly vertical where seen. The displacement is large, more than 2,000 feet in most places, but a good estimate cannot be made because the formations are of various thicknesses, and they are much deformed near the fault. Along most of the length of the fault the rocks on the northeast, or downthrown side of the fault, dip toward the fault for a distance of 1 or 2 miles. The depression of the beds by tilting is commonly 1,000 feet or more. Thus, about half of the displacement along the fault is due to tilting of the beds near the fault. North of Piedra River the Alboroto rhyolite has been dragged up into the fault on the downthrown side for a short distance away from the fault. This fault divides into a complex of faults in the head of Turkey Creek, and where these faults reach the base of the volcanic rocks they have small displacements.

The group of faults bounding the horst on the southwest is irregular near Middle Fork, but over most of its course it is a fairly straight fault. As with the rocks northeast of the horst, those to the southwest dip toward the horst, and this dip may account for a considerable part of the displacement along the fault. Moreover, on both sides of Middle Fork the beds dip toward the creek and into the irregular part of the fault forming part of the boundary. The fault (13) bounding on the southwest the sharp wedge at the extreme northwestern part of the graben is well exposed and crops out in a narrow gorge. The fault is nearly vertical. West of the fault (14), bounding the horst west of Middle Fork, the base of the Huerto quartz latite drops from an altitude of 11,700 feet to about 9,500 feet at the fault, a drop of 2,200 feet in a distance of 1.3 miles. On the west slopes of this ridge the rocks dip to the west toward the fault in Williams Creek, making the crest of the ridge the axis of an anticline, with both limbs of the anticline dipping into faults and the result of faulting. The rocks southeast of the fault (15) with northeasterly strike and just southeast of the east fork of Middle Fork also dip toward the fault and drop about 1,000 feet.

In the southern part of this horst, in the Pagosa Springs quadrangle, the cross fault (16) takes up part of the displacement of the fault forming the southwest boundary, and northeast of Quien Sabe Mountain the throw of the fault is only 600 feet.

The throw of the fault (17) east of Pagosa Peak is about 400 feet. The fault that strikes northeast (16), south of Four Mile Lakes, is mapped largely from the distribution of the rocks. It probably has a displacement of a few hundred feet. The long fault (18), east of Fourmile Creek, is well exposed west of Eagle Mountain where it is nearly vertical. It has a displacement of about 600 feet south of fault 20 and a much larger displacement to the north. It must join the fault to the west and it, with faults 19 and 16, bounds a rudely triangular block that has been elevated about 600 feet. The crooked fault (20) east and south of Eagle Mountain is well exposed in many places. Its displacement is probably moderate.

To the north, chiefly in the drainage of Turkey Creek and in the Summitville quadrangle, the fault bounding the horst on the northeast divides into a number of faults, and faulting ends in the basin of Turkey Creek. The fault (21) bounding the graben on the northeast has a displacement of the thickness of the Alboroto rhyolite (about 1,500 feet) between the forks of Turkey Creek but it appears to die out about 2 miles to the south. Between the forks of Turkey Creek the beds on both sides of the fault are nearly flat, and northwest of Saddle Mountain the beds on the northeast side dip rather steeply to the north or northwest and thus account for the decrease in the displacement. The fault southwest of the fault forming the boundary has a throw west of Turkey Creek of about 1,000 feet, but south of the branch faults it has a much smaller throw.

Another small horst (bounded by fault 22) is east of the one just described, chiefly in the southwestern part of the Creede quadrangle and adjoining parts of the Summitville quadrangle. The uplifted block is only about 1 mile wide and 3 miles long and is made up of Alboroto rhyolite. The Huerto borders the block. The block has probably been elevated nearly 2,000 feet in its northern part but the displacements on both faults that form the boundary decrease to nothing within a few miles. The faulting is post-Huerto and pre-Piedra, for Piedra rhyolite overlies the fault. The bordering faults are nearly vertical.

East of this horst in the basin of West Fork of San Juan River a fault (23) trends nearly east-west near the river, and east of the river curves around to trend generally north. At West Fork of San Juan River the north side is downthrown about 500 feet and a nearly parallel fault a mile to the north has a displacement of more than 500 feet in the same direction, making a total displacement of more than 1,000 feet. To the north, in Bennet Creek, the throw is about 3,000 feet. This fault displaces the Piedra rhyolite but not the Fisher quartz latite. It is therefore younger than the horst a few miles to the west, with which it appears to connect in space. There appears to be no sharp tilting of the rocks on either side of this fault.

The southern fault (2) east of Williams Creek dips about 50° to the southwest. The block to the southwest of the fault is tilted toward the north. The throw of the fault is about 1,500 feet.

The fault (3) north of the one just described is well exposed. About half way up a west-facing slope it dips 65° N. Just east of Williams Creek the displacement on this fault is more than 1,000 feet, but it decreases rapidly to the east, and the fault dies out near the crest of the hills. The block north of the fault dips to the west.

The acute wedge of Huerto quartz latite to the north is bounded by two faults (4 and 5) of undetermined displacement. The rocks on both sides of this wedge dip at considerable angles westward toward the Williams Creek fault, and rocks of the wedge must dip at an even steeper angle.

The small triangular block (6) of Alboroto rhyolite is elevated and probably tilted at an undetermined but probably large angle. The faults that form the boundary are well exposed and are all nearly vertical.

The fault near the head of Middle Fork (7) is in an area of altered rocks and the fault is inferred from the distribution of the rocks.

The next fault to the south (8) is well exposed. It has a throw of about 700 feet, and on the west side of the creek it dips 80° NE. Twenty feet of brecciated rock lie along the fault. The next fault to the southwest (9) parallels a small gulch and is well exposed. It is nearly vertical and has a throw of a few hundred feet.

The fault (10) near the head of Piedra River dips 80° NE. The Piedra rhyolite on the north and downthrown side dips toward the river from both sides, and throw along the fault decreases rapidly both northwest and southeast of the river.

The small fault (11) that is between the Piedra River and Middle Fork and north of the graben has a dip of about 40° north and is a reverse fault. It is well exposed and has from 1 to 3 inches of crushed material along it.

OTHER FAULTS

The faults near Rico (Cross and Ransome 1905, p. 8) and La Plata (Cross, Spencer, and Purington 1899, p. 11) cut intrusive rocks, but the age of the rocks is not known. In the Telluride quadrangle, north of Telluride, there are many small faults, some of which are mineralized (Cross and Purington 1899, p. 14).

The fault in Square and Antelope Creeks in the western part of the Saguache quadrangle was nowhere seen; the mapping is based on the distribution of the rocks. The throw is probably not large.

In the northeastern part of the Summitville quadrangle and adjoining part of the Conejos quadrangle, a large block, including Cornwall Mountain and the mining camp of Platoro, is bordered on three sides by faults. Both walls of all three faults are Conejos quartz latite and the fault has been located largely by the abrupt change in the type of rocks in the Conejos. The block between the faults has been elevated. No accurate estimate of the displacement can be made but east of Caldwell Mountain the throw appears to be about 2,000 feet.

The fault a few miles east of those just described is well exposed and has a steep dip. It drops Treasure Mountain rhyolite on the east against Conejos quartz latite on the west. In its northern part the displacement is about 300 feet but the Treasure Mountain rocks dip to the south and the displacement may increase to the south. This fault does not appear to displace the Hinsdale formation.

The fault south of the Rio Grande in the Creede quadrangle, west of Sentinal Peak, separates the Alboroto rhyolite from the Treasure Mountain rhyolite. The two rocks are very much alike but the fault can be located. Over much of its course it occupies a saddle or a gulch. It has an estimated throw near Sentinal Peak of 1,000 feet.

The faults near Creede, which have been described by Emmons and Larsen (1923, p. 85–97), are probably all post-Fisher in age. The Amethyst fault is the largest and dips 50°–70° W. It has a throw of at least 1,400 feet. It, like most of the other faults near Creede, strikes west of north.

COMPARISON OF OLIGOCENE (?) FAULTS WITH THE FAULTS THAT CUT THE VOLCANIC ROCKS

Most of the Oligocene (?) faults are of moderate length and are nearly straight or gently curved. Most of them are normal faults with steep dips; the Crookton fault and possibly some others are reverse faults. In most of these faults the rocks on the downthrown side have been dragged up along the fault and dip at rather steep angles away from the fault for as much as 1,000 feet. Large areas of rock have been displaced by the faulting.

Most of the faults that cut the volcanic rocks are relatively short, have angular breaks and branch faults, and are concentrated in short, narrow strips. For the most part they bound or are associated with small horsts and graben. Most of them are steep, normal faults; a few are reverse faults. The throws of the faults commonly change rapidly, either by branch faulting or by bending of the rocks. The areas of faulting and bending are relatively small, and the rocks surrounding these areas are nearly flat and are not appreciably displaced.

Around the graben in the northeastern part of the San Cristobal quadrangle, the rocks on the upthrown sides of the faults locally dip toward the faults and graben, and locally most of the throw is taken up by the bending of the beds bordering the graben. On the southern part of this graben the beds on the downthrown side of the fault dip away from the fault. Here also much of the throw is taken up by the bending of the beds within the graben.

The beds to the west and on the upthrown side of the small depressed block west of Williams Creek, in the southeastern part of the San Cristobal quadrangle, dip toward the fault bounding the block. This fault is believed to be a reverse fault although its dip was nowhere seen. The simplest explanation of this structure is that where the faults bounding a sunken block dip away from the block, the settling of the block removed the support of the rocks on the opposite side of the fault, and the rocks settled by bending for a mile or so from the fault, beyond which they are not disturbed. Where the bounding fault dips into the block, the beds on the downthrown side have been dragged against the fault and they dip in the same direction as the fault.

The area of faulting in the southeastern part of the San Cristobal quadrangle and adjoining areas is bounded on the northwest by the Williams Creek fault. The area in which the rocks are faulted and disturbed is 3 miles wide and about 20 miles long. In its northwestern part and in its southeastern part where there are two horsts, it is 12 miles wide. It contains two narrow horsts, elongated nearly at right angles to the Williams Creek fault. The faults bounding the horsts are characterized by angular breaks. There are some small upraised blocks, some small depressed blocks, and many branching and associated faults. All, or nearly all, of the disturbance of the rocks is in or near the fault zone, as the rocks on all sides are nearly horizontal and the mapped units are at their normal altitude on all sides of the fault zone. Near many of the main faults, commonly not more than a mile away, the beds are tilted. In some places the dip is along the fault, and in many it is toward the fault on the downthrown side. The larger horst has been thrust up about 2,000 feet. So far as determined, most of the faults are nearly vertical, normal faults.

On the downthrown side of some of the faults southwest of the graben in the northwestern part of the San Cristobal quadrangle, particularly northwest of Cottonwood Creek, the beds dip into the faults. Because of this tilting the depression in a distance of 1.5 miles is about 2,000 feet.

These horsts and graben must be due to local, vertical forces, possibly the movement of magma in depth. The bending of the beds toward the graben on the upthrown side of the bordering faults may be explained by settling of the beds on a sunken block that widened in depth. The bending of the beds bordering the horsts, and hence on the downthrown side, toward the faults bounding the horsts might be due to collapse of the beds if the elevated block became narrower with depth. It is also possible that if the rocks were broken by tension, due to some local cause such as the movement of magma, the rocks on the hanging wall side might settle along the fracture.

Gardner (1941) has described the Great Hurricane fault of southwestern Utah and northwestern Arizona, and attributes much of the post-Miocene movement to a local sagging of the strata on the downthrown side of the fault. He proposes the term sag in contrast to drag for this type of movement. The faulting in this area was more complex and the strata involved in the faulting were folded before the faulting and the structure is not so simple or clear as in the San Juan Mountains. Koons (1945, p. 163–166) does not agree with

Gardner but follows Dutton's interpretation that the Hurricane structure was formed by monoclinal flexing, followed by faulting that raised the lower limb of the monocline. Dutton's interpretation could not apply to the similar faults in the San Juan Mountains.

GEOLOGIC HISTORY

PRE-CAMBRIAN

Early pre-Cambrian time probably lasted as long and was as eventful as all of later time, but its records have been so obscured by later processes that only vague and incomplete traces remain. Repeated intrusions of granitic rocks took place, clastic sandstones and shales were deposited, and some volcanic rocks were probably extruded. All of these rocks have been so greatly metamorphosed that their original character must be determined chiefly from their chemical composition. The igneous rocks range in composition from granites to gabbros.

The ancient schists and gneisses of the Needle Mountains area and the Black Canyon schist of the Gunnison area are the oldest rocks of the region and they have been greatly metamorphosed and highly compressed. The River Portal mica schist and the Dubois greenstone are somewhat younger and they, too, have been subjected to a later metamorphism.

After extensive erosion of the older, highly metamorphosed pre-Cambrian rocks, a local volcano erupted andesitic rocks, the Irving greenstone. Some sands were interlayered with the extrusive rocks.

After some erosion of the Irving greenstone, a thick quartzite-conglomerate, the Vallecito conglomerate, was deposited, and this was followed by sandstones and shales of the Uncompahgre formation. These sediments, which make up the Needle Mountains group, are several thousand feet thick. No trace of the older quartzites which furnished the pebbles for this group is known. The quartzites of the Uncompahgre had a wide distribution, as they are known near Rico, Ouray, in the Needle Mountains, and in the Brazos canyon area of New Mexico a few miles south of the Conejos quadrangle. They and the Irving greenstone have been mildly metamorphosed and complexly folded and faulted.

The granitic rocks that intrude the schists and gneisses of the older pre-Cambrian differ greatly in age, texture, and composition. Some of the mapped rocks are closely related in time and form complex batholiths, but batholithic intrusion occurred many times. The Twilight, Tenmile, and Whitehead granites, the granite of Pine River, and the syenite of Ute Creek were probably intruded before the deposition of the Irving greenstone. They are all gneissoid.

The rocks of the Pine River batholith, which show no metamorphism, intrude the Uncompahgre quartzite. The granite of the Florida River area and the Trimble granite, the granodiorite of the Needle Mountains, and probably the gabbro of the Needle Mountains are younger than the Pine River batholith.

The stock of pyroxenite and alkalic rocks, with associated carbonate, near Iron Hill in the eastern part of the Uncompahgre quadrangle are younger than the youngest of the granites of the area and older than the Morrison formation of Late Jurassic age.

PENEPLANATION AND DEPOSITION OF PALEOZOIC SEDIMENTS

In late pre-Cambrian time, after the granitic rocks were intruded, the area must have been occupied by great mountains. It remained relatively stable, and erosion reduced it to a flat surface of low altitude. In the western area this peneplain was submerged beneath the sea in late Cambrian time and the sands of the Ignacio were deposited on it. Rare fossil shells show that life was present in this sea. In the northwestern part of the area near Bonanza the Cambrian is absent and Ordovician limestones and sandstones overlie the smooth surface of the pre-Cambrian. In the western area there was either a long period of erosion, or a period during which no sediments were deposited, as Ordovician, Silurian, and Lower and Middle Devonian rocks are absent. In the northeastern part of the area the Ordovician is present but the Silurian and Lower and Middle Devonian are absent. In late Devonian time the western area was again beneath the sea and the calcareous shales and impure limestones of the Elbert formation were deposited on the Cambrian with apparent conformity, except that locally the Cambrian is missing. The shales of the Elbert commonly contain the casts of salt crystals, indicating that they were deposited from a concentrated brine. The Elbert also contains fossil fish.

After the deposition of the Elbert formation the western area was more deeply submerged and the uppermost formation of the Devonian, the Ouray limestone, was laid down. Deposition of limestone continued without break into the Mississippian, when the Leadville limestone was deposited. Fossil shells are abundant in both these formations. In the eastern area the Devonian, corresponding approximately to the Ouray, consists of a lower sandstone member and an upper limestone, and has been called the Chaffee formation. It is overlain by the Leadville limestone.

The western area was elevated above the sea, but without folding of the beds. After the deposition of the Ouray limestone, weathering leached the limestone, leaving a residue of red mud. In Pennsylvanian time the area was again depressed beneath the sea and the red muds and sands of the Molas formation were laid down, and were followed by a thick series of interbedded sands, shale, and limestone called the Hermosa formation. Both these Pennsylvanian formations contain fossil shells. In Permian (?) time the fossiliferous red beds of the Rico formation were deposited beneath the sea. Elevation probably followed, and then ensued the deposition, probably subaerially, of the thick series of red sands, muds, and conglomerates called the Cutler formation.

In the northeastern area the dark shales and sandstones, with some coal and plant remains, called the Kerber formation, of Pennsylvanian age, overlie the Leadville limestone. The Maroon formation, which is of Pennsylvanian and Permian age and which carries fossil shells and leaves, was laid down next and is probably the equivalent of the Rico and Cutler formations.

DEFORMATION, PENEPLANATION, AND DEPOSITION OF TRIASSIC AND JURASSIC (?) SEDIMENTS

In the San Juan region there was little elevation or deformation following the Permian, as the Upper Triassic and Jurassic (?) red beds of the Dolores formation overlie a rather smooth surface of the Permian beds without unconformity, except near Ouray where they transgress all of the Permian. However, to the west and northwest there were much folding and elevation, followed by peneplanation. The position of the Dolores beds on the beveled, upturned edges of the older rocks, and in places on the pre-Cambrian indicates this. The Dolores is terrestrial and contains the remains of crocodiles and dinosaurs.

DEFORMATION, PENEPLANATION, AND DEPOSITION OF JURASSIC AND CRETACEOUS SEDIMENTS

After the deposition of the Dolores formation, extensive folding and elevation, followed by peneplanation, took place east of Ouray and in the southern area east of the Piedra River. The overlying Jurassic rocks, the Entrada sandstone, and the Morrison formation, rest on the bevelled edges of the older rocks and over large areas rest directly on the pre-Cambrian. However, in the western area the Jurassic rocks seem to be conformable, except for some erosion, on the Triassic and Jurassic (?).

Beds of Early and Late Cretaceous are present. The Early Cretaceous strata rest with apparent conformity on the Morrison formation. The Cretaceous is a thick series of sandstones and shales, with some beds of coal and some conglomerates, and has been divided into several formations. The members are conformable except that the upper one, the McDermott formation, locally overlies an erosional surface cut on the older Cretaceous rocks.

DEFORMATION AND VOLCANISM IN LATE CRETACEOUS TIME

No evidence of volcanism in the area, with the possible exception of the alkalic rocks of the Iron Hill area, has been found in the rocks from Cambrian to the upper part of the Upper Cretaceous, but volcanism was active, probably in the Needle Mountains area, during McDermott time, because the McDermott formation near Durango contains abundant fragments of andesitic and rhyolitic rocks. Volcanism may have continued into early Paleocene time, for the Animas formation and the Ridgway till contain abundant fragments of volcanic rocks. The volcanic rocks were largely eroded away by the end of Animas time and no further eruptions took place, for the later Eocene and Oligocene (?) rocks are nearly or quite free of volcanic material.

THE PALEOCENE AND EOCENE

At the base of the Paleocene there is an unconformity, represented by extensive erosion. The Paleocene and Eocene beds are of terrestrial origin. There is an unconformity with no great discordance of dip at the top of the Animas formation and another at the base of the Wasatch formation. Alpine glaciation took place in early Paleocene time and is represented by the Ridgway till.

DEFORMATION FOLLOWING THE EOCENE

One of the great periods of deformations of the area may have begun at the end of the Cretaceous, but the main movement followed the Eocene, for the Eocene beds are folded with the older rocks. Doming, accompanied by folding and faulting, elevated the central area near the Needle Mountains as much as 15,000 feet. In the eastern part of the mountains the pre-Eocene rocks are in large part covered by volcanic rocks, but the presence of a few outcrops of pre-Cambrian rocks in this area indicate that it, too, was greatly elevated. The elevated area corresponds roughly with the main San Juan Mountains, with some extension to the north and northeast, an uncertain extension to the east, and a prong east of the Chama River extending southward into New Mexico.

Erosion reduced the area to a peneplain which seems to have been rather flat in the western and southern parts of the mountains but had some relief in the central and northeastern parts. The surface sloped away from the present mountains on their western and southern flanks.

THE OLIGOCENE (?) OR EARLY MIOCENE

The Telluride conglomerate was deposited in the western part of the mountains on the peneplain. It is thick near the western border of the mountains, becomes thinner to the east, and pinches out east of Ouray. In the southern part of the mountains the Blanco Basin formation was laid down on the post-Eocene peneplain. Both the Telluride and Blanco Basin are terrestrial and neither contains fragments of volcanic rocks.

PRE-POTOSI VOLCANISM

In the western part of the area the main volcanism of the mountains began in the late Miocene (?), and the earliest eruptions built up a volcano consisting of flows and clastic beds of dark quartz latites, the Lake Fork quartz latite of the Uncompahgre quadrangle. This volcano doubtless is younger than the Telluride conglomerate. The San Juan tuff, which is a series as much as 3,000 feet thick of poorly bedded quartz latite tuffs and conglomerates, followed the Lake Fork. It rests conformably on the Telluride conglomerate or older rocks. Few of the fragments in the San Juan were derived from the Lake Fork and most of the San Juan, at least in the northern area, was derived from explosive eruptions from volcanoes whose positions are not known.

For a short time after the deposition of the San Juan tuff no eruptions took place and deep canyons were eroded in the volcanic rocks.

The different formations of the Silverton volcanic series followed. The Picayune quartz latite filled in the canyons and formed a blanket on the volcanic mountains. It was followed by the Eureka rhyolite.

Another short period without volcanic eruptions followed, and canyons were again eroded in the older rocks. The Burns quartz latite was deposited on the mountainous surface. Still another interval without volcanic eruptions followed, and new canyons were cut by erosion. The dark quartz latite of the Silverton volcanic series was erupted on this surface. The pyroclastic eruptions of the Henson tuff were next deposited.

In the eastern part of the area pre-Potosi rocks are made up of several groups of quartz latites, which are separated by surfaces of erosion. At the beginning of the Potosi eruptions they formed a mountainous terrain.

DEPRESSION AFTER THE ERUPTION OF THE SILVERTON VOLCANIC SERIES

After the eruption of the Silverton volcanic series the northwestern area was depressed several thousand feet and a long interval without eruptions followed, during which the area was reduced by erosion to a land of low relief. The eruption of the Potosi volcanic series then followed.

THE POTOSI AND FISHER ERUPTIONS

In the southern part of the mountains the Potosi volcanic series rests with apparent conformity on the Blanco Basin formation; in the western and central part it rests on a mature surface cut on older rocks; and in the eastern part it rests on a rather mountainous surface of older rocks. The Potosi makes up about three-quarters of the Tertiary and Quaternary volcanic rocks of the area. It has been divided into six formations. The first eruptions, called Conejos quartz latite, make up about half of the volume of the Potosi and is a dark quartz latite, consisting of flows and clastic rocks with several volcanic necks in the central part, and bedded tuff near the margins. The tuff grades to tuffaceous sands and conglomerates with interlayered arkoses on its margins. For a short time after the Conejos eruptions volcanism ceased, and canyons several thousand feet deep were eroded. The Treasure Mountain rhyolite spread over this surface and was followed, with a sharp break in the character of the rocks, by the Sheep Mountain quartz latite. A second short interval followed without volcanism and new canyons were eroded. The Alboroto rhyolite were next erupted and form the largest of the rhyolitic formations. The dark quartz latites of the Huerto were next erupted and were followed by a third short interval without volcanism, and a third series of canyons were eroded. The Piedra rhyolite was spread over this surface.

RELATIVE STABILITY DURING POTOSI AND FISHER ERUPTIONS

Another interval without volcanism followed the deposition of the Piedra rhyolite, and a deep canyon near Creede was partly filled with rhyolitic tuff with some flows from a local center. Much talus and wash from the steep slopes overlie the tuff and are interbedded with it. A further time without eruptions followed and canyons were eroded in the tuff. The Fisher quartz latite erupted upon this surface from several centers.

During Potosi and Fisher time the central part of the volcanic area remained as a high mountain mass, but the eastern border, and especially the area of the Conejos quadrangle, must have been depressed as the volcanic rocks were erupted nearly as much as the thickness of the volcanic rocks. This seems so because no canyon erosion has been found in the area, and the rocks from Conejos quartz latite to Hinsdale formation seem to be conformable.

SUBSIDENCE AND PENEPLANATION FOLLOWING THE FISHER ERUPTIONS

Just after the Fisher eruptions, the main mountain mass must have subsided several thousand feet, but near the margins of the mountains, especially on the eastern and southeastern margins, little or no subsidence took place. The San Juan peneplain was eroded on this surface, probably in early Pliocene time.

HINSDALE VOLCANISM

The Hinsdale formation was erupted on the San Juan peneplain. The Hinsdale is made up chiefly of thin flows of basalts and latite and has local bodies of rhyolite in the lower part.

DOMING FOLLOWING ERUPTION OF HINSDALE FORMATION

After the Hinsdale eruptions the mountains were domed and folded. The maximum uplift of the dome in the Needle Mountains area was more than 10,000 feet. The last movement took place after the Cerro glaciation. A few small bodies of andesitic rocks were erupted during the Quaternary.

Erosion, in part by glaciers, has carved the present mountains.

AGE OF THE VOLCANIC ROCKS

The volcanic pebbles found in the conglomerates of the McDermott and Animas formations must have come from volcanic mountains that existed in the San Juan area in very Late Cretaceous and very early Paleocene times. These volcanic mountains were probably removed by erosion by early Paleocene time, since most of the Eocene beds contain no volcanic fragments. Some intrusive rocks near Ouray must have preceded the great doming of the mountains that followed the Eocene.

The Lake Fork quartz latite and the pre-Potosi rocks of the eastern area are younger than the post-Eocene deformation and are probably Miocene. The San Juan tuff overlies the Telluride conglomerate and is also probably Miocene.

Well-preserved fossils are not abundant in the volcanic rocks but in a few places and in a number of the formations fossil plants and insects have been found in the interbedded tuff horizons. Fresh-water shells have been found in some of the limey layers. Knowlton has examined fossil plants from the tuff of the Burns quartz-latite of the Silverton volcanic series, from the Conejos, Huerto, and Piedra formations of the Potosi volcanic series, and from the Creede formation near Creede. The latter contain the best flora. Knowlton (1923) described the fossils collected by us and concluded that the fossils from all the beds from the Silverton to Creede are much alike and are to be correlated with the Florissant beds of late Oligocene or early Miocene age. This crowds a great amount of complicated volcanism into a short time.

Much larger collections of fossils have since been made from the Creede formation. After studying these, Roland W. Brown of the U. S. Geological Survey furnished the following report to us:

> Most of the flora from the Creede formation come from outcrops along the Rio Grande and its tributaries in the vicinity of Creede, Colo. The composition of this flora, except for a few apparently discordant species, is not greatly unlike that of the flora growing near Creede today, or in areas not too distant from Creede, so that the assignment of the flora to the late Miocene or perhaps early Pliocene seems reasonable and in accord with the aspect of the flora.
>
> Collections from the Conejos and Huerto formations, underlying the Creede formation, are poor in species and not well preserved. Therefore the identifications and, in consequence, the correlations of these florules are uncertain.
>
> The strong resemblance formerly seen between the Creede and Florissant floras is unfounded. Only a few species in both floras seem to be closely related, but when viewed in their total aspects and compositions the floras are strikingly dissimilar. The Florissant flora contains elements reminiscent of the later Eocene floras of Colorado, Wyoming, and Utah, and of the Oligocene floras of Montana, Idaho, Oregon, and Washington. Moreover, the Florissant lake beds have yielded an opossum, whose evolutionary position strongly suggests Oligocene age. Consequently, the Florissant flora is now regarded as most likely of Oligocene age and considerably older than the flora from the Creede formation.

The Fisher quartz latite is younger than the Creede formation and older than the subsidence of the area that preceded the erosion of the San Juan peneplain. It is probably of late Miocene age.

The subsidence that preceded the San Juan peneplain took place near the end of the Miocene. The erosion of the peneplain was probably in the Pliocene and the eruption of the Hinsdale rocks was probably late Pliocene. The elevation of the mountains that followed was not completed until after the Cerro glaciation. The small scattered bodies of Quaternary volcanic rocks are not all of the same age. The latite and basalt in the Conejos quadrangle probably were deposited after the Cerro glaciation.

GENERAL PETROLOGY

CRYSTALLIZATION AND TEXTURE

MINERALOGY

The detailed mineralogy of the lavas of San Juan Mountains, including many chemical analyses, has been discussed by Larsen, Irving, Gonyer, and Larsen (1936, 1937, 1938) and only an outline and the petrologic results will be discussed here.

THE SILICA MINERALS

Quartz, tridymite, and cristobalite are all abundant in the lavas of the San Juan Mountains. Quartz is present as phenocrysts in lavas ranging from basalt to rhyolite. In the dark rocks, the associated phenocrysts, sanidine, sodic cores to the plagioclase, and the extensive resorption lead to the conclusion that quartz did not crystallize from these magmas but represents phenocrysts from a rhyolitic lava that was partly dissolved by the mafic rock. Because the Potosi volcanic series is a complex succession of dark quartz latites and light-colored rhyolitic rocks, because they are the most widespread group of rocks, and because they make up the greater part of the volcanic pile, they offer the most data on the minerals and crystallization of the lavas.

The distribution and amount of quartz phenocrysts in the analyzed rocks of the Potosi is shown in figure 38 and that of the other petrographic provinces in figures 36, 37, 39, and 40. Quartz phenocrysts are rare in rocks to the left of position 15 on the variation diagram—they are much less common than the figure indicates, for rocks with quartz phenocrysts were selected for some analyses. All of these quartz phenocrysts are believed to be relicts of rhyolitic inclusions. Between positions 15 and 21 quartz phenocrysts are rather common on figure 38; and they are much more common in the Potosi rocks as a whole, where they are present in the great mass of rhyolitic quartz latites of the Alboroto rhyolite and in the upper layers of the Piedra rhyolite. However, they are uncommon in the small bodies of such rocks in the dark horizons of the Potosi, and in some of such rocks in the Piedra. Probably more than 90 percent by volume of the Potosi rocks of this composition contain quartz phenocrysts. In the rocks between positions 21 and 30 quartz phenocrysts are rare, but some of the rhyolites on the extreme right contain abundant quartz phenocrysts.

These facts, together with the break in the variation curves of the Potosi volcanic series at positions 15 to 21, indicate that quartz begins to crystallize near position 15 on the variation curve and crystallizes until position 21 is reached where there must be a reaction relation and quartz is resorbed. Quartz does not again crystallize until about position 30.

Quartz is the only silica mineral in the intrusive rocks, except those that crystallized near the surface. It is present in the groundmasses of some of the rhyolitic rocks but is less common than tridymite and cristobalite. It is common as a spongelike intergrowth, with alkalic feldspar in the groundmasses of the dark lavas. Quartz is rare in the spherulitic intergrowths.

Tridymite does not form phenocrysts but it is a common and abundant mineral in many of the rhyolitic rocks of the San Juan Mountains where it is commonly present in the porous parts of the rocks. It is present in the vesicles of some of the dark rocks. Not uncommonly, rocks with quartz phenocrysts contain abundant tridymite in the groundmasses; yet quartz and tridymite are rarely found together in the groundmass. Tridymite is abundant as the cementing material in some of the welded tuffs.

Cristobalite in small amount is common as small white hemispheres attached to the walls of the larger gas cavities of the dark rocks, but such hemispheres are most uncommon in the rhyolitic rocks. In the rhyolitic rocks cristobalite is the chief silica mineral in the spherulites and other dense submicroscopic groundmasses.

The inversion of tridymite or cristobalite to quartz has been found in few places in the San Juan Mountains and only where mineralizing solutions have permeated the rocks. These minerals appear to persist almost indefinitely, if not indefinitely, under ordinary conditions. No doubt, hot solutions or slight metamorphism will cause their inversion to quartz.

Quartz is the only silica mineral formed in the early stages of crystallization of any of the lavas, and the temperature of crystallization must have been within the range for which quartz is stable—below 876° C. plus an adjustment for pressure. Tridymite was formed as an unstable mineral by rapid crystallization in the presence of abundant mineralizers. The hemispheres of cristobalite on the walls of large gas cavities are similar to the cristobalite formed by Greig, Merwin, and Shepherd (1933) by volatile transport in water vapor. The cristobalite in the dense, submicroscopic groundmasses was formed by rapid crystallization without equilibrium.

In the lavas of the San Juan Mountains there are probably more tridymite and more cristobalite than quartz.

PLAGIOCLASE

Plagioclase phenocrysts of various amounts are present in nearly all the lavas of the San Juan region except for the soda-rich rhyolites. They commonly make up from 18 to 30 percent of the quartz latites and a smaller amount of the rhyolites. This is about half the amount in the norm. The average anorthite content of the plagioclase phenocrysts differs greatly in rocks of the same composition, but in general it is about An_{70} at position 0 and decreases to the right to An_{20} at position 30. Plagioclase poorer in anorthite than An_{20} is rare. The phenocrysts of a rock commonly contain about 20 percent more anorthite than the normative plagioclase.

Nearly all of the plagioclase phenocrysts are zoned as described by Larsen, Irving, Gonyer, and Larsen (1938, p. 228–233). Some have calcic cores, much resorbed and replaced, with sharp outer zones that are much more sodic. In a quartz latite of the Los Pinos gravel the core is An_{85} and the outer part about An_{20}. Others have very sodic cores with calcic borders. No doubt, both the calcic cores and the sodic cores represent foreign feldspar that was not in equilibrium with the melt and that has been partly resorbed and reworked. These foreign feldspars form only a small part of the feldspar phenocrysts of any rock.

The Alpine Plateau type of the basalt, of the Hinsdale formation which is abundant in the Uncompahgre quadrangle, commonly carries abundant phenocrysts of plagioclase, some of which are 40 mm across. Nearly all of the larger crystals and the outer zones of the smaller ones are intergrown with coarse sanidine, and the plagioclase itself is an antiperthite with tiny lamellae of orthoclase. The cores of the plagioclase are strongly zoned from An_{15} to An_{45}. The outer porous parts are An_{10}, the coarsest intergrown sanidine has high indices of refraction and is probably rich in soda.

About 15 percent of the lavas contain phenocrysts of two different kinds of plagioclases.

The plagioclase phenocrysts contain some potash. The labradorites contain only a few percent of potash feldspar, the oligoclase and sodic andesines from 7 to 12 percent.

SANIDINE

In the Potosi volcanic series phenocrysts of sanidine are rare in rocks to the left of position 15 on the variation diagram (fig. 38), and they are present in nearly all the rocks to the right of that position. In the other formations of the San Juan region phenocrysts of sanidine are not common. Some of the dark rocks carry such phenocrysts, but they are believed to be foreign to the rocks. The phenocrysts of sanidine contain little lime—from 1 to 3 percent of anorthite; those in the rhyolitic latites carry about 24 percent of albite, and the albite increases as the rock moves to the right on the variation diagram and in the rhyolites, about position 30, they contain about 55 weight percent of albite. The evidence indicates that there is a reaction relation between sanidine and plagioclase near position 29 on the variation diagrams. Larsen, Irving, Gonyer, and Larsen (1938, p. 417–425) have given analyses and a detailed discussion of the sanidines.

AMPHIBOLES

Amphiboles are rare minerals in the rocks of the Hinsdale formation but they are common in the other formations. In the Potosi volcanic series they are commonly present in rocks between positions 10 and 26 on the variation diagrams but they are rare in quartz latites near the basalts and in the rhyolites. Some rocks have typical basaltic hornblende, others common green hornblende, others intermediate varieties. Two rocks of almost identical character may have different hornblendes—the one basaltic, the other green. This is true of the rhyolitic quartz latite of the Alboroto and of the lavas of the Los Pinos gravel. In a few flows the hornblende in the black glass at the base of the flow has green hornblende; the red porous or vesicular part of the flow has basaltic hornblende. The two amphiboles from the rhyolitic quartz latite of the Alboroto are identical in chemical composition, except that the basaltic hornblende contains little water and its iron is largely ferric. The loss of hydrogen from the hornblende would account for the low content of water and the high content of Fe_2O_3. The basaltic hornblende was probably formed near the surface and the iron of both the hornblende and the rock were oxidized during the separation of the mineralizers as a separate gas phase.

Much of the amphibole of the lavas has been partly resorbed, and the resorption has gone to completion in some rocks. Resorption is more extensive in the dark rocks than in the rhyolites, and it is rare in the glassy rocks. These facts indicate that much of the resorption took place after the lavas were erupted. The resorption is accompanied by precipitation of pyroxene and iron oxide, and the pyroxene may be in larger crystals at some distance from the hornblende. In some of the small intrusive bodies the small apophyses have hornblende that has been little resorbed and no pyroxene. More slowly cooled parts show all stages in the resorption, and the granular parts of the body are pyroxene rocks with no relicts of hornblende. The resorption of the hornblende is believed to be caused by the loss of mineralizers when the magma was near the surface

BIOTITE

In the Hinsdale formation, biotite is common only in the rhyolitic rocks, but it is common in the rocks of the other formations. It is common in all rocks to the right of position 10 on the variation diagram of the Potosi volcanic series. It is more abundant than hornblende in the rhyolites.

Biotite has been resorbed in much the same way as the hornblende and in any rock the two show about the same amount of resorption. Some of the biotites contain chiefly ferrous iron, others contain little ferrous iron. A rock in which the hornblende is rich in ferric iron has biotite that is rich in ferric iron. The oxidation and resorption of hornblende and biotite take place under similar conditions.

PYROXENES

Pyroxenes are the most aboundant mafic mineral in the lavas of the San Juan Mountains. They are associated with olivine in the basaltic rocks, are the only mafic silicate in the low-silica quartz latites, are associated with biotite, with or without hornblende, in nearly half of the rhyolitic quartz latites, and are present in small amount in some of the rhyolites. Clinopyroxene that approaches pigeonite in composition is the only pyroxene in most of the basaltic rocks. Both clinopyroxene, with some clinoenstatite in solution, and hypersthene are present in most of the silica-poor, dark quartz latites, the clinopyroxene commonly predominating. Diopside is the common pyroxene in the more siliceous rocks.

Hypersthene is present chiefly in rocks that lie between positions 5 and 10 on the variation diagram. Clinopyroxene has a much wider range.

Except for the pigeonites of the basaltic rocks, the pyroxenes of the quartz latites and rhyolites, which cover a wide range in composition, are much alike. There is a tendency for those in the rhyolites to be low in iron content. This is not in agreement with the physical and chemical data on the pyroxenes nor with the data available for differentiated bodies or complex batholithes where the pyroxenes are low in iron content in the gabbros and become progressively richer in iron as the rocks become richer in silica (Larsen, 1948; Chapman and Williams, 1935, p. 514).

OLIVINE

Olivine is found chiefly in the less siliceous rocks, but it is present in rocks with 17 percent of quartz in the norm. Many rocks with olivine phenocrysts contain quartz in the groundmass or tridymite or cristobalite in the gas cavities. The olivines are all much alike and contain about 23 percent molecular weight of fayalite.

PHENOCRYSTS

The distribution and amounts of the various phenocrysts in the rocks of several of the formations are shown in figures 36–40 and the total amount of phenocrysts is shown in figure 41. The horizontal scale is that used on the variation diagrams (see p. 270 et seq.).

Plagioclase phenocrysts are present in nearly all the rocks, except for a few basalts and silica-rich rhyolites. Sanidine, quartz, and biotite appear at nearly the same place, position 17. Biotite is present in nearly all rocks to the right of this position and sanidine in many, but quartz has a short range and is rare in rocks to the right of position 22.5. Hornblende has about the same range as quartz but it is present in some rocks that are less siliceous. Augite is present in most of the rocks poor in silica, and it continues to position 26. Hypersthene is rare in rocks to the right of position 19. Olivine has a short range in rocks to the left of position 6.

Phenocrysts are most abundant in the intermediate rocks—the siliceous quartz latites. They are in small amount in the rhyolites.

CRYSTALLIZATION

Concerning chiefly the Potosi volcanic series, which range from basalt to quartz latite, and finally to rhyolite, the phenocrysts and other characteristics indicate that the crystallization took place about as follows:

The chief mineral to crystallize from the basalts is olivine, and it is followed by augite and plagioclase (An_{80}). Olivine, accompanied by augite and plagioclase, continues to crystallize as far as position 5 on the variation diagram, where the liquid part of the magma has about 10 percent of normative quartz. At this stage the plagioclase has about the composition

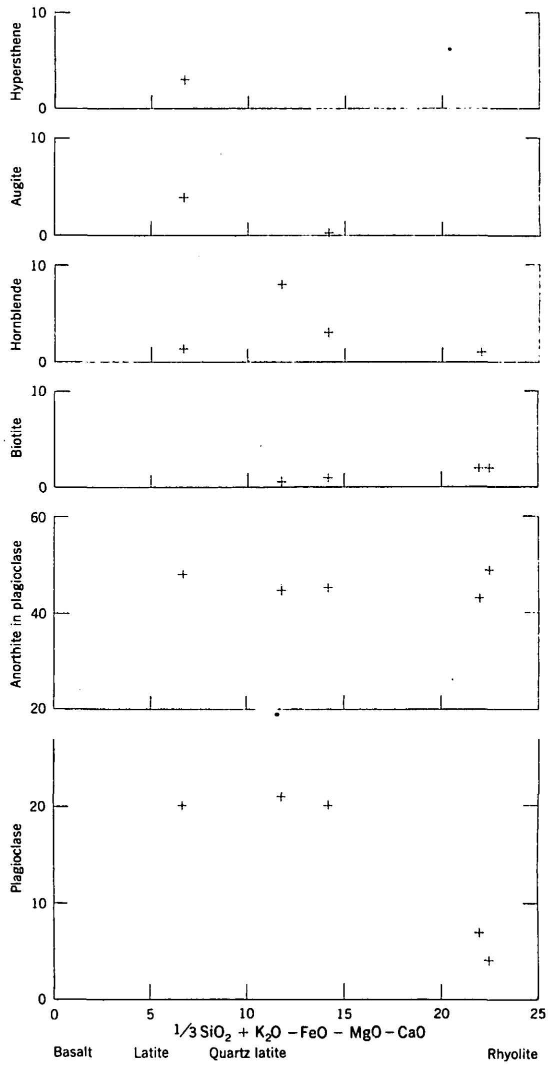

FIGURE 36.—Diagram showing variations in weight percent of phenocrysts in the Lake Fork quartz latite. [Weight percent calculated from Rosiwal analysis.]

$An_{65}Ab_{33}Or_2$, and the augite has about 12 percent of total iron (as FeO) and about 18 percent of clinoenstatite, and the olivine about 20 percent of Fe_2SiO_4.

After the olivine ceases to crystallize, plagioclase, augite, and hypersthene, with about 21 percent of total iron (as FeO), are precipitated. Hypersthene has a rather short range of crystallization, and augite is a common phenocryst only a little longer than hypersthene, until position 12 is reached and the silica content of the magma is about 63 percent. Under normal conditions there is a reaction at this point between hornblende and biotite, and between hornblende and the pyroxenes. Biotite is present in nearly all the rocks to the right of position 10, and hornblende is present in most rocks as far as position 27. However, pyroxene (especially augite) is fairly common, either with or without hornblende, to the right of position 10. Part

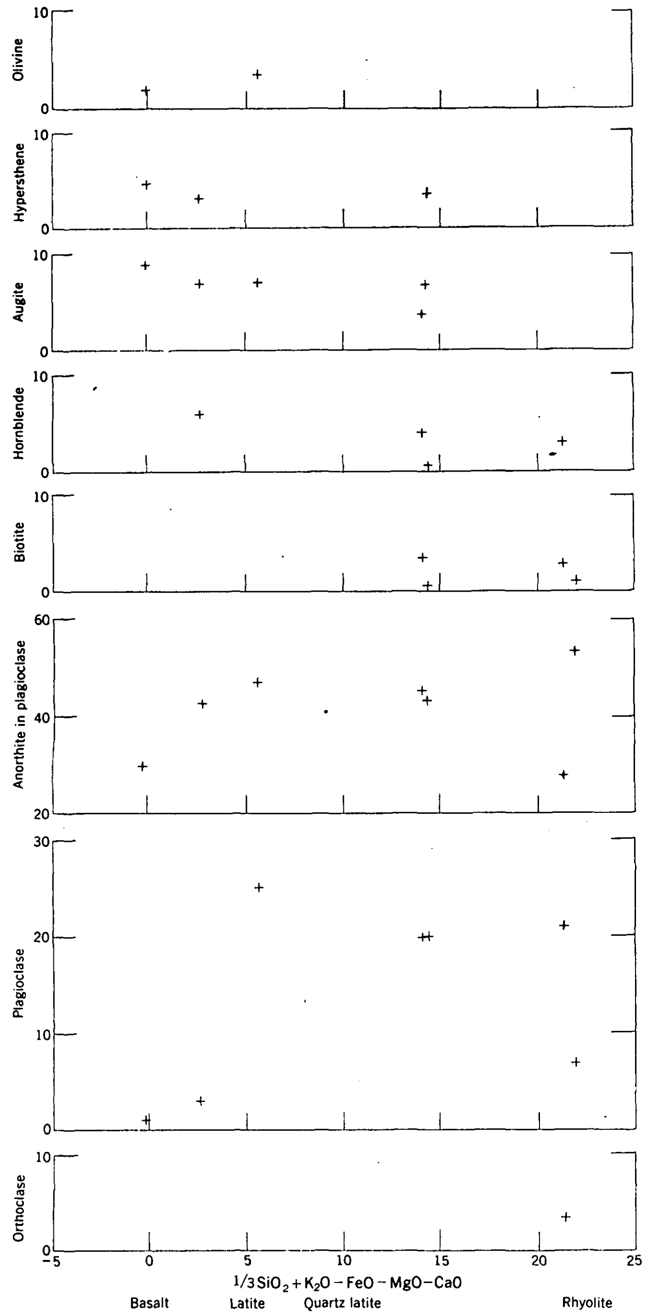

FIGURE 37.—Diagram showing variations in weight percent of phenocrysts in pre-Potosi rocks of the eastern area. [Weight percent calculated from Rosiwal analysis.]

of the pyroxene in the range may be due to reaction on hornblende near the surface, but much of it probably represents normal crystallization, especially where it is accompanied by biotite and hornblende that show little resorption. There is no appreciable difference in composition between augite rocks and hornblende rocks. Probably a difference in water content determines which mineral forms, and through an intermediate range both crystallize.

The relations between hornblende and biotite and between hornblende and the pyroxenes are not the same in the plutonic rocks as in the lavas. In plutonic rocks (Larsen and Draisin, 1948) it is common to find hornblende and, less common, biotite formed at the expense of pyroxene by a residual fluid enriched in mineralizers; whereas in the volcanic rocks the hornblende and biotite are resorbed and pyroxene crystallized, because of the loss of mineralizers by the magma. It is also true that the biotites and hornblendes of the plutonic rocks do not become enriched in ferric iron by loss of hydrogen as they do in lavas.

Data on the iron content of the dark minerals are not complete but the data indicate no systematic decrease in the ratio of MgO to FeO from basalt to rhyolite. This is in marked contrast to the minerals of related batholithic rocks. In the complex batholith of southern California (Larsen and Draisin, 1948), the dark minerals in the gabbros are rich in MgO, they become progressively richer in iron as the silica content becomes higher, and are rich in FeO in the granites.

The plagioclase decreases in anorthite content as the silica increases, and it reaches a limiting value of about 20 percent at position 29 on the variation diagram, or at a silica content of 74 percent. Beyond that point plagioclase is not present.

Sanidine of about the composition $Or_{74}Ab_{24}An_2$ begins to crystallize in small amount at position 15 where the silica content is about 65 percent, and it increases in amount and in soda content to the rhyolites on the extreme right. At position 30 on the variation diagram it has the composition $Or_{42}Ab_{55}An_3$.

Quartz begins to crystallize about the same time as sanidine and continues only to position 21, where it seems to become unstable. It is a rare phenocryst to the right of position 21 until the rhyolites are reached at about position 30, where it again appears with orthoclase and biotite.

Mineralogically, the Fisher rocks are much like the Potosi rocks except that they have fewer phenocrysts of quartz, and the phenocrysts are larger.

The pre-Potosi rocks of the eastern area are richer in potash and poorer in silica than the Potosi volcanic series. They have no phenocrysts of quartz, few of hypersthene and orthoclase, and fewer of hornblende and biotite than the Potosi.

The basalt and latites of the Hinsdale formation have much less silica and lime and more alkalies than the Potosi volcanic series. They lack hypersthene and hornblende, contain very little quartz as phenocrysts, and have very few phenocrysts of plagioclase except in the latites on the extreme right in the variation diagram where they are poor in lime, and rich in potash. They have abundant normative orthoclase but few pheno-

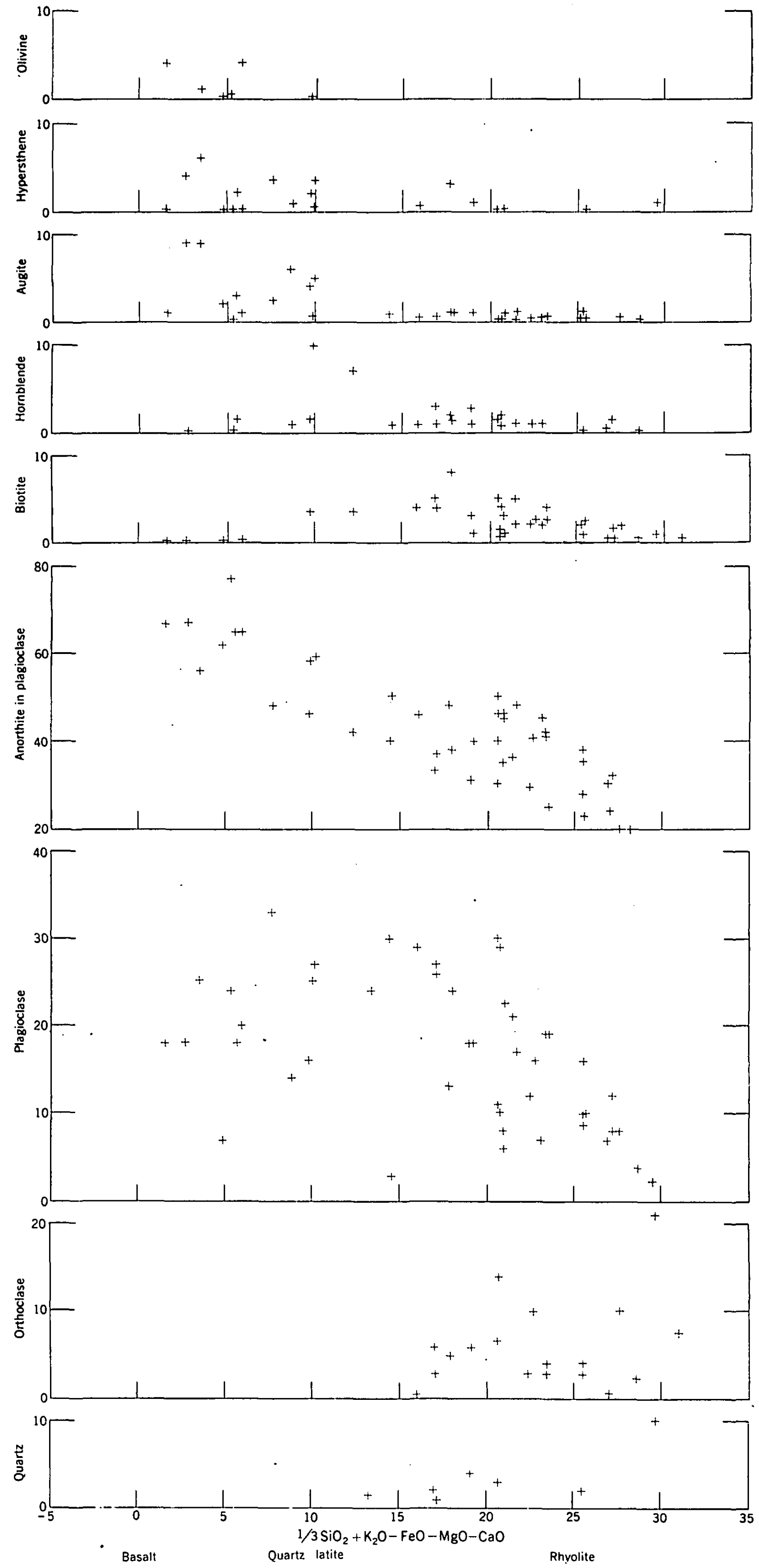

FIGURE 38.—Diagram showing variations in weight percent of phenocrysts in the Potosi volcanic series. [Weight percent calculated from Rosiwal analysis.]

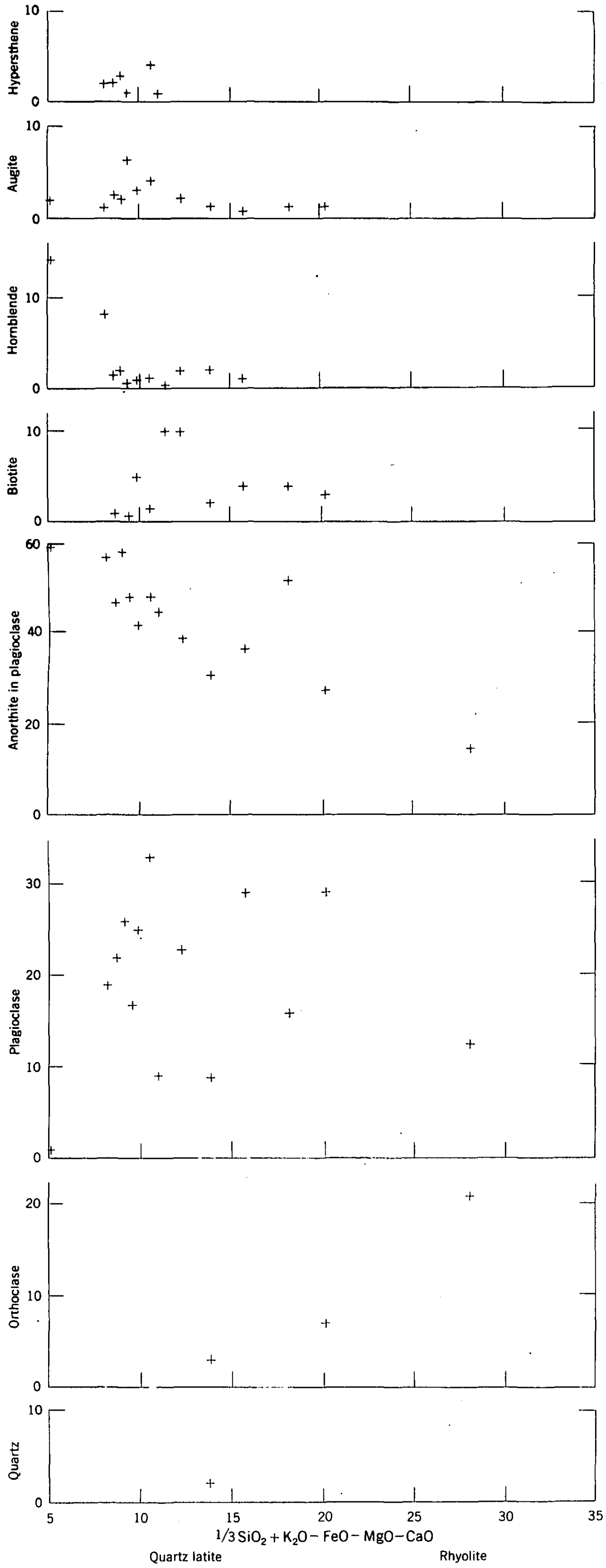

FIGURE 39.—Diagram showing variations in weight percent of phenocrysts in the Fisher quartz latite. [Weight percent calculated from Rosiwal analysis.]

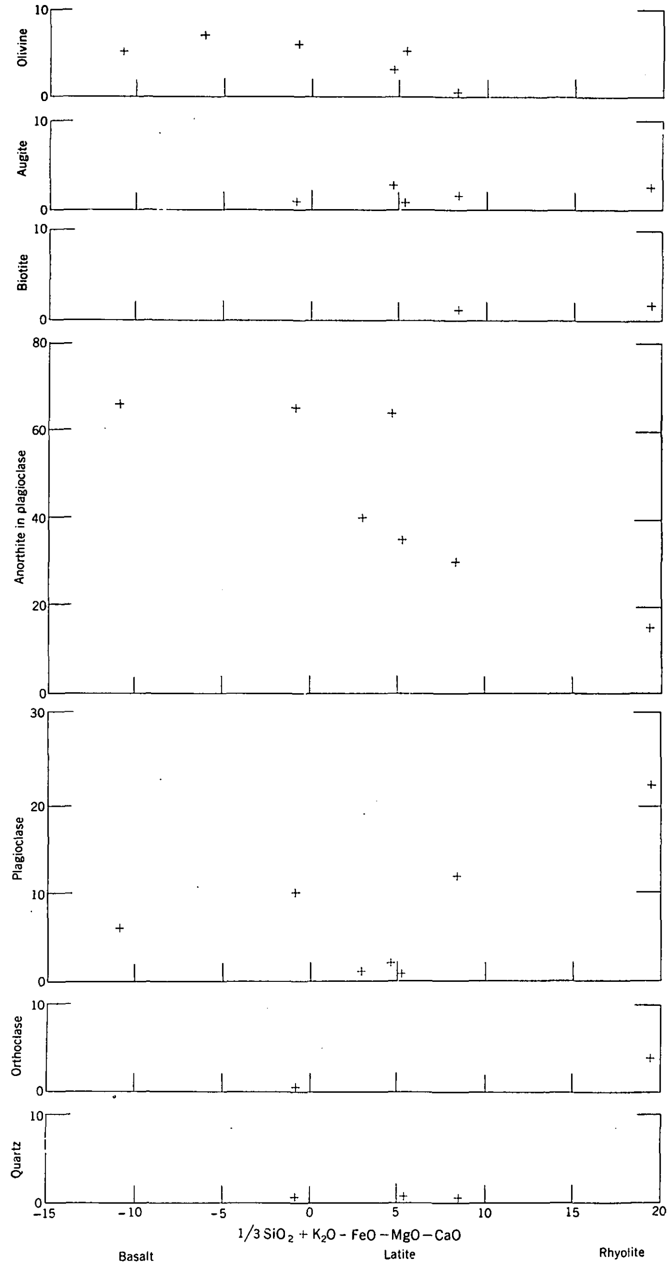

FIGURE 40.—Diagram showing variations in weight percent of phenocrysts in the Hinsdale formation. [Weight percent calculated from Rosiwal analysis.]

crysts of orthoclase. In the rocks richest in silica and alkalies the plagioclase ranges from An_{10} to An_{45} and is intergrown with orthoclase.

TEXTURES AND STRUCTURES

PERSISTENCE OF TEXTURES

In some respects, the textures of the rocks of a formation or of a group of related formations are more persistent and characteristic than either the mineral or chemical compositions. The rhyolitic quartz latite of the Alboroto rhyolite, estimated to have a volume of 1,000 cubic miles and distributed in an area 100 miles

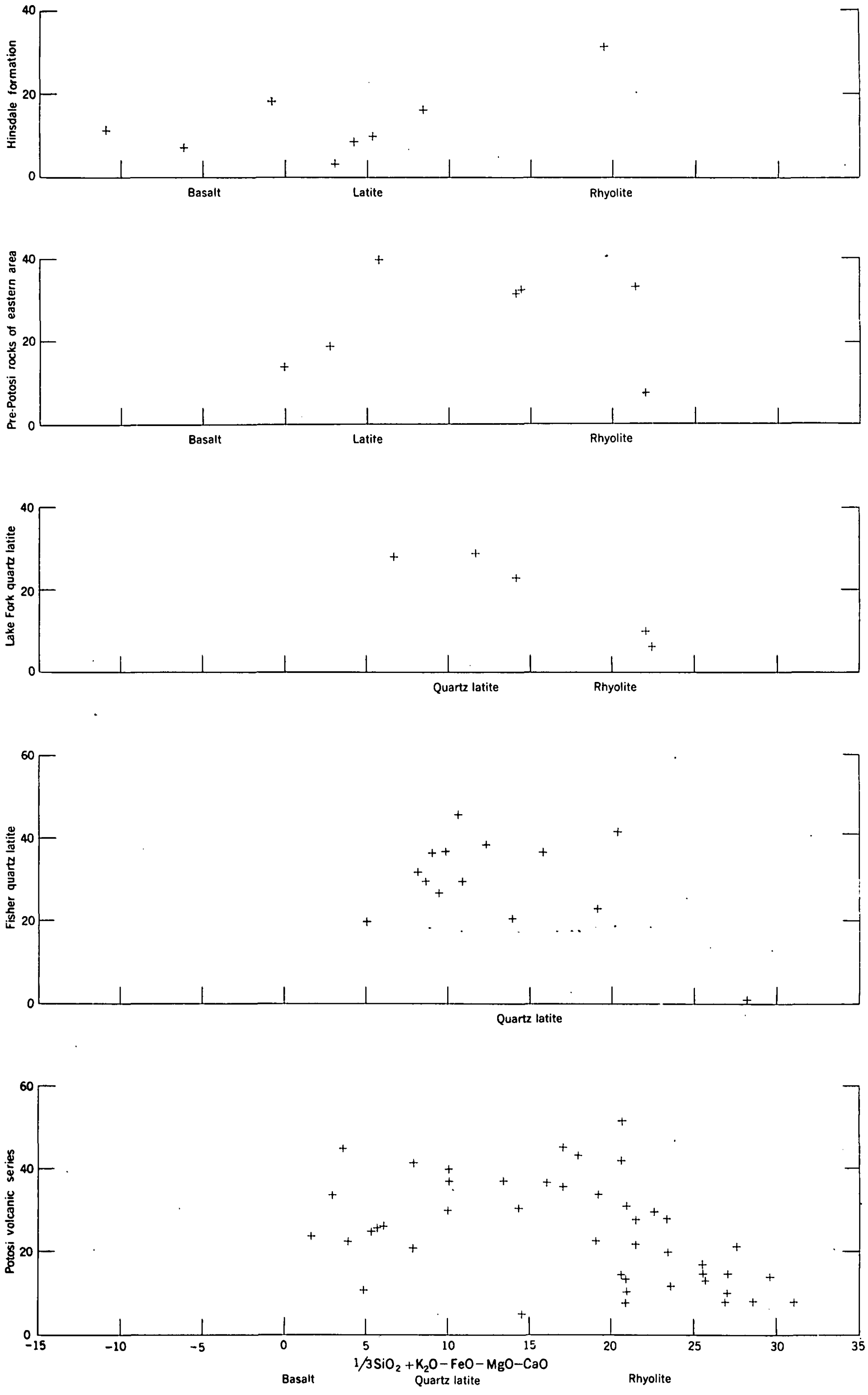

FIGURE 41.—Diagram showing variations in weight percent of phenocrysts in various rocks of the San Juan region. [Weight percent calculated from Rosiwal analysis.]

across, is nearly everywhere so uniform in texture, whether a flow or a tuff, that a collection of specimens from widely separated areas will differ chiefly in color and cohesiveness. The rhyolitic quartz latites of the three rhyolitic formations of the Potosi volcanic series are so much alike that great difficulty was experienced in mapping them separately when two such formations are in contact. The rhyolitic tridymite latite of the Piedra rhyolite is much like the tridymite rhyolite of the Alboroto, even to the character of the porous streaks. The cavernous rhyolites of Treasure Mountain, Alboroto, and Piedra rhyolites are essentially identical. It is generally true that the rocks of the rhyolitic formations of the Potosi are characterized by rather abundant, moderate-sized phenocrysts and by a glassy, spherulitic, or related felsitic groundmass that contains no tiny plagioclase laths. On the other hand, the rocks with similar compositions in the dark formations of the Potosi tend to have fewer phenocrysts and most of them have glassy or spherultic groundmasses with scattered tiny plagioclase laths.

The rhyolitic rocks in the pebbles of the McDermott and Animas formations have rather conspicuous phenocrysts of quartz and orthoclase in a microgranular groundmass. This groundmass may be due to recrystallization. The rhyolites of the Hinsdale and Sunshine Peak formations also have phenocrysts of quartz and iridescent sanidine. Those of the Potosi volcanic series and Eureka rhyolite have few or no phenocrysts of quartz. Those of the Eureka have a thin fluidal banding.

The Fisher rocks range from quartz latites to rhyolites, and they are characterized by large phenocrysts. In some, the large phenocrysts are plagioclase, biotite, hornblende, and pyroxene; in others they are quartz, plagioclase, sanidine, and biotite. The most persistent character of the group is the large size of the phenocrysts. Small, local bodies of the rhyolitic quartz latite of the Alboroto, the Sheep Mountain quartz latite, or other Potosi rocks have large phenocrysts and resemble the Fisher quartz latite.

The tabular feldspar-pyroxene-quartz latite is chiefly a dark rock near a basalt in composition but some of these rocks are much more siliceous. Their texture is characteristic, and they make up local horizons in the Conejos quartz latite, much of the Sheep Mountain quartz latite of the Sheep Mountain mass, and about half of the Huerto quartz latite of the Huerto Peak area. They also characterize nearly all of the dark pyroxene-quartz latite of the Silverton volcanic series. Other rocks of the Potosi with essentially the same composition as the tabular feldspar rock have different textures.

The quartz latite of the San Antonio domes has nearly the same compositions as some of the Potosi rocks but their texture is different; they have fewer phenocrysts and a general basaltic appearance.

In many groups of related rocks the chief difference between the different flows or breccia beds is in the proportion of phenocrysts. This is conspicuous in some of the rhyolitic quartz latites and rhyolites of the Lake Fork volcano. The groundmass of all of the rocks is rhyolitic and some of the rocks have 30 percent of phenocrysts of plagioclase and mafic minerals; others have only a few percent.

In the basalt and latite of the Hinsdale formation the basaltic rocks have a few phenocrysts of plagioclase and are made up chiefly of small tabular labradorite with interstitial pyroxene and some glass. The latites have abundant large phenocrysts of oligoclase and a groundmass that is made up of nearly equant crystals of alkalic feldspar.

PHENOCRYSTS ARE INTRATELLURIC

In large part the phenocrysts are intratelluric, for they are present in about the same amount and are about the same size in the glassy zones at the base of the flows as in the crystalline parts of the flows. A small part of the phenocrysts were derived from partly assimilated inclusions, and in a few places the phenocrysts in thick flows are larger than usual and may have grown after extrusion.

The phenocrysts must have formed in a magma that remained in the deeper part of the magma chamber for a period longer than the time between individual eruptions. The evidence for these conclusions follows. In whole groups of lava flows and tuffs the size, character, and amount of phenocrysts remain about constant. Some of these groups of similar rocks cover large areas and have a large volume. The typical Alboroto rhyolite underlies an area nearly 100 miles across and has a volume of about 1,000 cubic miles. It is made up of many flows and tuff beds, all of essentially the same kind of rock. Many of the lava flows have a glassy zone in their lower parts, and such glassy zones have the same phenocrysts—in size, quantity, and composition—as the main parts of the flows which have a finely crystalline groundmass.

GROUNDMASSES

The groundmasses already have been described. Many of the flows of rhyolitic rock have at their bases a few feet of obsidian. This obsidian is rather sharply separated from the upper holocrystalline rock that makes up the main parts of the flows. No regular glassy zones were found at the tops of flows. Many of the welded tuffs have a basal zone of obsidian.

In the basalts and quartz latites near the basalts some of the rocks have various amounts of interstitial glass in their groundmasses. In the rhyolites and rhyolitic quartz latites interstitial glass is never present in the groundmasses. Crystallization begins at a center and grows outward, commonly as spherulites, with the whole of the material within the spherulite crystalline. The spherulite may be imbedded in a glassy matrix. In the crystallization of rhyolitic material—made up almost entirely of alkalic feldspar and SiO_2—the material crystallizes as a cotectic. Much of the material called glass in rhyolites is either tridymite, crystobalite, or submicroscopically crystalline. In the rapid crystallization of rhyolitic groundmasses, the silica mineral and the feldspar are commonly unstable as tridymite or crystobalite and a solid solution-feldspar whose composition is determined by the material available, and that may be rich in soda and lime.

Many of the rhyolitic rocks have typical perlitic cracks—a feature commonly considered as evidence of devitrification. It probably does indicate that crystallization took place after the magma was vitreous enough to crack, but the field and laboratory study shows that this crystallization took place during, and as a normal result of, the relatively slow cooling of the magma. A felsite with typical perlitic cracks commonly has a few feet of obsidian at its base. Devitrification as commonly used includes crystallization that took place during the cooling of a glass. In this sense it has no great value in petrology. Where crystallization takes place in a glass after the complete cooling as a result of later metamorphism that fact should be clearly indicated and not indicated by the general term "devitrification."

GAS CAVITIES

The basaltic rocks have rounded or flattened gas cavities. In some lavas hemispheres of cristobalite with or without needles of hornblende, plates of biotite, or fayalite are attached to the walls of the cavities. Rarely the cavities are nearly filled with tridymite. Some of the rhyolites, such as the cavernous rhyolite of the Potosi, have irregular, nearly equant gas cavities that are locally several inches across. These cavities rarely contain crystals and the very finely crystalline to submicroscopic groundmass is about the same next to the cavities as at a distance from them. In these lavas the gas must have gathered as a separate phase after the lava had come to rest. In other rhyolites, such as the tridymite rhyolites of the Potosi, the main part of the flow has a groundmass that is a dense, reddish felsite, and interlayered with it are lenses of nearly white porous material. The dense part is finely crystalline to submicroscopic, and the white, porous lenses are much more coarsely crystalline, and more or less layered with orthoclase concentrated near the borders of the lenses and quartz or tridymite concentrated in the central porous parts. The coarsely crystalline part is rather sharply separated from the dense matrix. The sanidine crystals tend to grow out from the walls and in part are well formed and are as long as half a millimeter. The lenses may be as thick as an inch and they grade downward to microscopic films. Some lenses are only moderately elongated, others are much drawn out. Lenses of this kind from the Alboroto rhyolite near Creede, with quartz as the silica mineral, have been illustrated by Emmons and Larsen (1923, pls. 5, 6, and 17). To form the fluidal lenses of this type the mineralizers must have separated before the lava completed its flow movement. The flow after the formation of most of the lenses must have been small, but in some, where the porous streaks are much drawn out, there must have been appreciable flow. The separation of the gas phase and its concentration into lenses had a large influence in determining the crystallization of the rock. In many ways the porous lenses resemble pegmatites.

The groundmasses of the rhyolitic members of the Potosi and other formations never contain tiny crystals of plagioclase scattered through the glassy or spherulitic groundmasses, but the small bodies of rocks of the same composition in the dark quartz latite members commonly do, whether the groundmass is glassy or felsitic. These tiny plagioclase tablets were formed before extrusion and were probably caused by some interruption in the movement of the magma toward the surface to cause moderately rapid crystallization before final extrusion.

COLUMNAR JOINTING IN OBSIDIAN

The obsidian at the base of a flow of cavernous rhyolite in the Piedra in the basin of Turkey Creek in the Pagosa Springs quadrangle has an excellent columnar jointing. The columns are about an inch thick and tend to be six sided. The talus fragments look like huge bundles of black kindling wood.

PETROGENESIS

VARIATION DIAGRAMS

GENERAL STATEMENT

The analyses of the rocks of the San Juan region show a wide scattering of points if collected together on one variation diagram, but if the analyses of each formation are plotted in a symbol peculiar to the formation, it becomes evident that some of the groups fall in the upper part of the pattern, some in the lower, and that the different formations are not all alike chemically. (See Larsen, 1938, for definition of variation diagram.) Separate diagrams for groups of related rocks have most of the points near simple variation curves and the variation curves for the different formations are not all alike. Such diagrams for the formations for which there are enough analyses to construct a diagram are shown in figures 42–50. Several of the formations for which there are few available analyses have been grouped in some of the diagrams. Diagrams for the norms of the Potosi and Hinsdale rocks are given in figures 51 and 52.

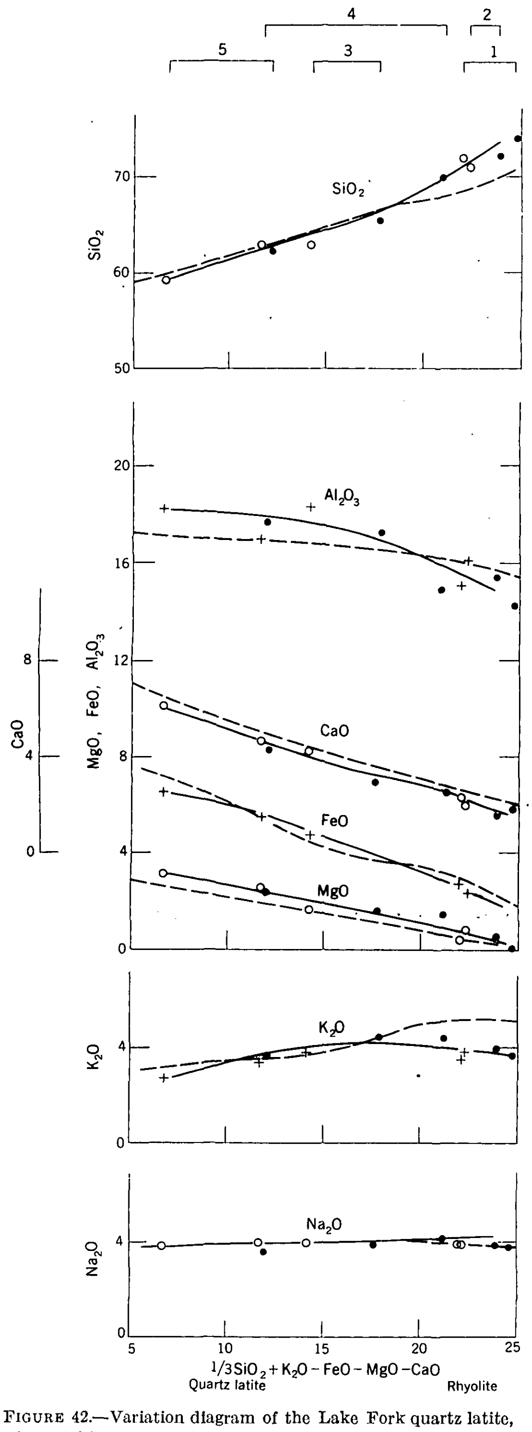

FIGURE 42.—Variation diagram of the Lake Fork quartz latite, in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. Ends of brackets place the position of a rock and its corresponding groundmass. Numbers above brackets refer to analyses of corresponding number in table 13, page 68. Solid curves are variation curves for Lake Fork rocks; dashed curves are for the Potosi volcanic series.

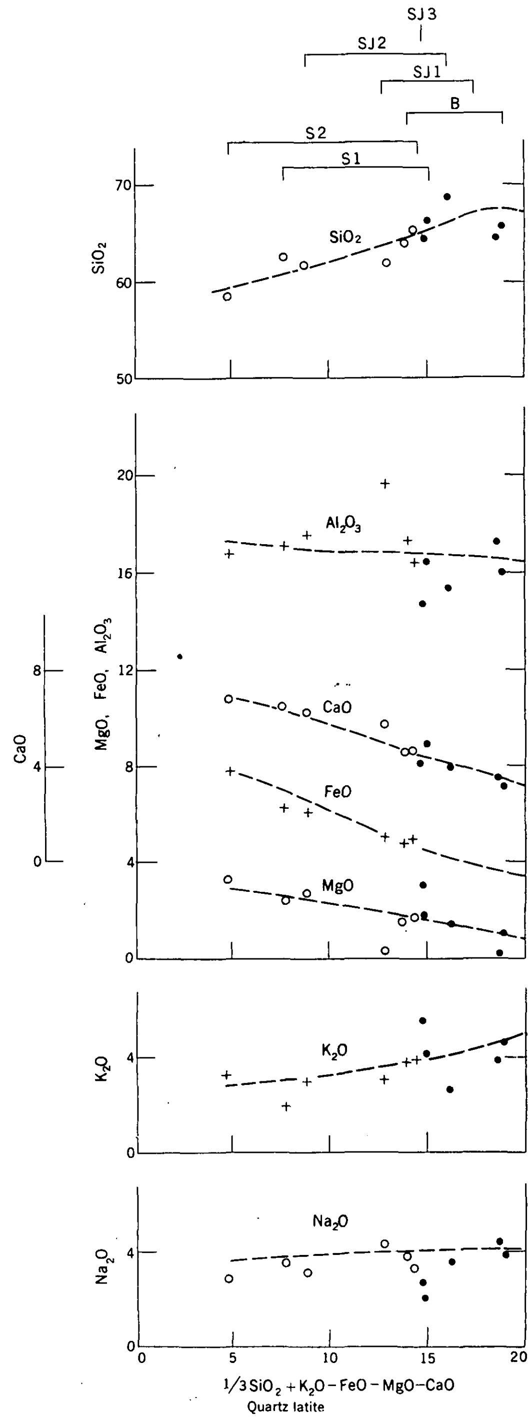

FIGURE 43.—Variation diagram of the San Juan tuff and Silverton volcanic series in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. Ends of brackets place position of a rock and its corresponding groundmass. Nos. SJ1–SJ3 refer to analyses of corresponding number in table 14, page 75; B refers to the analysis in table 15, page 78; and S1 and S2 refer to table 16, page 80. Curves are variation curves for the Potosi volcanic series.

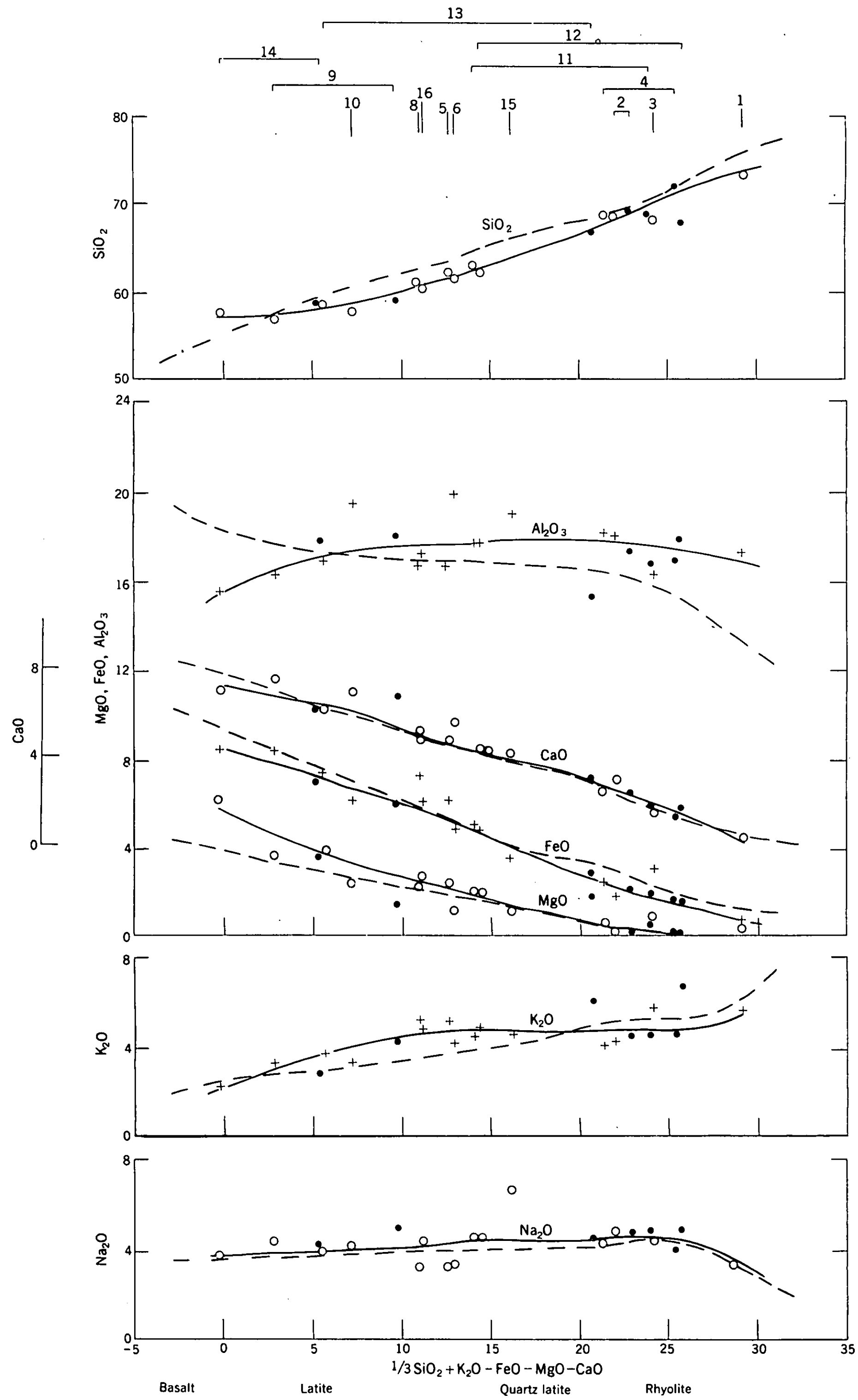

FIGURE 44.—Variation diagram of the pre-Potosi rocks of the eastern area in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. Ends of brackets place position of a rock and its corresponding groundmass. Numbers above brackets and lines refer to analyses of corresponding number in table 17, page 87. Solid curves are variation curves for the pre-Potosi rocks of the eastern area, and dashed curves are for the Potosi volcanic series.

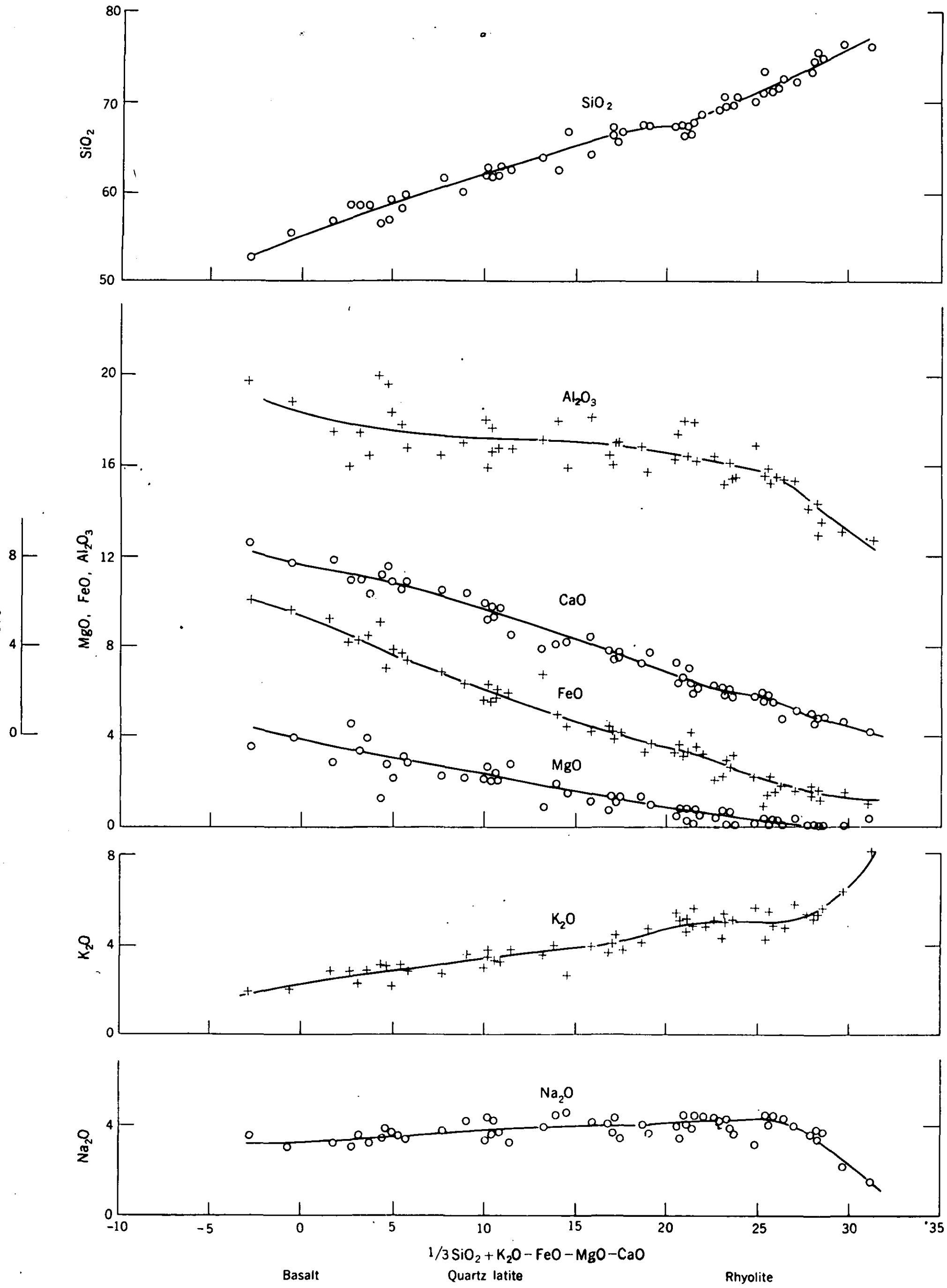

FIGURE 45.—Variation diagram of the Potosi volcanic series, in weight percent.

THE GROUNDMASSES ON THE VARIATION DIAGRAMS

The method of determining the phenocrysts has been described in the introduction. In most of the rocks the phenocrysts are sharply separated from the groundmasses and are imbedded in a glassy or very finely crystalline matrix. A few of the rocks are seriate porphyritic and for such rocks no attempt was made to determine the compositions of the groundmasses. Some of the basalts have olivine as the chief large crystal. In many such rocks small crystals of plagioclase and pyroxene may have crystallized with the olivine. The large crystals were considered to be the phenocrysts, and this may have led to a rather large error in the calculated composition of the groundmasses. The calculated groundmasses of such rocks do not fit the variation curves. In general the calculated compositions of the groundmasses are believed to be somewhat less accurate than the rock analyses. The estimate of

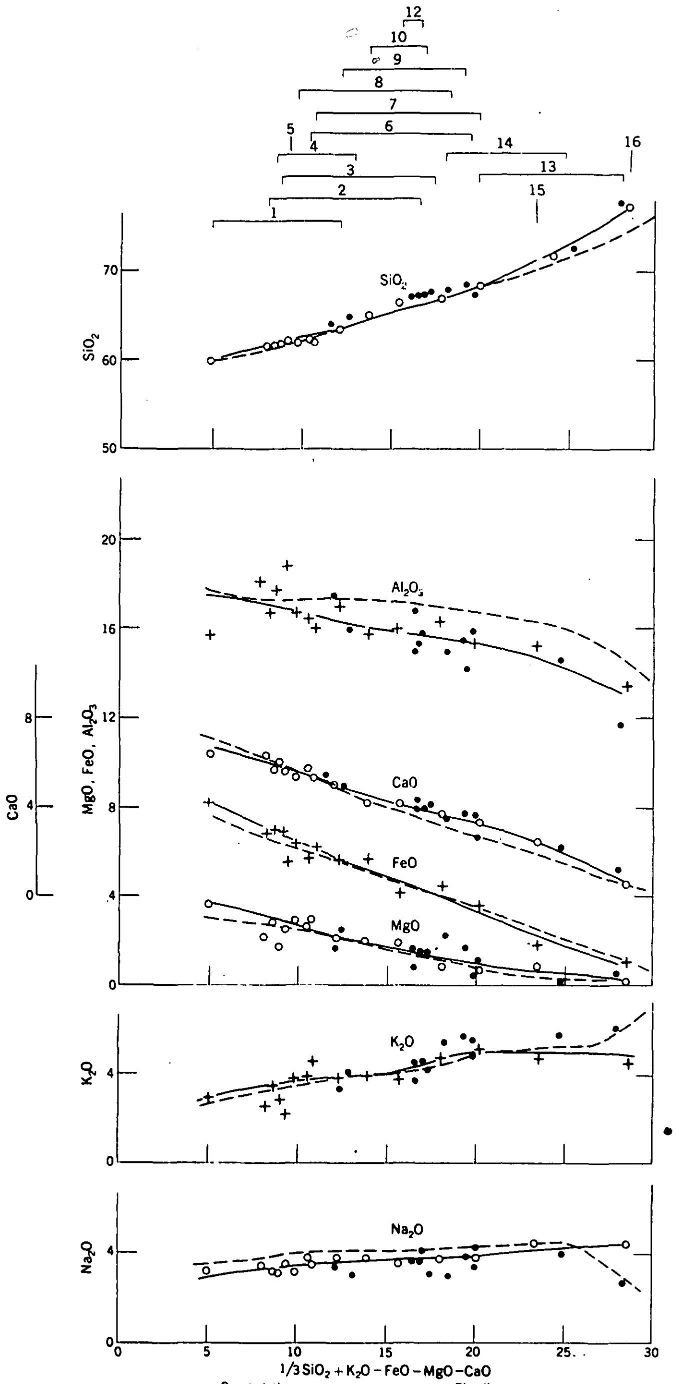

FIGURE 46.—Variation diagram of the Fisher quartz latite in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. Ends of brackets place position of a rock and its corresponding groundmass. Numbers above brackets or lines refer to analyses of corresponding numbers in table 23, page 190. Solid curves are variation curves for Fisher rocks; dashed curves are variation curves for the Potosi volcanic series.

the amount of phenocrysts and their compositions is subject to some error, and any error in the analysis of the rock will be increased in the calculation of the groundmass—if 50 percent of the rock is phenocrysts, the error will be doubled; if 25 percent, it will be one-third larger. The variation diagrams (figs. 42–48) show that the groundmasses fall nearly as close to the variation curves as do the rocks. Some of the rocks have as much as 50 percent of phenocrysts, and the average is about 25 percent. The groundmass, as compared with the rock, is invariably toward rhyolite. In some of the quartz latites the rock and the groundmass are far apart—a third of the way across the varia-

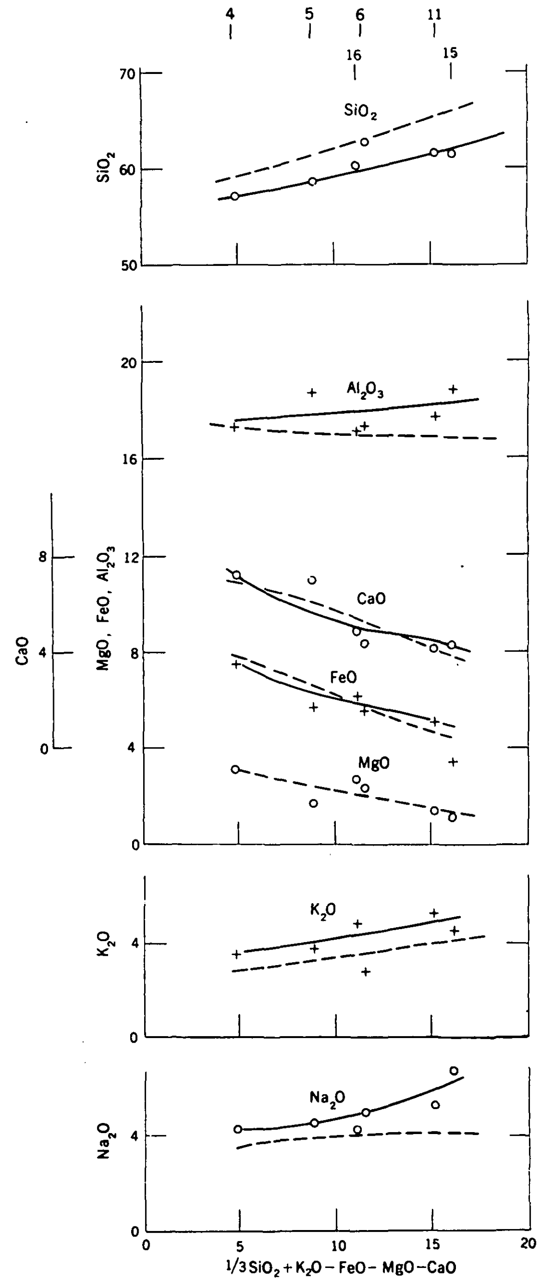

FIGURE 47.—Variation diagram of stocks and laccoliths cutting the sediments in weight percent. Nos. 4, 5, 6, and 11 at top of diagram refer to analyses of corresponding number in table 27, page 232; and nos. 15 and 16 refer to analyses of corresponding number in table 17, page 87. Solid curves are variation curves for stocks and laccoliths; dashed curves are for the Potosi volcanic series.

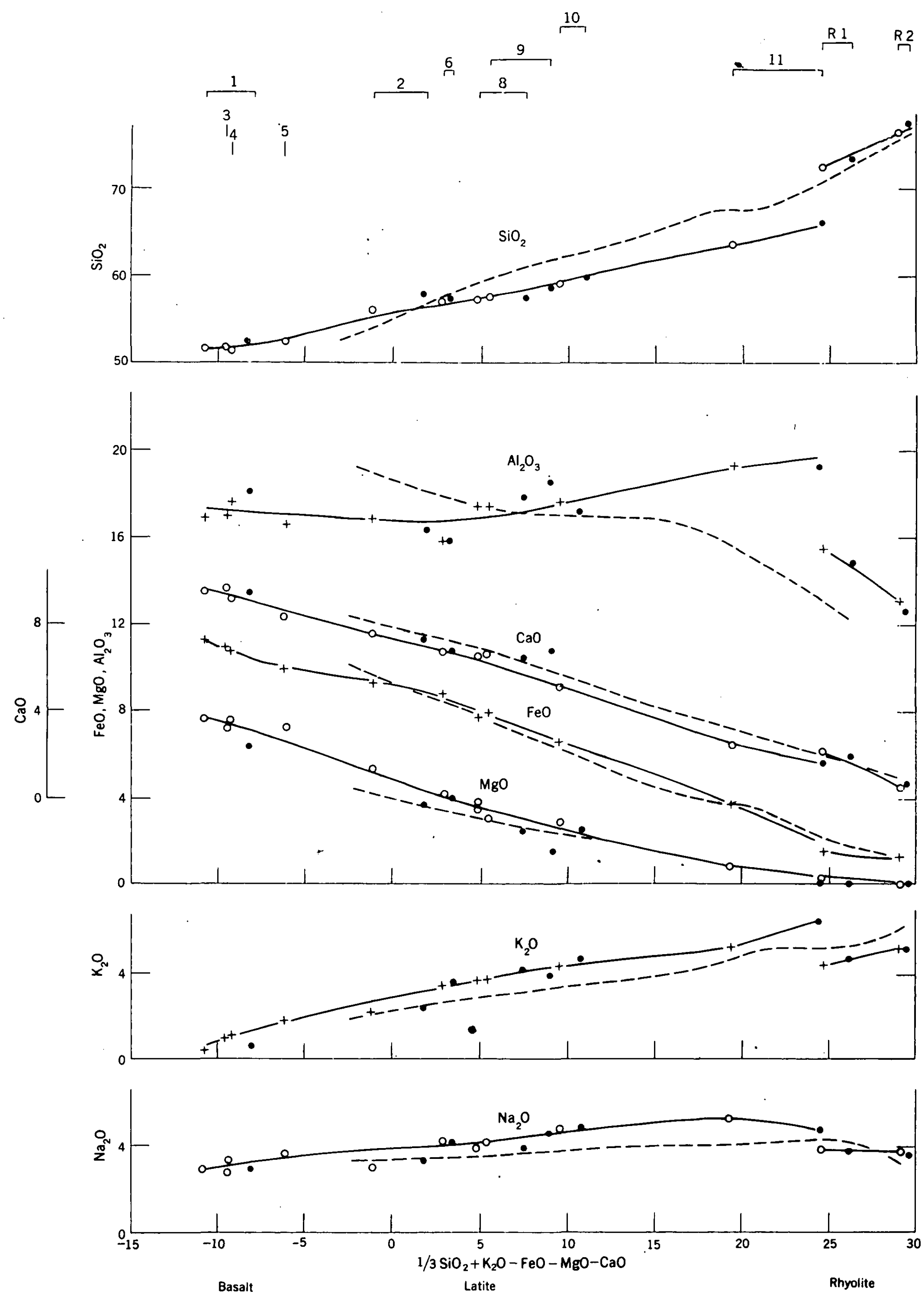

FIGURE 48.—Variation diagram of the Hinsdale formation, in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. Ends of brackets place position of a rock and its corresponding groundmass. Nos. R1 and R2 refer, respectively, to analyses 1 and 2 in table 24, page 195; the other numbers refer to corresponding analyses in table 25, page 208. Solid curves are variation curves for the Hinsdale formation; dashed curves are variation curves for the Potosi volcanic series.

tion diagrams for the Potosi rocks, or as much as 7 percent difference in SiO_2 content. In general, the difference between rock and groundmass is roughly proportional to the amount of phenocrysts but this is far from true where the phenocrysts are quartz and sanidine. The Sunshine Peak rhyolite has as phenocrysts 10 percent of quartz, 21 percent of sanidine, and 0.5 percent each of biotite and iron oxide; yet the rock and the groundmass have essentially the same composition. The compositions of the groundmasses fall near

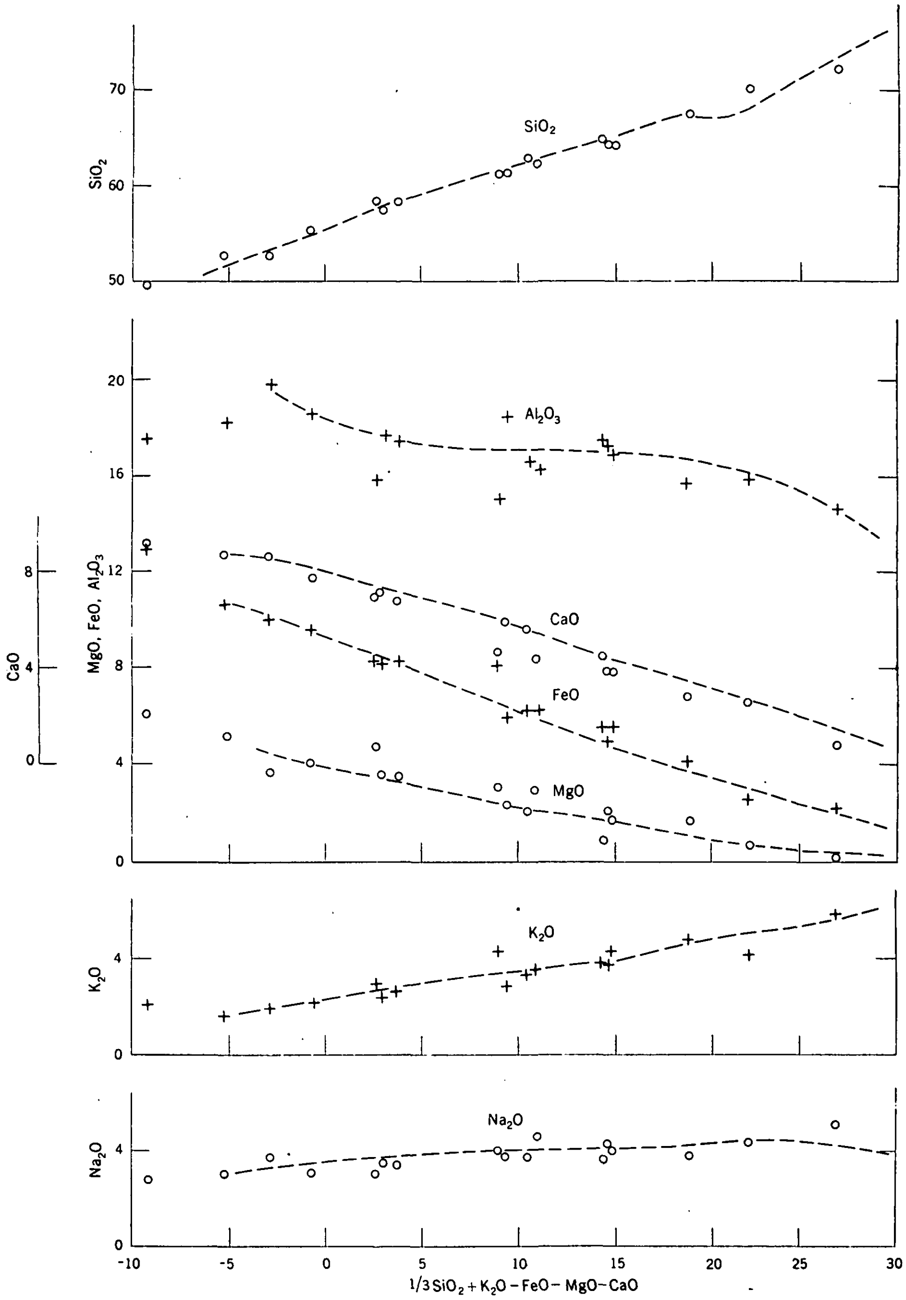

FIGURE 49.—Variation diagram for stocks and laccoliths cutting the San Juan tuff and the Potosi volcanic series in weight percent. Dashed lines are variation curves for the Potosi volcanic series.

the same curves as do those of the rocks, and if a rock has a high or low content of any oxide the groundmass is commonly correspondingly high or low. The analyses of rocks and groundmasses from each of the formations fall fairly near regular variation curves although some analyses plot erratically.

ACCURACY OF THE VARIATION CURVES AND ERRATIC POINTS

An examination of the variation diagrams shows that if enough analyses of a closely related group of rocks are available—commonly at least five covering a range in compositions—satisfactory variation curves can be drawn. Altered rocks, tuffs, stocks, and laccoliths tend to be much more erratic than the lavas or small intrusive bodies. Nevertheless, some of the lavas fall far from the variation curves.

To test how much the erratic points were due to imperfect analyses and sampling, 11 of the rocks that were more erratic than common were again analyzed. In all cases a new sample of the rock was prepared so that the sampling would also be taken into account.

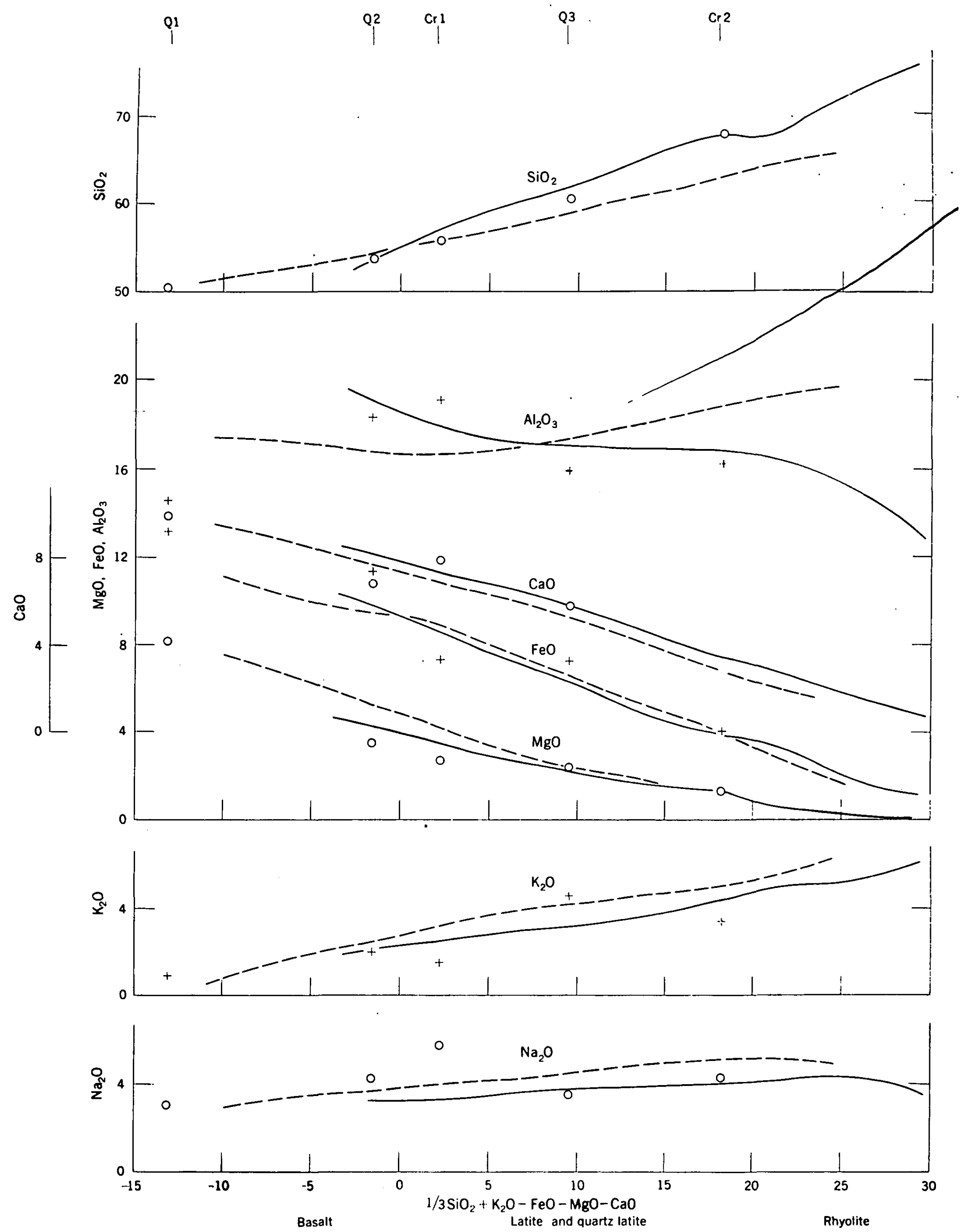

FIGURE 50.—Plot of chemical analyses of rocks, in weight percent, of Late Cretaceous age (Cr 1, 2) and Quaternary age (Q 1, 2, 3) from the San Juan region compared with the variation diagrams of the Potosi volcanic series (solid line) and the Hinsdale formation (dashed line). (See p. 287.)

Six of the 11 new analyses fit the variation curves fairly well, but 5 reaffirmed the first analyses. For 8 other rocks, selected because the alkalies of the first analyses did not fit the variation curves, new determinations of the alkalies were made. For nearly all of these there was a fairly large difference between the two determinations, and most of the new determinations fall fairly near the variation curves.

Table 29 gives the percent of analyses of rocks and groundmasses of the Potosi, Fisher, Lake Fork, pre-Potosi of the eastern area, San Juan, and the Hinsdale that do not fit their variation curves by amounts of more than 2 percent and 1 percent for SiO_2 and Al_2O_3, and 0.8 percent and 0.4 percent for the other oxides; 123 rocks and 81 groundmasses were used for the calculations.

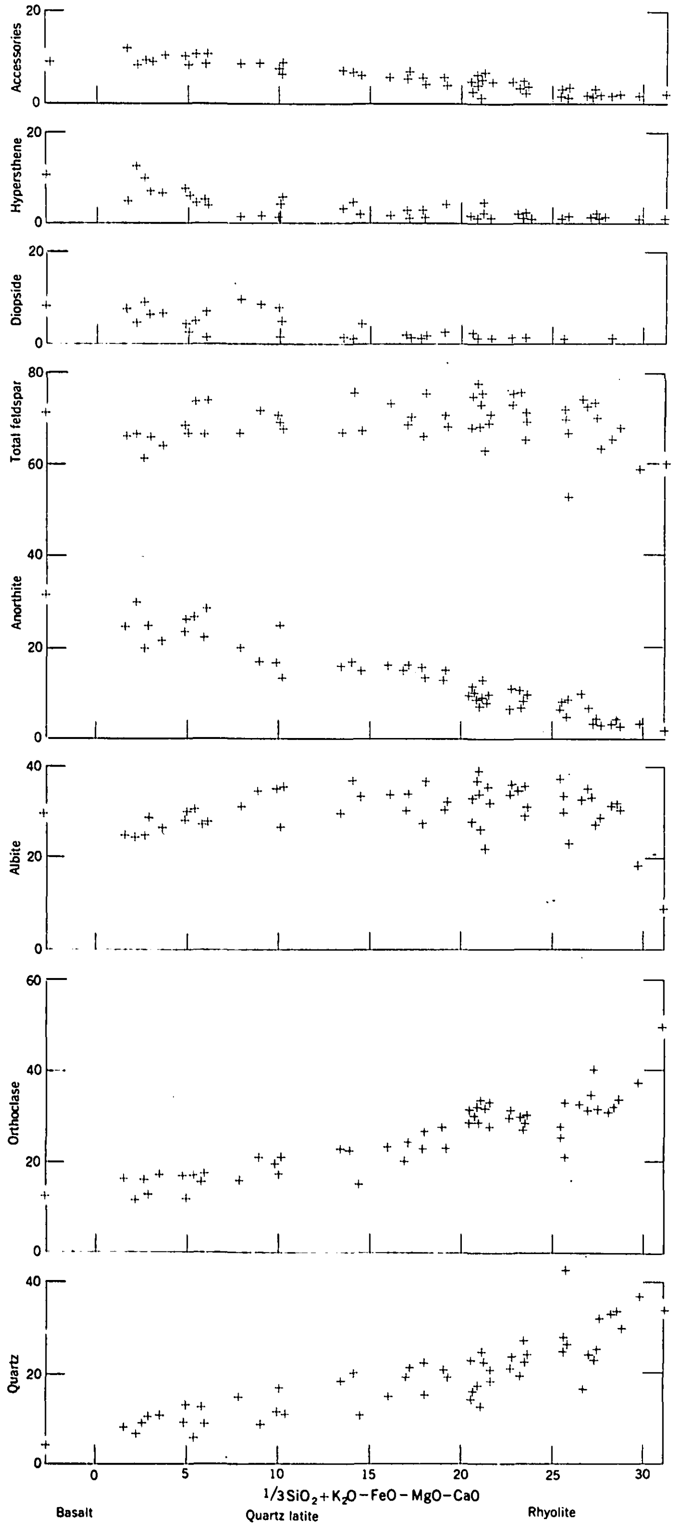

FIGURE 51.—Norms of the Potosi volcanic series.

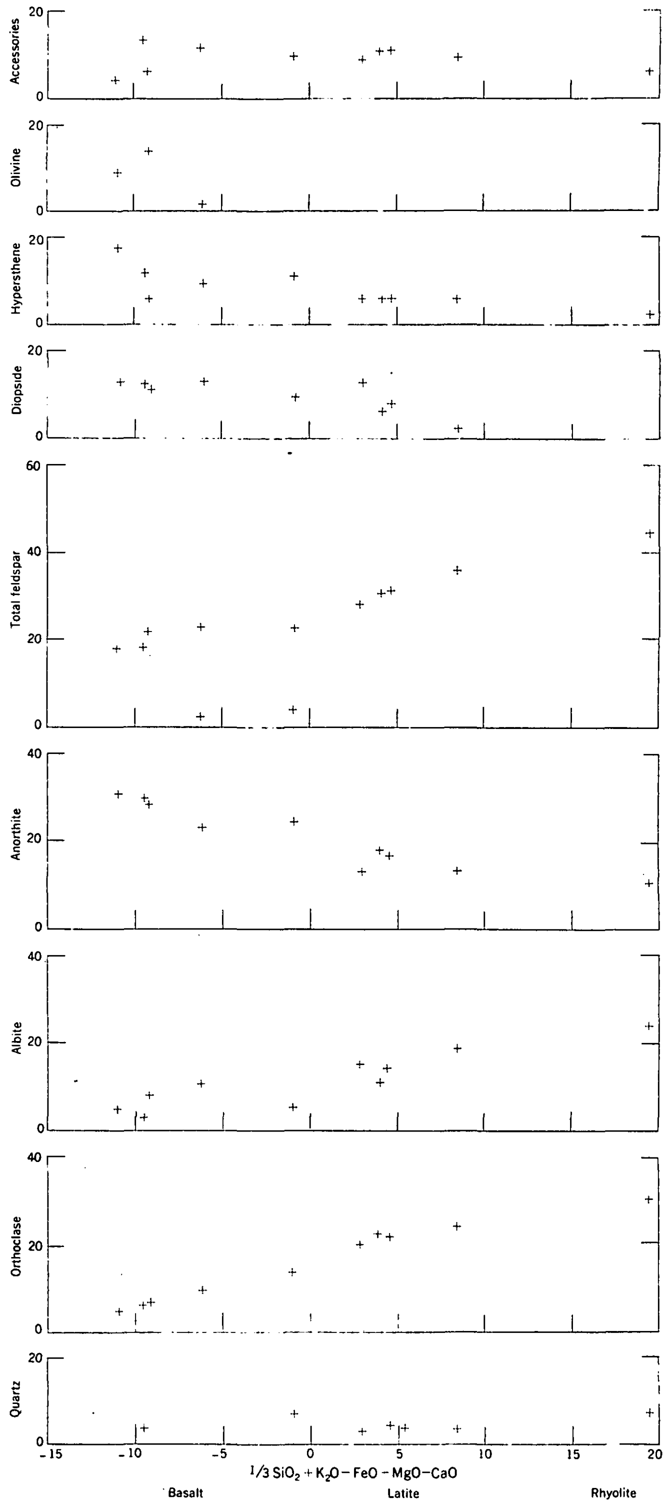

FIGURE 52.—Norms of the Hinsdale formation.

TABLE 29.—*Percent of analyses that do not fit the variation curves by stated amounts*

	SiO_2	Al_2O_3	CaO	FeO	MgO	K_2O	Na_2O
ROCKS							
2 percent or more	3	4	-------	-------	-------	-------	-------
1 to 2 percent	16	15	-------	-------	-------	-------	-------
0.8 percent or more	-------	-------	5	7	3	8	3
0.4 to 0.8 percent	-------	-------	16	17	19	23	25
GROUNDMASSES							
2 percent or more	7	6	-------	-------	-------	-------	-------
1 to 2 percent	18	21	-------	-------	-------	-------	-------
0.8 percent or more	-------	-------	4	-------	7	9	8
0.4 to 0.8 percent	-------	-------	11	-------	21	31	34

A part, probably less than half, of these determinations that do not fit the curve are due to imperfect sampling and analyses or, for the groundmasses, imperfect determination of the phenocrysts. Many of them however must be due to variations in the rock and groundmass. Among such rocks the eutaxitic tuff of the Treasure Mountain rhyolite (analysis No. 57 of fig. 54) falls far from the variation curves. It has a tridymite cement and would fit the diagram if 25 percent of the SiO_2 were removed from it. It is possible that much tridymite was added to this tuff after its eruption by the gases that were erupted with it. Some of the analyses that were made in duplicate certainly fall far from the variation curves and no reason for their erratic character is evident.

There is some tendency for two of the oxides to fall away from the variation curves systematically. High- or low-content SiO_2 tends to be accompanied by low- or high-content Al_2O_3. Table 30 lists the oxides and indicates any observed tendency for two oxides to fall systematically from the curves.

If one or more of the oxides of a rock analysis does not fit the variation curves, those same oxides for the groundmass of the rock also commonly do not fit their curves and both fall on the same side of the curves.

TABLE 30.—*Observed tendency of any two oxides to fall systematically from the variation curves*

	SiO_2	Al_2O_3	CaO	FeO	MgO	K_2O	Na_2O	Interpretation
SiO_2		— —				— —	—	High SiO_2 content found with low alkalic feldspar.
Al_2O_3	— —		+	—	—	—	+	High Al_2O_3 content found with high plagioclase and low femic and orthoclase.
CaO		+		—	— —			High CaO content found with high anorthite and low femic content.
FeO		—	—			+	—	High FeO content found with high orthoclase and low plagioclase.
MgO		—	— —			+		High MgO content found with high orthoclase and low plagioclase content.
K_2O	— —	—		+	+			High K_2O content found with high femic and orthoclase and low plagioclase content.
Na_2O	—	+		—	—			High Na_2O content found with low femic and high sodic plagioclase content.

\+ moderate tendency for both to be on the same side of their curves.
— — strong tendency for one to be above or below its curve and the other below or above.
— moderate tendency for one to be above or below its curve and the other below or above.

BREAKS IN VARIATION CURVES

There is a definite break in the variation curve (fig. 45) of SiO_2 for the Potosi volcanic series, and this break shows less clearly on the four curves for the subdivisions of the Potosi (fig. 53–56) because near the break there are few points. There is a slight change in slope in the curve for K_2O at this position, but the other oxides show no clear break. There are similar breaks in the curves for SiO_2 and K_2O in the Fisher quartz latite (fig. 46). These oxides are somewhat to the left of those for the Potosi. No breaks can be recognized in the other groups—the curves for the Lake Fork quartz latite (fig. 42) and the pre-Potosi rocks of the eastern area (fig. 44) seem to be nearly straight across the range where the break is present in the Potosi. In moving right toward increasing silica on the Potosi curves, there is for a short distance near position 18 a flattening of the SiO_2 and FeO curves, a steepening of the K_2O curve, the Al_2O_3 curve begins to slope downward to the right, and the MgO curve flattens. Many analyses are

TABLE 31.—*Phenocrysts in the rocks of the Potosi volcanic series and Fisher quartz latite in which the rock analyses fall on one side of the break in the variation curves and the groundmass analyses on the other*

Analysis No.	Sample No.	Position on curve		Norms									Total phenocrysts (weight percent)
		Rock	Groundmass	Quartz	Orthoclase	Plagioclase	Anorthite in plagioclase	Biotite	Hornblende	Augite	Hypersthene	Magnetite	
Potosi volcanic series [1]													
		Break in curves 18 to 21											
40	LaG 174	16. 8	23. 6	1	3	26	37	4	------	0. 5	------	2	36
39	SC 2094	15. 5	23. 2	------	------	27	46	4	0. 5	tr	tr	2	34
38	SC 2585	19. 0	23. 1	3	5	18	26	3	3	------	------	1	33
37	LaG 1059	17. 0	24. 3	3	6	27	55	7	1. 5	------	------	2	47
23	DN 2241	18. 7	25. 8	------	------	19	40	1	1. 5	2	1. 5	2	27
22	Con 563	18. 2	25. 8	------	5	28	38	8	1. 5	1	------	2	45
19	LaG 1120	13. 4	25. 1	1. 5	------	24	42	3. 5	7	------	------	2	38
16	Con 320	17. 2	23. 3	------	------	13	48	------	1. 5	1	3	2	20
15	Con 591	9. 9	21. 7	------	------	25	58	------	10	. 5	. 5	3	39
8	SV 115	10. 1	20. 9	------	------	28	59	------	------	2. 5	2. 5	2	35
Fisher quartz latite [2]													
		Break in curves 16.5 to 19.0											
14	LaG 1598	18. 2	26. 1	------	------	21	52	4	------	1	------	2	28
12	LaG 1021	15. 7	23. 5	------	------	29	37	6	2	. 5	------	2	39
10	SC 1683	13. 9	17. 1	1	7	8	32	2	2	. 5	------	2	22
9	Con 606	12. 3	21. 0	------	------	22. 1	38	10	2	2	------	2	38
7	SC 1315	10. 9	18. 9	------	------	9	45	1. 5	------	7	2	1	30
6	LaG 1027	10. 6	18. 7	------	------	20	47	1. 5	1	4	4	3	33
4	SC 1663	9. 0	17. 5	------	------	23	59	------	2. 5	1	1. 5	4	32

[1] Analysis and sample nos. from table 21.
[2] Analysis and sample nos. from table 23.

available along and on both sides of the break and most of the formations are represented. Few groundmasses fall along the break in the curves, but they fall on both sides. The diagram for the Fisher quartz latite shows similar breaks and an apparent break in the CaO curve.

Since the break is repeated at essentially the same place for each of the four units deposited during the Potosi eruptions and for a fifth unit deposited during Fisher eruptions, it cannot be accidental.

The break occurs where, if the rocks were granular, they would have abundant quartz, little dark mineral, and about equal amounts of orthoclase and andesine. The phenocrysts of the rocks that fall on one side of the break and that have groundmasses falling on the other are shown in table 31. There is little difference between the phenocrysts in the rocks on the two sides of the break as shown in table 31.

The break in the variation curves might be explained by the separation of about 5 percent of quartz, 15 percent of Ab–An, and 5 percent of hypersthene or biotite. This would require that quartz began precipitation about position 18 on the variation diagram and continued precipitation to about position 21, beyond which point it would not be in equilibrium with the melt. There is some evidence in the rocks that this is true. Among the rocks of the three rhyolitic formations of the Potosi volcanic series that are to the left of the break in the variation curves, more than three-quarters by volume contain some phenocrysts of quartz; whereas few of those to the right of the breaks contain quartz phenocrysts, except the rhyolites free of plagioclase phenocrysts which are on the extreme right of the diagram. Nearly all rocks that contain quartz phenocrysts contain phenocrysts of orthoclase. The separation of orthoclase phenocrysts at this stage would tend to flatten the curve for K_2O near the break, but the curve actually steepens.

For rocks on the left of the break, whose groundmasses are on the right, the silica content should be low in the rocks if quartz has separated and settled, and it should be high in the groundmasses if quartz has not crystallized. There is a slight tendency for the groundmasses of rocks that lack quartz phenocrysts to be high in SiO_2 content.

Another possible explanation for the break is that at the position of the break resurgent boiling takes place and the escaping vapors remove SiO_2 from the rock.

THE CAUSE OF THE ERRATIC COMPOSITIONS OF SOME ROCKS

If we imagine a large body of magma in the upper part of the crust of the earth, the loss of heat and mineralizers (Larsen, 1945, p. 415) will be largely from the upper surface, and there will be an increase in temperature from the surface downward. If crystal fractionation took place in such a magma and the crystals all settled to the bottom of the magma chamber, there would result a body of magma that gradually changed from siliceous near the top to mafic in depth. The rocks from such a body would yield an ideal variation diagram. However, the lavas of the San Juan region commonly contain abundant phenocrysts; this indicates that crystal settling was far from perfect. At a given time at any depth in the body the magma would contain crystals that settled from the more siliceous magma above, as well as crystals that were precipitated in place. The heavier and larger crystals would settle more rapidly than the lighter and smaller ones. This loss and gain of selected crystals would displace the rock from the ideal variation curve.

If all of the phenocrysts from a siliceous magma settled into a somewhat more mafic magma the effect would be to displace the contaminated mafic magma to the left on the variation diagram without displacing it far from the variation curves.

If this simple type of selective settling of some kinds of crystals is the cause of the erratic positions of rocks on the variation curves, the groundmasses should fit the curves. However, in the lavas of the San Juan region most of the groundmasses fall away from the curves in about the same way as do the rocks of which they are a part. Reaction of the magma on the crystals, especially those from the overlying magma, followed by further crystal settling, might cause the erratic character of the rock. In general, it would increase the FeO and decrease the CaO of the groundmass. This mechanism might account for some of the rocks that are only slightly off the variation curves but probably not for those that are farthest from the curves.

Assimilation of foreign material of the proper composition would explain the erratic rocks. Material from the other parts of the igneous mass of which the rock is a part would not be favorable unless it was near one end of the variation curves in composition because most of the curves are nearly straight over most of their lengths.

The San Juan and other rocks indicate that plagioclase phenocrysts are not readily reworked when out of equilibrium with the enclosing liquid, but they tend to be corroded. The dark minerals are much more rapidly reworked. A plagioclase settling in a differentiating magma chamber such as that of the San Juan area should have a large core of sodic feldspar surrounded by successive zones that become more calcic and that were formed while the crystals were settling. These calcic zones should be bordered by zones that become progressively more sodic and that formed after eruption.

A modification of this type of zoning may be common in the lavas of the San Juan area but the cores of the plagioclase that are definitely foreign do not show this. The sodic and calcic cores that are foreign were probably derived from rock fragments or bodies of partly crystalline magma enclosed in the host rock, as are the associated quartz, orthoclase, and other minerals. Analysis 4 (table 21) falls rather far from the variation curves, and two analyses that are fairly well alike have been made of the rock. The rock (DN 68) has 24 percent of bytownite phenocrysts and a few percent of olivine crystals. The plagioclase is unusually calcic, and large cores of the plagioclase phenocrysts must have been derived from a more calcic rock. The groundmass of this rock falls fairly near the variation curves and the erratic composition of the rock is no doubt due to the presence of the foreign crystals. Rocks that do not fit the variation curves because of foreign crystals appear to be more common in the rocks low in silica content than in those high in silica.

Loss or gain of mineralizers or change in the state of oxidation of the iron might affect the course of the crystallization of the magma and thus cause the erratic composition of some rocks.

Heterogeneity in the primary magma might account for the erratic rocks.

THE PETROGRAPHIC PROVINCE OF THE SAN JUAN MOUNTAINS

The Miocene and younger volcanic rocks of the San Juan Mountains form a well-defined geologic unit in both time and space, and they are no doubt genetically related. They form a complex petrographic province. The Late Cretaceous and early Paleocene volcanic rocks are probably somewhat less closely related. The younger volcanic rocks and remnants or outliers of some of the older members extend for many miles south of the San Juan Mountains in New Mexico. The volcanic rocks of the Valles Grandes Mountains, west of Santa Fe, are probably a closely related but separate group. The rocks of similar age in other parts of the Rocky Mountains are also related.

SUBPROVINCES

The volcanic rocks have been divided into four or more major groups based on geologic mapping and our field study. Each group is separated from both the underlying and overlying group by an extensive surface of erosion representing a relatively long interval during which little volcanic material was extruded. Important earth movements took place during most of these intervals. The oldest volcanic rocks, which are of Late Cretaceous and early Paleocene age, are separated from the next group, the Lake Fork, San Juan, and Silverton volcanic rocks, by the longest time—most of the Eocene and Oligocene and much of the Miocene. A great elevation of the mountains took place during this interval.

In the western area, the Lake Fork, San Juan, and Silverton rocks were greatly depressed and later eroded to a mature topography before the Potosi rocks were erupted. In the eastern part of the mountains the pre-Potosi rocks are exposed only as small bodies. They were eroded to a mountainous topography before the eruption of the Potosi volcanic series. The Potosi rocks were moderately eroded to a canyon topography before the eruption of the Fisher rocks. The Potosi and Fisher were depressed and the San Juan peneplain was eroded on them before the eruption of the Hinsdale rocks.

Within the major groups, some of the subdivisions are separated by a break in the lithology but without much erosion; this indicates nearly continuous eruption. Others are separated by erosional surfaces that reached the stage of a deep canyon topography, representing a moderate interval of erosion. Such an erosional surface separates the San Juan tuff from the Silverton volcanic series. Three such surfaces separate various Silverton units; two are in the pre-Potosi rocks of the eastern area, and three are in the Potosi. In the Potosi they are at the top of each dark quartz latite unit.

The analyses of the rocks from each mapped unit were plotted on variation diagrams, and for each of the formations for which several analyses were available the analyses fall on or near smooth variation curves. The variation curves for groups of mapped units that are related in time were carefully compared. It was found that the analyses of rocks from all six subdivisions of the Potosi volcanic series fall on or near a single group of variation curves (figs. 53–56), showing that in chemical composition all of the Potosi rocks belong to a single group, as far as the available data show (fig. 45). Likewise, the pre-Potosi rocks of the eastern area, with the possible exception of the rocks near Beidell, fall near a single group of variation curves. The few analyses of San Juan and Silverton rocks indicate erratic composition, but those groups are probably similar to the Lake Fork rocks. The Late Cretaceous volcanic rocks are too much altered for good chemical analyses. The volcanic rocks of the San Juan Mountains can, therefore, be considered to belong to six subprovinces: (1) Late Cretaceous, (2) pre-Potosi of the western area, (3) pre-Potosi of the eastern area, (4) Potosi, (5) Fisher, and (6) basalt and latite of the Hinsdale. For the most part the subprovinces are separated by major periods of ersosion.

The rocks near the basaltic side of the variation diagrams and those near the rhyolitic side are much alike for nearly all petrographic provinces, and the peculiarities of any petrographic province are best shown by the intermediate rocks. Position 15 on the variation curves is a good position for comparisons. The general relations and characters of the various subprovinces of the San Juan region are therefore shown at position 15 in table 32.

TABLE 32.—*Petrographic subprovinces of the San Juan Mountains showing composition of rocks at position 15 on the variation diagrams*

	SiO_2	Al_2O_3	CaO	FeO	MgO	K_2O	Na_2O
Late Cretaceous and early Paleocene	Low (?)	--------	--------	--------	--------	High (?)	--------
Long period of erosion.							
Miocene:							
Lake Fork quartz latite	64. 7	17. 6	3. 8	4. 6	1. 9	3. 9	3. 9
Some erosion.							
San Juan tuff.							
Erosion.							
Silverton volcanic series		(Similar to Potosi volcanic series; variable)					
Subsidence and erosion.							
Pre-Potosi of eastern area	62. 8	17. 8	4. 2	4. 7	1. 6	4. 8	4. 2
(Relation to rocks of western area unknown.)							
Long period of erosion.							
Potosi volcanic series	65. 0	16. 8	4. 1	4. 7	1. 5	3. 8	4. 0
(Some erosion between members.)							
Erosion.							
Fisher quartz latite	66. 0	15. 8	4. 1	4. 8	1. 6	3. 8	3. 7
Subsidence and long period of erosion.							
Pliocene (?):							
Basalt and latite of the Hinsdale formation	61. 5	18. 4	3. 7	4. 9	1. 5	4. 7	4. 8
Elevation.							
Quaternary.							

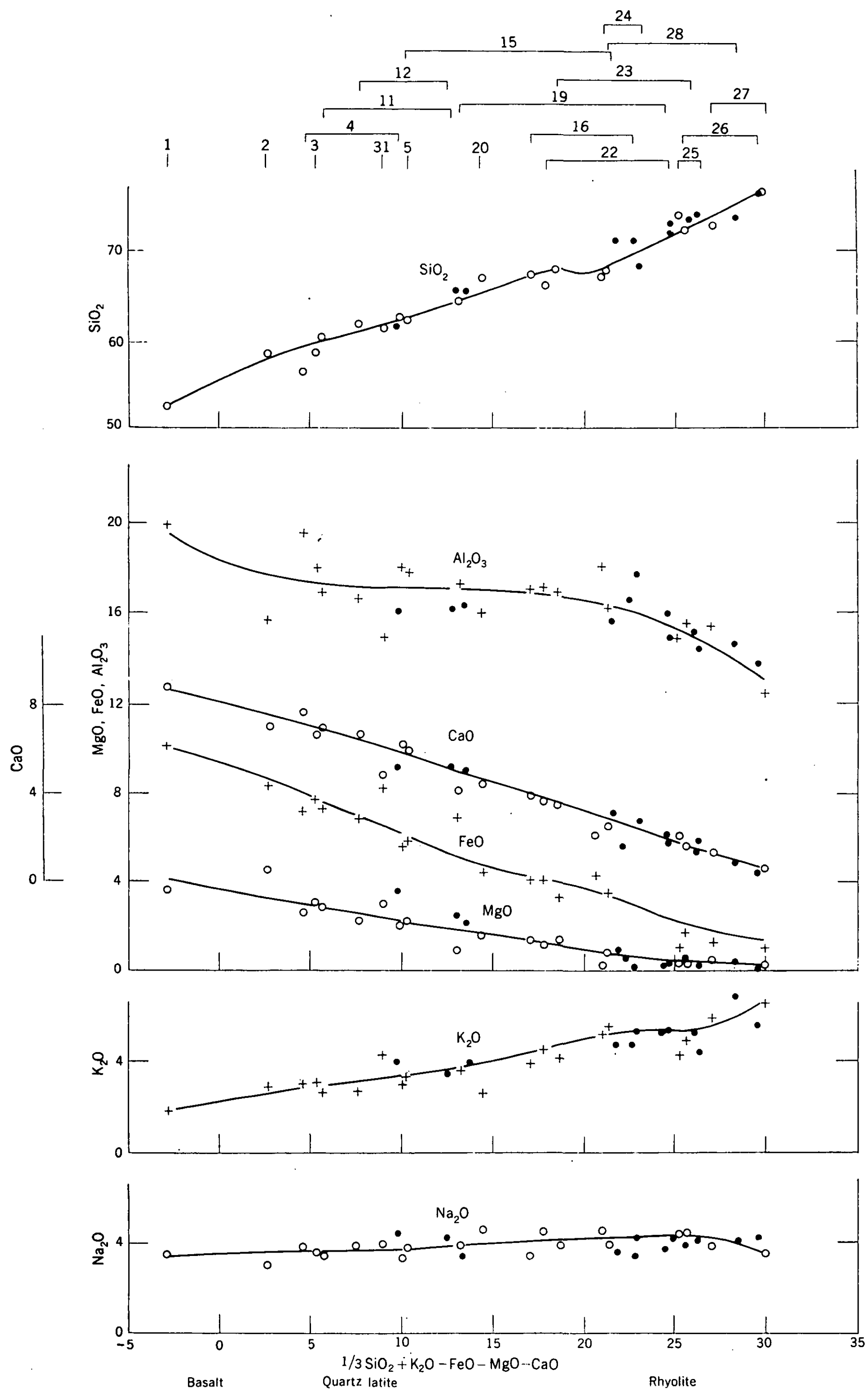

FIGURE 53.– Variation diagram of Conejos quartz latite, in weight percent. Crosses and circles indicate rocks; dots are groundmasses. The ends of each bracket place the position of a rock and its corresponding groundmass. Numbers on the brackets or lines refer to analyses of corresponding number in table 21, in pocket. Curves are variation curves for the Potosi volcanic series.

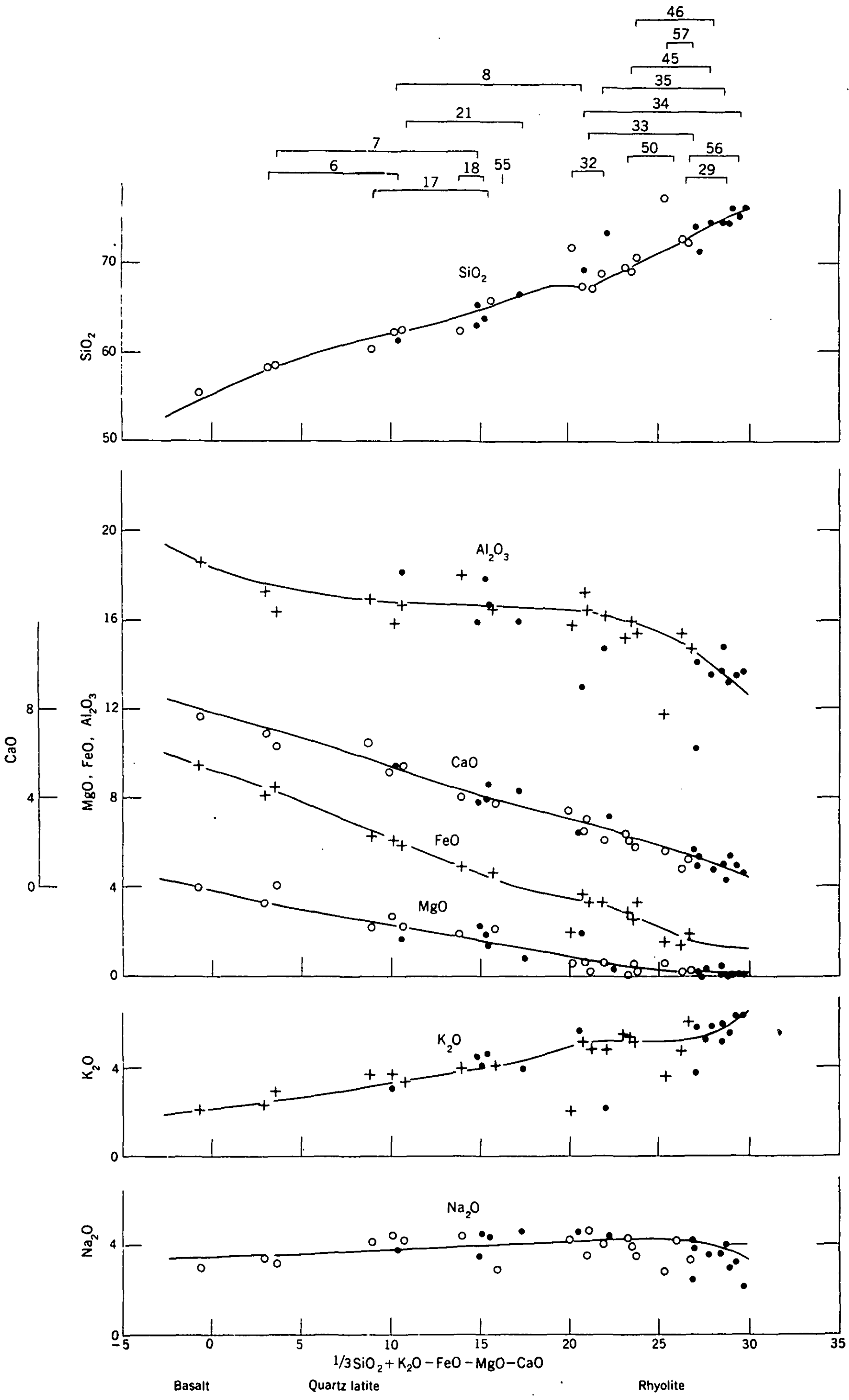

FIGURE 54.—Variation diagram of Treasure Mountain rhyolite and Sheep Mountain quartz latite, in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. The ends of each bracket place the position of a rock and its corresponding groundmass. Numbers above the brackets refer to analyses of corresponding number in table 21, in pocket.

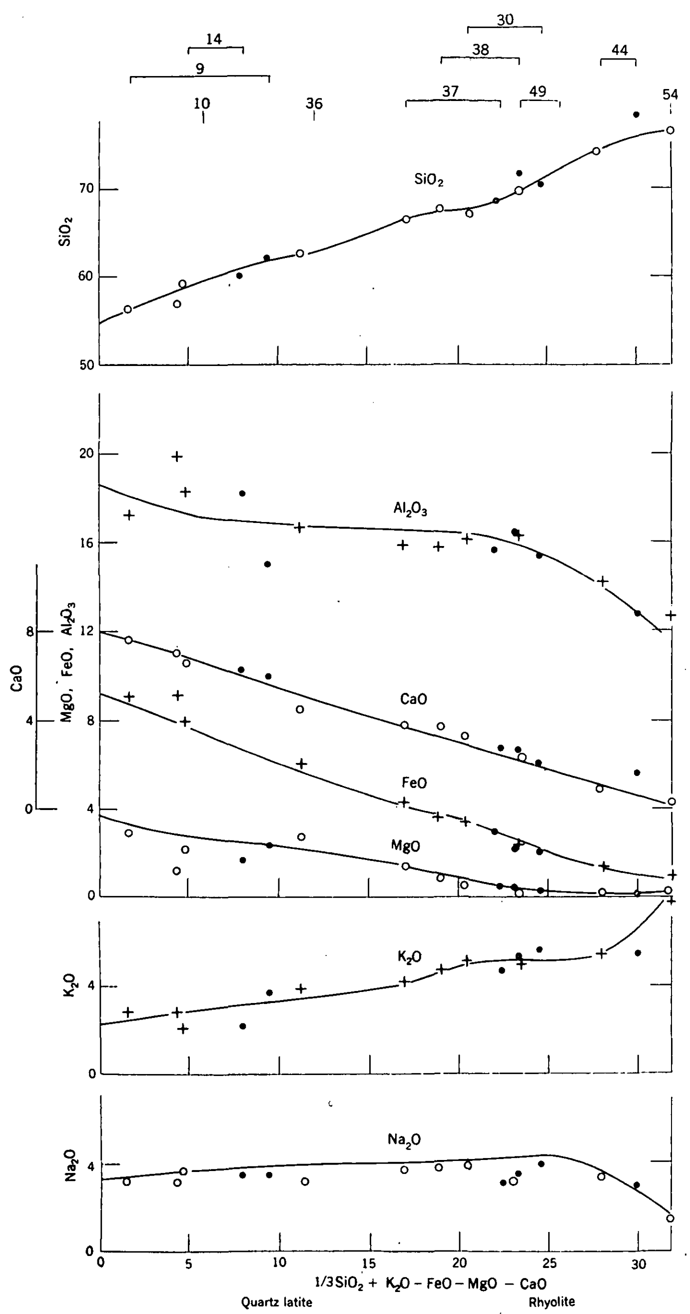

FIGURE 55.—Variation diagram of Alboroto rhyolite and Huerto quartz latite in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. The ends of each bracket place the position of a rock and its corresponding groundmass. Numbers above the brackets refer to analyses of corresponding number in table 21, in pocket.

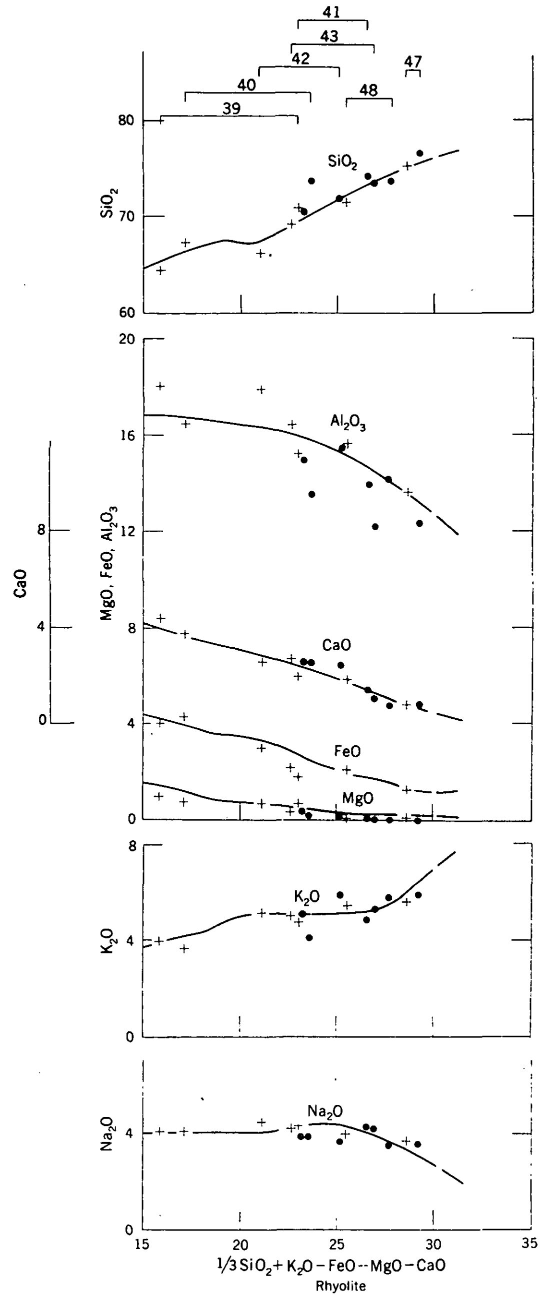

FIGURE 56.—Variation diagram of Piedra rhyolite, in weight percent. Crosses and circles indicate rocks; dots indicate groundmasses. The ends of each bracket place the position of a rock and its corresponding groundmass. Numbers above the brackets refer to analyses of corresponding number in table 21, in pocket. Curves are variation curves for the Potosi volcanic series.

There appears to be no systematic change in the character of the subprovinces with time. In general the subprovinces that are closely related in time and that were erupted between the major periods of deformation and erosion are much alike. In the western area the magmas seem to have been very similar from Lake Fork to Fisher time but in the eastern area the pre-Potosi rocks are low in SiO_2 content and high in Al_2O_3 and K_2O. They are much like the latites of the Hinsdale formation.

TABLE 33.—*Range of rocks on the variation diagrams for the several petrographic subprovinces*

	Basalt	*Latite*	*Quartz latite*	*Rhyolite*
Pre-Potosi rocks of eastern area	----------	0 to 6	6 to 27	27 to 29
Lake Fork quartz latite	----------	----------	7 to 22	----------
Potosi volcanic series	−2 to 2	----------	2 to 27	27 to 33
Fisher quartz latite	----------	----------	5 to 21	----------
Hinsdale formation (basalt and latite)	−10 to 3	3 to 18	18 to ?	? to 29

The rocks of the subprovinces are somewhat different in character, as their chemical compositions indicate. The classification of the rocks and their range on the variation diagrams for the different subprovinces are shown in table 33 and figure 57. The Lake Fork, Potosi, and Fisher rocks are much alike. The Lake Fork and Fisher have only quartz latites, and the Potosi volcanic series has basalts, quartz latites, and rhyolites. Some of the rocks in the Potosi are typical basalts, with calcic feldspar, olivine, and abundant pyroxene. As the feldspar becomes less calcic and before it is as sodic as An_{50} quartz and orthoclase appear in the groundmass. As the feldspar reaches a composition of An_{50} quartz and orthoclase are present in amounts somewhat greater than 5 percent, and the rocks are quartz latites. The quartz latites cover a wide range and are followed by rhyolites. There are no latites or andesites. The pre-Potosi rocks of the eastern area are lower in SiO_2 content. They contain no typical basalts, and the most femic rocks are latites which cover only a narrow range before quartz appears and the rocks are quartz latites. The basalt of the Hinsdale formation and latite are lower in SiO_2 than the others. They range from typical basalts to latites, quartz latites, and probably to rhyolites.

POTOSI VOLCANIC SERIES

A variation diagram, including all of the Potosi volcanic series as a unit, is shown in figure 45, and variation diagrams of the six subdivisions of the Potosi are shown in figures 53 to 56. Mapped units that were not separated by a period of considerable erosion have been included on a single diagram, as the Treasure Mountain rhyolite and Sheep Mountain quartz latite, on one diagram, and the Alboroto rhyolite, and Huerto quartz latite on another. On these diagrams the curves for the whole of the Potosi, taken from figure 45, are likewise shown.

On the diagrams of the divisions all the available analyses for each division are shown and the calculated groundmasses are included, but on the curve on which all the Potosi rocks are shown, the altered rocks, tuffs, stocks, and laccoliths are omitted. Also, to avoid crowding, only the rock analyses are included, except at the right end of the diagram where a few groundmasses are plotted in order to extend the curve as far as possible to the right.

Comparison of the positions of the various plotted points on the diagrams for the formations with the curves for the Potosi volcanic series shows that all the subdivisions of the Potosi are much alike but that some differences may be greater than the probable error of the data. The chief differences between the curves for the whole of the Potosi volcanic series and those for each of the mapped units are shown in table 34.

TABLE 34.—*The chief apparent differences between the variation curves for the Potosi volcanic series and those for each of the mapped subdivisions of that series*

	Conejos quartz latite	*Treasure Mountain rhyolite*	*Sheep Mountain quartz latite*	*Alboroto rhyolite*	*Huerto quartz latite*	*Piedra rhyolite*
FeO	Variable	--------	--------------	High (?)	High (?)	Low
MgO	--------------	--------	Slightly high	------------	Low	------
Na_2O	--------------	Low (?)	High (?) at position 0.4	Low	----------	------
K_2O	Slightly low (?).	--------	High (?) at position 0.2	High at position 0.2	----------	------

COMPARISON OF THE CHEMICAL COMPOSITIONS OF THE MAPPED FORMATIONS

The six subdivisions of the Potosi volcanic series have slight, if any, difference in chemical character and as a large number of analyses are available and furnish rather accurate variation curves, and as this series has a wide range in composition and makes up the greater part of the volcanic pile of the San Juan Mountains, the other formations will be compared with it.

The way in which the variation curves for the other formations differ from those of the Potosi volcanic series is shown in table 35.

The Lake Fork quartz latite rocks (fig. 42) are much like the Potosi volcanic series but are somewhat low in CaO content, slightly low in Na_2O, and high in MgO; and the two SiO_2-rich rocks are high in SiO_2 content, low in Al_2O_3, and very low in K_2O.

The San Juan tuff is represented by three analyses (fig. 43), all from the Uncompahgre and eastern part of the Montrose quadrangles. The three analysed rocks were carefully selected as fresh rocks of types that represented the greater part of the fragments of an area. They are much alike in appearance and are not very different in mineral and chemical composition. However, they fall rather far from and on both sides of the variation curves of the Potosi volcanic series so that they fit no probable variation curve. Analysis 1 represents a rock very low in ferromagnesian minerals and very high in Al_2O_3 and low in SiO_2, TiO_2, and MgO. Its groundmass falls much nearer the Potosi variation curves than does the rock. The groundmass of analysis 2 is very low in Na_2O. Analysis 3 falls near the Potosi curves. On the whole, there is no recognizable difference between the Potosi and San Juan but much more data would be required to prove this.

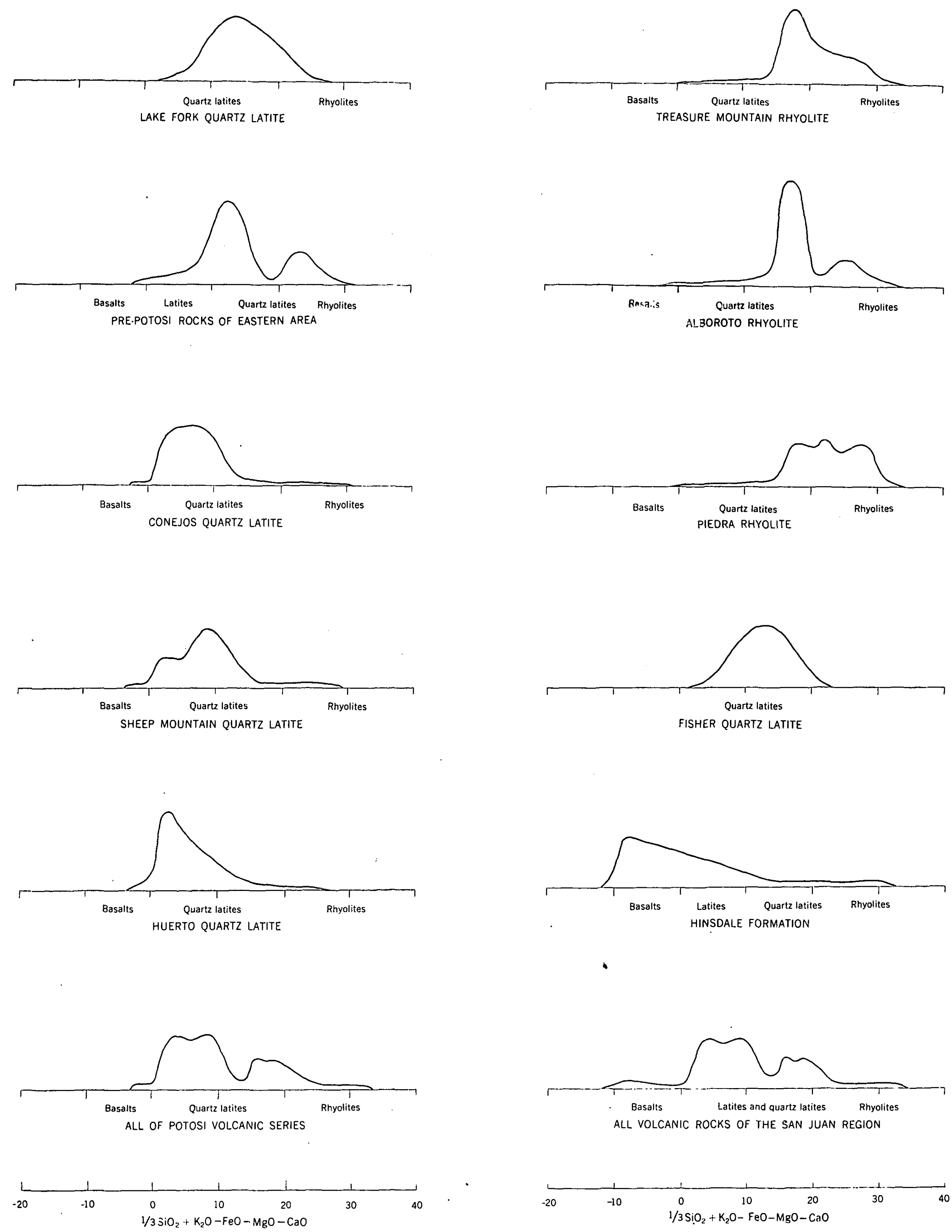

FIGURE 57.—Variation diagrams showing the relative abundance of rocks of the various formations.

TABLE 35.—*The way in which the variation curves for some other rocks of the San Juan region differ from the Potosi volcanic series*

	Lake Fork quartz latite	*Pre-Potosi rocks of eastern area*	*Fisher quartz latite*	*Hinsdale formation*		*Quaternary rocks*	*Stocks and laccoliths cutting sediments*	*Stocks and laccoliths cutting San Juan tuff*	*Stock of San Luis Hills*
				Rhyolite	*Basalt and latite*				
SiO_2	0 at pn[1] 0; +2 at pn 22.	−2.0 at all positions.	0 at pn 10; +1.2 at pn 24.	+2.0 at all positions.	+2 at pn −10; 0 at pn −3; −5 at pn 20.	Low (?)	About −3 at all positions.	----------	About −1 at all positions.
Al_2O_3	Variable	Variably high	0 at pn 10; −1.2 at pn 24.	−0.6 at all positions.	−1 at pn −10; 0 at pn 5; +2 at pn 20.	----------	About +1 at all positions.	----------	About +1 at all positions.
CaO	−0.4 at all positions.	Variable	Slightly viarable.	0 to −0.3 at all positions.	0 at pn −10; −0.6 at other positions.	----------	----------	Slightly low at all positions.	----------
FeO	About 0 at all positions.	Variably low	+0.4 near pn 10	−0.4 at all positions.	−5.0 at pn −10; 0 at pn 0 and upward.	High (?)	----------	----------	----------
MgO	+0.3 at all positions.	0 at all positions.	+0.4 at all positions.	About 0 at all positions.	+1.2 at pn −10	----------	----------	Slightly high at all positions.	----------
K_2O	0 at pn 0; very low at pn 22.	+0.8 at all positions.	About 0 at all positions.	−1.0 at all positions.	−8 at pn −10; 0 at pn −5; +1.2 at pn 20.	----------	+0.8 at all positions.	----------	About +1 at all positions.
Na_2O	Slightly low at all positions.	Variable	−0.4 at all positions.	Slightly variable.	+0.2 at pn −10; +0.8 at most positions.	----------	+0.8 at all positions.	Slightly low at all positions.	High at all positions.

[1] Pn is position (on curve of Potosi volcanic series).

The single analysis of Burns quartz latite falls fairly near the curves of the Potosi volcanic series. Analysis 2 of the pyroxene-quartz latite of the Silverton volcanic series is fairly near the Potosi but its groundmass is 3.2 percent low in Al_2O_3, 1.8 low in Na_2O, 2.4 percent high in K_2O, and rather high in FeO and MgO. This may be partly due to the calculation because some of the small pyroxene crystals may be early and the feldspar may be rich in potash. Analysis 1 is high in SiO_2 and low in alkalies. On the whole, there is no consistent difference between the Silverton and the Potosi rocks.

The pre-Potosi rocks of the eastern part of the mountains (fig. 44) fall fairly near smooth variation curves except for the Beidell latite-andesite and one Tracy Creek quartz latite. These three rocks are much alike, and, compared with the other rocks of this group, are higher in SiO_2, Al_2O_3 and Na_2O, and lower in FeO, MgO, and K_2O.

In general, these pre-Potosi rocks, compared with the Potosi volcanic series, are about 2 percent lower in SiO_2, somewhat high in Al_2O_3, variable to low in FeO, and 0.8 percent high in K_2O.

The Fisher quartz latite (fig. 46) are much like the Potosi rocks but are somewhat lower in Na_2O, and higher in MgO. Except in the silica-poor rocks they are higher in SiO_2 and lower in Al_2O_3.

The rhyolite of the Hinsdale formation has been plotted with the Fisher and the Hinsdale basalt and latite. There is a marked break on the diagram between the rhyolite and the latite of the Hinsdale but the rhyolite appears to be continuous with the Fisher.

The basalt and latite of the Hinsdale formation (fig. 48) is much lower in SiO_2 than the Potosi volcanic series, and this low SiO_2 increases to the right side of the figure. Al_2O_3 is correspondingly high, CaO low, MgO high, K_2O and Na_2O very high. It differs from the Potosi more than any of the other formations do. It resembles somewhat the pre-Potosi rocks of the eastern part of the mountains.

The Late Cretaceous and Paleocene, the Quaternary, and some dike rocks of uncertain age are plotted on figure 50. The Late Cretaceous fragment from the gravels of the McDermott formation is represented by Cr 1 and is the freshest andesite available from the pebbles, although its feldspar is albitized and the dark minerals are partly altered. The very high soda content is probably the result of albitization. The rock appears to be high in SiO_2 content, low in Al_2O_3, and low in FeO and MgO. It is somewhat like the pre-Potosi rocks of the eastern area. Cr 2 is the average of three rather similar analyses of the Late Cretaceous laccolith near Ouray. It is much like the Potosi rocks but is low in K_2O content.

The Quaternary basalts from the Brazos Canyon area, a few miles south of the Conejos quadrangle, are represented by three analyses, one of which (Q 3) is a scoria and does not represent the original magma accurately. They are somewhat like the basalt and latite of the Hinsdale formation but are variable. As compared with the Hinsdale they are low in CaO and MgO content and high in FeO.

Camptonite from the Telluride quadrangle falls near the Potosi curves. Latite of the Cimarron area, which is present as many dikes and sills cutting the San Juan tuff in the Ouray quadrangle, is also much like the Potosi and it is probably of Potosi age. Latite of Difficulty Creek in the Ouray quadrangle also cuts the San Juan. It is much higher in SiO_2 and lower in K_2O and FeO than the Potosi. Intrusive latite of Nellie Gulch in the Lake City quadrangle cuts the Silverton rocks. It is low in SiO_2 and high in FeO. Rhyolite of Grayrock Peak in the Engineer Mountain quadrangle is low in SiO_2 and CaO and high in FeO and Na_2O.

The stocks and laccoliths of the La Plata area intrude the sedimentary rocks and their age is unknown. Four analyses of them are available and are plotted in figure 47. They are very low in SiO_2, and high in Al_2O_3 and alkalies. They are monzonites and syenites with little quartz. The two analyses of the pre-Potosi stock of the San Luis Hills are also plotted on figure 47. They are much like the intrusive rocks of the La Plata area.

Eight analyses of the stocks and laccoliths of the Telluride, Ouray, and Silverton quadrangles are plotted on figure 49. These intrusive bodies cut the San Juan tuff. Four analyses of stocks and laccoliths that intrude the Potosi are also plotted on figure 49. These stocks and laccoliths fit the variation curves of the Potosi less well than do the lavas of the Potosi but they show little systematic difference. The microscopic study showed that these rocks are variable and that diorites, syenites, and monzonites with little quartz are common. Rocks low in free silica content are entirely lacking in the Potosi lavas but are present in the associated stocks. Some of these intrusive rocks are much lower in silica than any of the lavas, and they enable an extension of the Potosi curves to the left as far as −10.

COMPARISON OF THE SAN JUAN PETROGRAPHIC PROVINCE WITH OTHER PETROGRAPHIC PROVINCES

CLASSIFICATION OF PETROGRAPHIC PROVINCES

Petrographic provinces range widely in chemical composition and in several dimensions, as do igneous rocks. Any classification will therefore be arbitrary. The classification here proposed is based on the range of rocks in the province and is therefore related to our scheme of rock classification. The batholith of southern California contains gabbros, tonalites, granodiorites, and granites and is called a tonalite province. The Potosi volcanic series contains basalts, quartz latites, and rhyolites and is a granodiorite province. The Hinsdale formation contains basalts, latites, quartz latites, and rhyolites and is a monzonite province. The general scheme of classification proposed for the provinces near in composition to the San Juan provinces is shown in table 36.

TABLE 36.—*Classification of petrographic provinces of the lime-alkalic rocks*

	Succession of rocks				*Illustration*
Diorite series	Gabbro basalt.	Diorite andesite	Granodiorite quartz latite.	Granite rhyolite.	
Tonalite series	do	Tonalite dacite	do	do	Southern California batholith.
Monzonite series	do	Monzonite latite	do	do	Hinsdale formation.
Syenite series	do	do	Syenite trachyte	do	White Mountain magma series of New Hampshire.
Granodiorite series	do	Granodiorite quartz latite.		do	Potosi volcanic series.

COMPARISON OF THE PETROGRAPHIC PROVINCES

Petrographic provinces may be characterized and compared in more detail by their variation curves. In general, the curves for different provinces for any oxide are approximately parallel and they are farthest apart at about position 15 on the variation curves. The values for the various oxides at position 15 may therefore be used to characterize a province and to compare provinces. Table 37 lists the values for the various oxides at position 15 for a number of petrographic provinces, most of them from the western United States, and figure 58 plots the data against SiO_2.

The table and figure 58 show:

1. Al_2O_3 is about 20 at 58 percent SiO_2 and decreases to 16.0 at 68 percent SiO_2.

2. K_2O is about 5 at 58 percent SiO_2 and decreases to about 2.4 at 68 percent SiO_2.

3. CaO remains about 4.1 percent for all values of SiO_2, FeO at about 4.6 percent, and MgO at about 1.7 percent.

4. Soda is commonly about 4.4 percent, but it is a little higher in the SiO_2-poor rocks and lower in the SiO_2-rich rocks.

5. Low (or high) K_2O content tends to be accompanied by low (or high) FeO.

A comparison of some of the provinces with the Potosi province of the San Juan area follows:

The batholith of southern California is high in SiO_2 content and low in K_2O at both positions 15 and 5 on the variation curves; Al_2O_3 is low at position 15 but not at position 5; FeO is low and MgO high at position 5 but not at 15. The batholith of the Sierra Nevada plots between the batholith of southern California and the Potosi volcanic series.

The various Tertiary and Quaternary volcanic rocks of Oregon and northern California are of various composition, but all are low in K_2O content and high in Na_2O, and nearly all are high in SiO_2; most are low in FeO at position 15 and lower at 5; and most are high in MgO at position 5. The rocks from Newbury are especially low in CaO content and high in Na_2O; those of Steens Mountain resemble the rocks of the Potosi volcanic series but are low in FeO; those from Mount Shasta are very low in FeO and K_2O. These volcanic rocks tend to be intermediate between the rocks of the batholiths of the Sierra Nevada and southern Cali-

TABLE 37.—*Percent by weight of the oxides at position 15 on the variation curves for 52 petrographic provinces*

	SiO_2	Al_2O_3	CaO	FeO	MgO	K_2O	Na_2O
Usu, Japan volcanic rocks	70.0	16.0	4.0	4.2	0.9	1.1	3.8
Southern California, batholith	68.6	15.5	4.1	4.4	1.4	2.3	3.8
Southern California, batholith, east of Peninsular Range	66.2	16.7	4.2	3.8	1.8	3.0	4.1
Lower California, batholith	68.3	14.8	4.0	5.0	1.3	2.9	3.4
Sierra Nevada, Calif., batholith	66.8	16.2	4.6	4.2	1.7	3.2	3.8
Sierra Nevada, Calif., Merriman area	68.5	15.0	4.7	3.9	2.4	2.4	4.0
Katmai, Alaska, volcanic rocks	68.4	15.2	4.0	4.4	1.6	2.1	4.1
Cascade Range, Oreg., volcanic rocks	68.4	15.0	3.8	4.7	1.7	2.5	3.8
Klamath Mts., Oreg. and Calif., volcanic rocks	67.0	17.2	4.6	3.2	2.0	2.7	4.5
Newbury, Oreg., volcanic rocks	66.9	16.2	3.2	5.0	1.2	2.5	5.1
Steens Mt., Oreg., volcanic rocks	66.0	16.4	4.0	4.0	1.6	3.2	4.1
Downieville, Calif., volcanic rocks	65.5	17.4	4.3	4.3	1.7	3.0	4.0
Modoc, Calif., volcanic rocks	66.4	16.5	3.7	4.6	1.6	2.8	4.2
Mt. Shasta, Calif., volcanic rocks	66.4	18.3	4.3	3.1	1.4	1.7	4.6
Crater Lake, Oreg., volcanic rocks	67.2	16.6	4.3	3.7	1.8	2.0	4.9
Mt. Lassen, Calif., volcanic rocks	67.6	16.6	4.6	3.3	2.0	2.2	4.1
Mt. Rainier, Wash., volcanic rocks	66.5	17.2	3.8	3.8	2.1	2.5	4.4
Roberts Mt., Nev., volcanic rocks	67.0	15.2	3.6	4.6	1.2	3.6	3.5
Tonopah, Nev., volcanic rocks	65.0	18.0	4.0	5.2	2.4	3.4	4.2
Goldfields, Nev., volcanic rocks	65.8	17.0	4.2	4.4	1.6	3.0	3.5
Bullfrog, Nev., volcanic rocks	65.0	16.0±	4.6	5.4±	1.5	3.8	3.6
San Francisco Mts., Ariz., volcanic rocks	65.4	17.0	3.6	4.8	1.6	3.1	4.8
Yellowstone Park, volcanic rocks	66.5	17.1	3.7	4.0	2.1	2.6	4.3
Yellowstone Park, Absaroka Range, volcanic rocks	60.0	19.2	3.7	5.2	2.0	4.5	5.4
Yellowstone Park, Crandall, volcanic rocks	65.0	16.6	4.0	4.1	2.2	3.7	4.3
Crazy Mts., Mont., stocks	65.0	16.8	4.4	3.8	1.6	4.0	4.4
Crazy Mts., Mont., alkalic rocks	60.0	19.2	4.0	3.8	1.6	4.4	5.0
Little Belt Mts., Mont., volcanic rocks	64.3	16.5	3.8	4.0	2.6	4.0	4.4
Highwood Mts., Mont., volcanic rocks	55.0	19.8	4.0	6.3	1.6	8.7	4.4
Navajo Country, Ariz. and N. Mex., volcanic rocks	64.0	16±	4.4	3.2	5.6	7.0	2.8
Sunlight, Wyo., volcanic rocks	61.0	17.8	4.0	4.8	2.0	4.7	5.4
Leucite Hills, Wyo., volcanic rocks	58.0	11.4	5.2	4.4	7.2	12.3	1.5
Mt. Taylor, N. Mex., volcanic rocks	62.5	17.4	3.5	4.8	2.0±	4.2	4.5
Valles Grandes Mt., N. Mex., volcanic rocks	65.2	16.2	4.4	4.6	1.7	4.0	3.9
Colfax County, N. Mex., volcanic, alkalic	56.7	22.0	3.0	3.4	1.8	4.8	8.4
Colfax County, N. Mex., volcanic rocks	67.0	15.8	4.4	3.4	2.2	3.0	4.3
Ortiz Mts., N. Mex., stocks	65.0	17.6	4.3	4.1	1.2	3.7	5.0
Cripple Creek, Colo., volcanic rocks	58.5	19.5	4.0	4.8	1.1	5.0	6.8
Pikes Peak, Colo., volcanic rocks	61.5	16.8±	4.2	5.2	1.0	4.7	4.4
Leadville, Colo., volcanic rocks	65.5	16.8	3.7	4.3	1.8	2.8	4.2
Near Gunnison, Colo., volcanic rocks	66.2	16.3	3.8	5.0	1.5	3.2	4.3
Silver Cliff and Rosita Hill, Colo., volcanic rocks	62.0	19.0	4.0	4.5	1.3	4.4	5.2
Breckenridge, Colo., volcanic rocks	65.0	17.1	4.1	5.0	1.1	3.8	4.0
Spanish Peaks, Colo., volcanic rocks	64.5	16.0	4.0	5.2	1.6	4.0	4.4
Idaho Springs, Colo., volcanic rocks	61.0	19.0	5.3	4.0	.3	3.6	6.2
Denver, Colo., volcanic rocks	60.4	20.8	5.6	1.8	.3	4.4	4.4
Elk Mts., Colo., volcanic rocks	65.1	16.8	4.4	4.5	1.6	3.6	3.6
Monarch, Colo., stocks	63.6	18.8	5.2	4.3	1.2	4.4	3.3
Imbros, Greece, volcanic rocks	64.0	17.0	4.5	5.0	1.2	3.8	4.0
San Juan Mountains, Colo.:							
Fisher quartz latite	65.9	15.8	4.0	5.0	1.9	3.8	3.6
Potosi volcanic series	65.2	16.8	4.1	4.8	1.7	3.8	3.9
Lake Fork quartz latite	64.9	17.1	3.7	4.8	1.9	3.9	3.9
Pre-Potosi rocks of eastern area	62.6	17.8	4.2	4.7	1.7	4.6	3.9
Hinsdale formation	61.6	18.4	3.7	4.7	1.7	4.8	4.8
Easter Island, south Pacific Ocean, volcanic rocks	66.0	14.6	2.6	7.1	.8	2.7	5.0
Chosica, Peru, intrusive body	66.5	16.0	4.0	4.7	1.7	3.3	4.0

fornia. As compared with the batholithic rocks, the volcanics tend to be lower in SiO_2, FeO, and K_2O and higher in Al_2O_3 and Na_2O.

The rocks from Katmai, Alaska, are similar to those of the batholith of southern California. The rocks of the intrusive body of Chosica, Peru, are much like the Potosi volcanic series. Those of Roberts Mountain, Nevada, are fairly near those of the batholith of the Sierra Nevada. The rocks of the San Francisco Mountains, Arizona, volcano are near those of the Potosi, but are lower in K_2O and higher in Na_2O. The rocks of the Yellowstone area are much like those from the volcanoes of northern California. They are low in FeO. The rocks of the Crazy Mountains stock, the Crandall volcano, and the Little Belt Mountains are much like those of the Potosi but are low in FeO content.

The rocks from Sunlight, Wyo., and the Absaroka province of the Yellowstone area are much like the rocks of the province of the Hinsdale formation but are higher in Na_2O.

The Tertiary volcanic rocks of the Tonopah, Goldfields, and Bullfrog districts in Nevada are much like the Potosi volcanic series although the data are not satisfactory. In Colorado, the analyzed Teritiary volcanic rocks of the Gunnison and Elk Mountains areas and Breckenridge are much like the Potosi rocks.

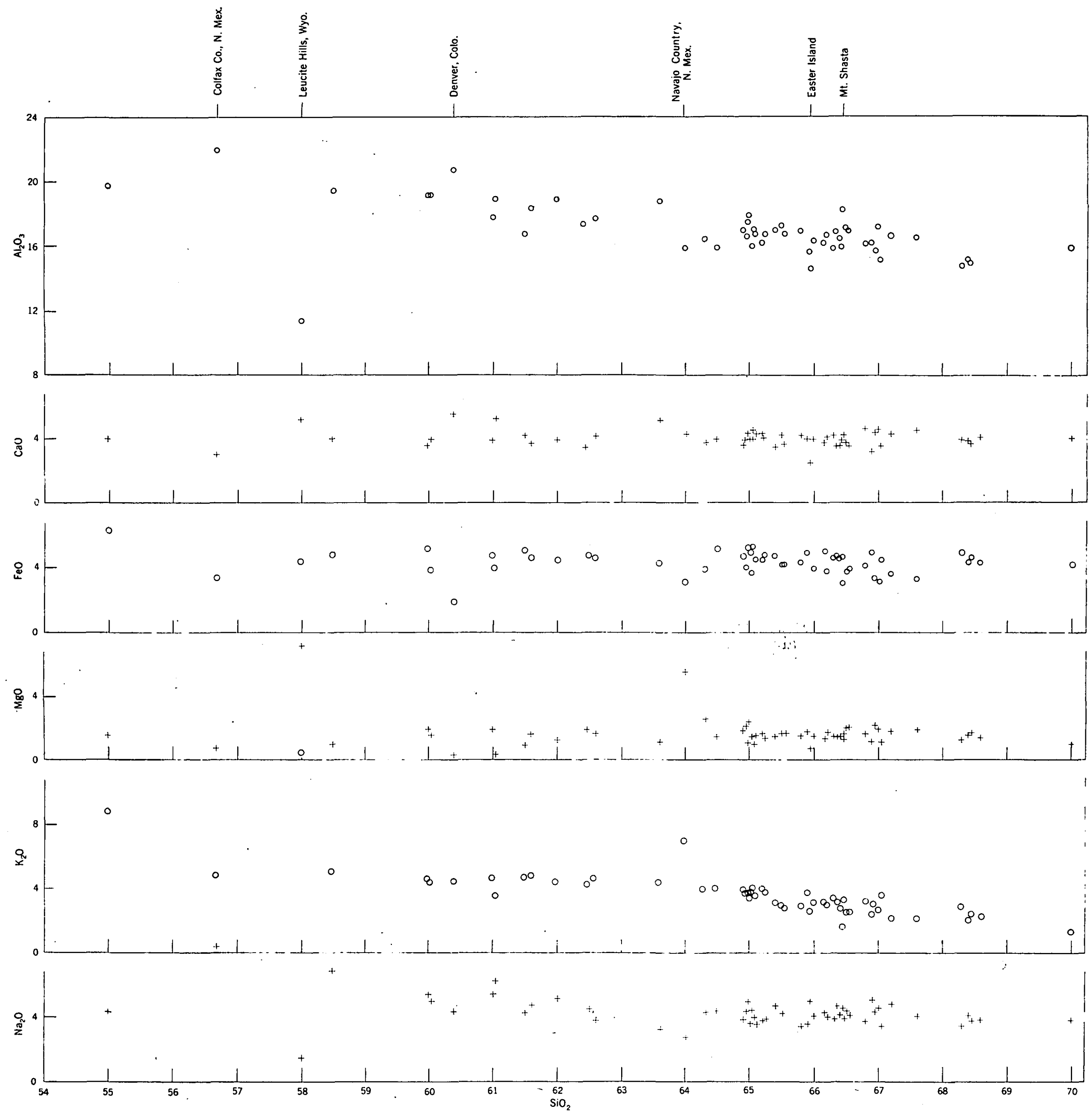

FIGURE 58.—Weight percent of oxides (at position 15 on the variation diagram for six of the petrographic provinces listed in table 37) plotted against the SiO_2 content

The rocks of the Leadville area are much like the Potosi but are lower in K_2O content. Those from Pikes Peak are near the Hinsdale rocks but are lower in MgO. Those from Silver Cliff and Rosita Hill are near the Hinsdale. Those from Cripple Creek are lower in SiO_2 and MgO and higher in Al_2O_3, Na_2O, and K_2O than the Hinsdale. The rocks from the Denver area are lower in content of SiO_2, FeO, and MgO, and higher in CaO, Na_2O, and K_2O than the Hinsdale.

The younger volcanic rocks of the Valles Grandes Mountain, west of Santa Fe in New Mexico, are much like the Potosi volcanic series. The rocks of the Mt. Taylor area in northern New Mexico are more like the pre-Potosi rocks of the eastern area but they are low in CaO and K_2O and high in Na_2O content.

The minettes and associated rocks of the Navajo Country in Arizona and New Mexico are very high in K_2O and MgO but not so high as the rocks of the

Leucite Hills of Wyoming. The rocks from the Spanish Peaks, Colorado, show a discontinuity at position 2 on the variation diagram. Those to the left of that position are near the rocks of the Navajo Country but are higher in iron. Those to the right are near the Potosi volcanic series, and the values of the oxides at position 15 are given in table 37.

The alkalic rocks of Colfax County, N. Mex., are high in Al_2O_3 and Na_2O and low in SiO_2 and MgO content.

In general, the Potosi volcanic series, and other rocks of the San Juan area, appear to be unusually high in K_2O and FeO content.

Figure 58 shows that the provinces low in silica content have a greater range in composition than do those high in silica.

A few of the petrographic provinces listed are considerably different from the average at position 15, and these are compared in table 38.

TABLE 38.—*Amounts in percent by which the oxides in some of the unusual petrographic provinces differ from the average at position 15*

	Al_2O_3	CaO	FeO	MgO	K_2O	Na_2O
Leucite Hills, Wyo	−8.8	+.8	-------	+5.6	+7.6	−4.8
Denver, Colo	+1.8	+1.0	−3.0	−1.2	-------	−0.8
Navajo Country, Ariz	−1.6	-------	−1.2	+4.0	+2.8	−1.6
Easter Island, south Pacific Ocean	−2.0	−1.5	+2.4	−.8	-------	+0.6
Mt. Shasta, Calif	+2.0	-------	−1.0	-------	−1.2	-------
Colfax County, N. Mex., alkalic rocks	High	-------	Low	-------	-------	Very high.

MAGMATIC DIFFERENTIATION

INTRODUCTION

It has been shown (Larsen, Irving, Gonyer, and Larsen, 1938, p. 426–429) that some of the cores of the plagioclase and some of the other phenocrysts of the lavas of the San Juan area were derived from partial assimilation of another rock or partly crystalline magma. The assimilated material appears in every case to have been related to the volcanic sequence of the San Juan area and not to have been a sediment or pre-Cambrian crystalline rocks. Mafic rocks have incorporated rhyolitic material, and felsic rocks have incorporated mafic material. A series of rocks formed by the assimilation of another rock by a magma or by the mixing of two magmas would fall on straight-line variation curves that joined the two end members. The variation curves for the various subprovinces of the San Juan Mountains are nearly straight lines over most of their range except at the rhyolite ends of the curves.

It is also true that the groundmasses of the rocks fit the variation curves for the rocks, and each groundmass is nearer the rhyolite end than the rock of which it is a part. Some of the rocks have as much as 50 percent of phenocrysts in which case the groundmasses and the rocks are far apart on the curves.

DIFFERENTIATION BY CRYSTAL FRACTIONATION

Recently Bowen has been the most vigorous advocate of the theory that magmatic differentiation takes place largely by crystal fractionation. The San Juan area offers an opportunity to test this theory for differentiation in a large and complex petrographic province.

The San Juan province is a typical lime-alkalic petrographic province and the variation curves for all such provinces are near, and nearly parallel to those of the San Juan province. In such provinces most of the chemical analyses fall near smooth variation curves, and a determination of any of the regularly variable oxides—SiO_2, CaO, FeO, MgO, or K_2O—enables us to write a fairly good analysis of the rock, providing the curves for the province are known. A few analyses (about 10 percent) fall far from the curves. The analyses of the rocks high in mafic constituents and low in silica are likely to plot erratically. For most lime-alkalic provinces, the variation curves are near together at the basalt end and show the greatest divergence in the intermediate rocks; and for nearly all petrographic provinces they are very near together, except for the relative proportion of Na_2O and K_2O, at the silica-rich end. For such provinces the variation curves are nearly straight lines over most of the range, but near the rhyolite range there is a sharp change in slope in most of the curves. In some provinces there is some change in slope in the basalt range. In the rocks of the Potosi volcanic series and Fisher quartz latite of the San Juan province there is a break in the slope of the variation curves about position 20.

Even a casual study of the San Juan or other lavas shows that the phenocrysts are such that the groundmass must be richer in silica and potash and poorer in calcia, iron, and magnesia than the rock. This is shown in a more quantitative way when the compositions of the rocks and groundmasses are plotted on the same variation diagrams (figs. 42–48). The groundmasses fall about as near to the variation curves as do the rocks, and in every pair—rock and groundmass—the groundmass is nearer the rhyolite end of the variation diagram, and for rocks with abundant (as much as 50 percent) phenocrysts the difference in position between the two is as much as 12 divisions on the diagram, or about 40 percent of the total range of the rocks of the Potosi volcanic series. Therefore, all of the rocks of any of the petrographic subprovinces of the San Juan region could be derived from a magma of the composition of the basaltic rocks of that subprovince. As the basaltic melt cooled, the rocks formed by fractional crystallization would change progressively from basalt to rhyolite, as shown by the variation diagrams. Partial crystallization and removal of the phenocrysts from the basaltic magma would leave an intermediate magma. The liquid phase would move along the variation diagram to the rhyolitic end.

The relatively regular way in which the rocks of the San Juan and other petrographic provinces range from mafic to felsic indicates a systematic and rather simple method of magmatic differentiation, with some occasional complication to yield the relatively few rocks that plot erratically.

Table 39 gives the estimated phenocrysts in the average rock of the Potosi type in which the positions on the variation diagram of the rock and groundmass are specified. These phenocrysts might be considered the actual minerals that would be removed from a magma at the position given under "Rock" to yield a new magma at the position given under "Groundmass."

TABLE 39.—*Estimated percent by weight of phenocrysts that have separated during different stages in the crystallization of the average rocks of the Potosi volcanic series, Lake Fork quartz latite, Fisher quartz latite, and San Antonio domes*

[Positions in table are those on the abscissa of the variation diagrams of this report]

Position		Number of rocks analyzed	Quartz	Orthoclase	Plagioclase		Biotite	Hornblende	Augite	Hypersthene	Olivine	Total	Percent removed–	
Rock	Groundmass				Amount	An content							Position 0	Position −10
−10	−5	1	-----	-----	10	66	-----	-----	-----	-----	9	19	-----	19
−5	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	[1]	22	-----	-----
0	5	2	0. 5	0. 5	20	66	-----	-----	1	tr	7	29	29	55. 1
5	10	10	tr	-----	15	57	1	1	4	2	tr	24	46	65. 9
10	15	18	tr	0. 5	16	49	1. 5	2	2. 5	1. 5	tr	24	59	74. 1
15	20	14	tr	0. 5	18	45	1. 5	2	1	1	-----	24	68. 8	80. 3
20	25	20	0. 5	3	18	39	3. 5	1	tr	tr	-----	26	76. 9	85. 4
25	30	11	1	6	21	31	3	0. 5	tr	-----	-----	32	84. 3	90. 1

[1] Estimated.

In the calculations, the porphyritic rocks in the four similar subprovinces, the Potosi, Lake Fork, Fisher, and San Antonio, were used. The fact that a small part of the phenocrysts in the rocks are foreign would not change the values significantly. The values for rocks at the basaltic end are not accurate, because there are very few rocks of this type and they are rather erratic in composition. These rocks may have been formed by some special process such as accumulation of olivine crystals, and the parent magma may have had a composition near position 0. The values at the rhyolite end of the variation curve may plot somewhat erratically because plagioclase no longer crystallizes beyond about position 28; and beyond position 28 quartz and orthoclase crystallize in large amount and there is little difference in composition between the rock and the groundmass. There is a change in slope of the curves for most of the oxides near this position.

In the next to the last column of table 39 is given the percent by weight of the magma that must be removed as phenocrysts from a primary magma of position 0 to yield a magma of the composition given for the groundmass. For example, if 29 percent by weight of the phenocrysts of a magma that plotted at position 0 were removed, the resulting groundmass would plot at position 5 (see first and second columns). This percent value coincides with that in the "Total" column, which is the sum of the constituents that would have to be removed as phenocrysts from a primary magma of position 0 to leave a groundmass of position 5. Similarly, 19 percent of a magma at position −10 would have to be removed as phenocrysts to leave a groundmass of position −5 (see "Total" column and last column).

To yield the average rock of the Alboroto and Treasure Mountain rhyolitic formations of the Potosi volcanic series, about 77 percent of a given weight of the primary magma would have to be removed as phenocrysts, assuming the magma to be of position 0. Assuming the magma to be of position −10, about 85 percent of it would have to be removed as phenocrysts to yield the average rock of the rhyolitic members of the Potosi.

The thickness of the body of settled crystals underlying the San Juan region can be determined if certain facts are assumed: If the magma chamber underlay the main part of the volcanic pile, if the composition of the primary magma was that of position 0 on the variation diagram, and if the average thickness of the Potosi volcanic rocks is 3,000 feet (as estimated), differentiation by crystal settling would have yielded a body of crystals 8,000 feet thick under the area.

If H_2O, TiO_2, and the minor elements are excluded, a magma has 8 components—SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, and K_2O. As shown in tables 17, 21, 23, and 25, most of the rocks of the lavas of the San Juan area have 4 or 5 minerals as phenocrysts, a few have 6, and a very few, chiefly Piedra quartz latite, have 7. In some of the rocks having 6 or 7 minerals as phenocrysts, some of the phenocrysts are known to be foreign to the rocks, and in the others some may be foreign or due to lack of equilibrium. Even excluding water, a system of 8 components with 6 crystalline and 1 liquid phase would have 3 degrees of freedom. Therefore, the composition of the liquid phase would vary with the bulk composition of the system. This is in agreement with the fact that in the different subprovinces of the San Juan area and in other petrographic provinces the variation curves are subparallel, and the liquid phase does not move toward a uniform position but depends on the composition of the original magma. However, at the extreme right of the variation curves most petrographic provinces tend toward a fairly uniform composition: in weight percent, 78 SiO_2, 12 Al_2O_3, and 10 of alkalies. The potash content appears to be high in these rocks (about 8 percent) and the soda low (about 2 percent), but the proportion of alkalies may be variable. In these rocks orthoclase, quartz, and a little biotite are the only phenocrysts, and the composition of the groundmass is very nearly the same as that of the rock, even where the rock has 20 percent of phenocrysts. If we omit the mafic constituents, which are in small amount, we might consider these rhyolites as four-component systems—H_2O, SiO_2, orthoclase, and albite. The system would have 2 degrees of freedom. These rocks have nearly the composition of a pegmatite granite, and crystal fractionation changes the composition of the magma very slowly. Where this magma cools slowly with a slow leakage of mineralizers, crystallization takes place largely because of a change in the composition of the melt (loss of water). Where cooling and crystallization are rapid compared with rate of leakage of mineralizers, resurgent boiling will take place as it does in most of the lavas above the glassy chilled zone.

The rocks of each of the subprovinces of the San Juan fall near their particular smooth variation curves, and the same is true of nearly all simple petrographic provinces which we have studied. For each subprovince, if the differentiation took place by the separation from the groundmasses of the actual phenocrysts found in the lavas, the resulting rocks would fall on the variation curves. Therefore, crystal differentiation is adequate to explain the variation in the rocks of each subprovince. The upper part of a magma being differentiated in a chamber by crystal fractionation would be mafic, possibly basaltic, at first, and it would become progressively more felsic as differentiation progressed. We might expect a corresponding regularity in the succession of intrusions or extrusions from this chamber. In the lavas of the San Juan region, as in most other groups of lavas, there is no such simple succession in the lavas, and succession is rather from rhyolitic to mafic. However, in batholiths and most large stocks, the succession of intrusions is fairly regular and progressively from mafic to felsic, as would be expected from differentiation by crystal settling.

The crystallization and differentiation of the primary basaltic magma of the Potosi would begin with the separation of olivine, which would continue until the liquid phase contained about 15 percent of normative quartz. Plagioclase and augite would accompany the olivine over most of this range. In this stage the liquid would be progressively enriched in normative quartz and orthoclase, somewhat enriched in albite, and impoverished in anorthite and femic constituents. After olivine ceases to crystallize plagioclase and pyroxene become the chief phenocrysts. When the silica content reaches about 60 percent, hornblende becomes the chief mafic mineral, and it is soon joined by biotite. Shortly thereafter biotite becomes the chief mafic mineral and it remains so to the end. Sanidine and quartz phenocrysts appear shortly after biotite. Quartz precipitates over only a short range, but sanidine continues to the end. Plagioclase continues until all but a trace of MgO, less than 1 percent of CaO, and about 1 percent of FeO have been removed; then it ceases. At this stage the liquid phase is made up about a third of quartz, more than a third of orthoclase, less albite and only a few percent of other constitutents. Quartz reappears near this stage, and sanidine, quartz, and a little biotite are the phenocrysts from here on. The sanidine phenocrysts have a higher ratio of Na_2O to K_2O than does the magma, and their crystallization enriches the liquid in K_2O. The proportion of quartz increases slightly. The final product is a potash-rich rhyolite of a composition near that of pegmatite. Normative albite, which has remained nearly constant over a wide range, decreases in amount in the last stage.

SOURCE OF THE PRIMARY MAGMA

The magma may have been furnished to the volcanoes of the San Juan area by any one or any combination of these four mechanisms:

1. There was no movement of material from outside the area, and as magma was erupted the crust settled.
2. Magma may have been developed under the vol-

canic pile without much movement of material from the outside or settling of the crust.

3. Magma may have been developed beneath the volcanic pile, fed by plastic or other flow of material from beyond the mountains to take the place of the material erupted.

4. A magma may have been injected into the volcanic area from the outside.

That there was no movement of material from the outside and that the crust settled during the eruptions are not possible because the crust remained relatively stable during the eruption of even such large masses of rock as were spread over the surface during Potosi time (Atwood and Mather, 1932, p. 19).

If there were no movement of material into the area and no depression of the crust during the eruption of the rocks of a magma series, there must have been a large expansion of the material in depth during the eruptions. There was a large subsidence of the crust after the Silverton eruptions and after the Potosi and Fisher eruptions, and extensive elevation by doming after the Hinsdale eruptions. The Potosi rocks underlie an area 100 miles across and are at least a mile thick. The expansion in depth to account for this building-up of the surface might have been due to expansion of the material in depth by melting and heating of that material.

Graton (1945) postulated extensive vesiculation of magma in depth because of a large volume of gas in the erupting magma. Such vesiculation might force the magma to the surface and build up a great volcano on the surface without movement of the crust or movement of outside material into the area of vulcanism. Escape or removal of the gas after the volcanic activity might account for the subsidence that took place after the eruptions of the magma series. However, there is good evidence that vesiculation such as postulated by Graton does not take place except at shallow depths. In dissected volcanic and other intrusive rocks, vesicles are rare in stocks, dikes, sills, laccoliths, and other intrusive bodies, even when the depth of crystallization was a few thousand feet or less. This is true in the chilled border as well as in the main body. Vesicles are most rare in batholithic rocks. The vesicles of the rare bodies that contain them are much better explained as being due to resurgent boiling during the later stages of the crystallization of the magma.

The subsidence after the Silverton and again after the Potosi and Fisher eruptions might have resulted from the cooling and crystallization of material in depth or from the elimination of the gas.

This mechanism would not change the load on the crust of the area and would not disturb the isostatic adjustment.

If during the eruptions, material moved by plastic flow from the outside into the area beneath the volcanic pile, the movement must have been periodic. During the Potosi and Fisher eruptions there were five periods of such movement, separated by intervals without movement. The material forced in from the outside must have approximately kept in balance with the material extruded because there is no evidence of large crustal movements during the eruption of any of the magma series. It would follow that the outside force caused the extrusion of the magma, and there must have been subsidence in some areas beyond the volcanic pile. The extrusive rocks would be an extra load on the crust, but the crust may have been out of equilibrium before the eruptions and the eruptions tended to adjust the load on the crust. However, the subsidences following the Silverton and Potosi and Fisher eruptions were probably due to isostatic adjustment.

Magma may have been injected beneath the San Juan area from the outside and this injection might have furnished the force necessary to erupt the volcanic rocks. The injections would have been by slow periodic movement; that is, periods of movement and volcanic activity separated by intervals of little movement and few eruptions. The periods of depression after the Silverton and Potosi and Fisher eruptions might represent times when magma was temporarily withdrawn, and the great doming that followed the Hinsdale may represent a period during which a large mass of magma was injected without eruptions.

ORIGIN OF THE MAGMAS

The law and the cause of the variation in the rocks of each magmatic series are accounted for with reasonable assurance as due to the differentiation of a parent basaltic magma, predominantly by crystal fractionation; but the origin of the parent magmas is much more complex and much less understood. There are so many possible explanations, so much complication, and so few tangible data that any explanation must be highly speculative. The principle of multiple hypotheses will therefore be followed, and no attempt will be made to exhaust all the possibilities.

Some data that bear on the problem have already been discussed and will be listed briefly here.

1. The lavas of each magma series have been derived from a primary basaltic parent magma.

2. These parent magmas were not all alike.

3. During the eruption of several of the magma series there were fairly long intervals in which few or no eruptions took place, and between the eruptions of the magma series there were much longer intervals of little activity.

4. There is evidence that no extensive earth deformation took place during the eruption of any of the magma series, but between eruptions of series there were commonly earth movements on a large scale. After the Late Cretaceous eruptions the area was greatly elevated, after the Silverton and Potosi and Fisher eruptions there were subsidences, each of several thousand feet, and after the Hinsdale eruptions the mountains were domed to their present form.

5. The rocks of each of the magma series have persistent chemical peculiarities, even though some of the rocks like the Potosi and Hinsdale were spread over an area more than 100 miles across and were erupted from many widely scattered vents. The Potosi and several of the other magma groups are made up of rocks ranging from basalts to rhyolite.

6. The mapped units are sharply separated. However, there are some local bodies of rhyolites in the dark quartz latite formations and some local bodies of dark quartz latites in the rhyolite formations.

7. Many of the formations have a variety of rocks, but some have large volumes of uniform rock. The main part of the Alboroto rhyolite is made up of flows and tuffs of a rather uniform rock—uniform in chemical composition, and in the size, character, and amount of phenocrysts. This uniform rock has an estimated volume of about 1,000 cubic miles and underlies an area more than 100 miles across.

8. Some, and probably most, of the formations were erupted from several rather widely separated centers.

9. There is no apparent regularity in the change in the parent magma with time. In the western part of the San Juan region the earliest eruptions were a quartz latite group, the second were quartz latite, and the last latite. In the eastern part of the area the first was a latite group, the second quartz latite, and the last latite. Compared with other volcanic areas, the latest eruptions are commonly high in alkalies and low in silica content and tend toward alkalic rocks.

Regardless of the source of the magma series, the parent magmas might have been derived in any one of the following ways:

1. By magmatic differentiation from a uniform basaltic magma.
2. By assimilation of limestone or some other material, accompanied by crystal fractionation or magmatic reaction on inclusions.
3. By having separate sources, each of different materials.

The wide distribution of some of the vents that furnished the rocks of any magma series indicates that the characters of those rocks were determined by the forces that acted on the crust during and immediately preceding those eruptions. This is true whether the parent magma was formed in a single large body or in several separated bodies, and whether the magma was formed beneath the San Juan area or moved in from outside that area.

If the magma came from outside the San Juan area, it must have maintained its peculiarities for the duration of the eruptions of a magma series such as the Potosi volcanic series, and have changed only during the long intervals between eruptions of magma series. Since there was no great movement of the crust during the eruption of a magma series, the magma must have moved in slowly and irregularly at about the rate at which magma was erupted.

If the magma originated beneath the San Juan Mountains its uniform character throughout the area during the eruption of any magma series must have been the result of uniform forces acting on the area during that period of eruption.

A magma crystallizing at great depth might precipitate different and, in general, denser minerals than those formed at the surface. The magma would have a high viscosity and crystal settling might be very slow. Little is known about the crystallization of magmas at high pressures. In metamorphic rocks the dense eclogites have generally been considered a high-pressure facies, but this conclusion is based largely on the fact that such dense rocks would be expected to form in crystallization at high pressure. Recent geologic data indicate, however, that such rocks may be and probably generally are formed under moderate pressure (Switzer, 1945).

The differentiation of the deep-seated magma might have taken place by some process other than crystal fractionation.

It is difficult to see how a magma could be so uniform over so large an area at any particular time if the peculiarities were due to assimilation or reaction on crustal rocks.

During the eruption of any one of the magma series, the magma may have been derived from a particular layer in the crust because of forces acting on the crust at that time (Kennedy, W. Q., and Anderson, 1938; and Kennedy, W. Q., 1933).

TO EXPLAIN THE SUCCESSION OF ERUPTIONS OF A SUBPROVINCE

Because rocks of the Potosi volcanic series cover a very large area, are well exposed in many places, are generally fresh, have furnished many analyses of carefully selected types, are a complex group, and provide the best data on the succession of events during their eruption, they are the best subprovince for a study of problems in petrogenesis. The dark quartz latite formations are nearly everywhere sharply separated from the light-colored rhyolite formations, and in cliff exposures the contacts can commonly be seen from a distance of a mile or more. However, there are local bodies of rhyolitic rock in the dark quartz latites, and there are local thin layers or small volcanic cones of dark rock in the rhyolitic members.

The succession in the Potosi volcanic series from oldest to youngest is:

Dark quartz latites	Conejos
Erosion.	
Rhyolites, followed by plagioclase rhyolites	Treasure Mountain
Dark quartz latites	Sheep Mountain
Erosion.	
Rhyolites Plagioclase rhyolites	Alboroto
Dark quartz latites	Huerto
Erosion.	
Rhyolites, followed by plagioclase rhyolites	Piedra
Erosion.	

During the periods of erosion little or no material moved into the area, but material did move in during active eruptions.

The regular succession of deposition between intervals of erosion—first, rhyolite, then plagioclase rhyolite, followed without erosion but with a sharp break by dark quartz latites—can be explained in many ways. A reasonable explanation is that a chamber beneath or near the mountains was quietly differentiating the magma during the periods of erosion or periods without movement of magma or eruptions. By the time the next earth movement and eruptions took place the magma had become differentiated by crystal settling and was layered at the top with rhyolite which graded downward to plagioclase rhyolite and dark quartz latite. The first eruptions were from the upper part of the magma body and yielded rhyolites which became richer in plagioclase at a later stage. The dark quartz latites followed, and were probably associated with some movement that tapped a lower layer of the magma.

The bodies of dark rocks in the rhyolitic members are due to the local movement of some of the lower magma toward the crust. The rhyolitic rocks in the dark members may be due to eruptions from local pockets of residual rhyolitic magma. The tiny plagioclase crystals in the groundmasses of these rhyolitic rocks would have formed while the magma was in a local pocket near the surface, where loss of heat was more rapid than the loss while the magma was in the main magma chamber.

CONCLUSIONS

The Tertiary lavas of the San Juan Mountains have been divided in the field and on the basis of age into four major series. Each series contains rock that covers a wide range in composition and texture; yet each series has its peculiar chemical, mineralogical, and textural characteristics. After the eruption of each magma series there was extensive deformation, followed by a long interval without eruptions. During the eruption of a magma series there were brief intervals without eruption long enough for deep canyons to be eroded, but there was little deformation. Within a magma series, the first eruptions after the brief intervals of erosion were rhyolite. They were followed, with a sharp break but no great erosion or other evidence of a long lapse of time, by dark rocks. Local bodies of dark rocks are interlayered with the rhyolites, and local bodies of rhyolitic rocks are associated with the dark rocks.

After the eruption of the Late Cretaceous rocks and during the Paleocene and Eocene, there was some deformation and, toward the end of the Eocene the mountains were domed and elevated in the central part at least 15,000 feet. There was little further deformation until middle Miocene. During Eocene, Oligocene, and early Miocene there were no volcanic eruptions. The first eruptions of the great mass of volcanic rocks that form the main bedrock of the San Juan Mountains were in middle or late Miocene and were not immediately preceded or accompanied by deformation of the crust.

The magma that furnished the Miocene and Pliocene rocks must have moved intermittently into the San Juan area slowly from the outside, with short and long interruptions. During the eruption of a magma series magma must have been erupted about as rapidly as it came in, for the crust was not greatly deformed during the eruption of such great volumes of lava as the Potosi volcanic series—nearly 6,000 cubic miles. After the eruption of the Silverton volcanic series and again after the eruptions of the magma series of the Potosi and Fisher, magma must have been withdrawn from the San Juan area, because there were great depressions of the crust following these series. After the eruption of the last of the major series—the Hinsdale—magma must have moved into the area without eruptions to form the present great dome.

For some time preceding and during the eruption of each of the magma series, there was little deformation of the crust, but after the completion of the eruption of each series the crust was greatly deformed—commonly depressed.

The primary magma that was the source of each magma series was essentially the magma that moved in from the outside. It had the composition of a basalt or of a rock between basalt and quartz latite. It was not the same magma for all the magma series. No satisfactory explanation of the differences in the compositions of the primary magmas was found. They may have been caused by crystal fractionation of peculiar kind in depth or by different sources—possibly originating at different depths—of the magmas.

Most of the analyses of the rocks of a magma series fall on or near smooth variation curves, but these curves for one series are not identical with those of the other series. The groundmasses of the rocks of a magma series fall on the same curves as do the rocks, and nearer the rhyolites than the rocks. Therefore, the progressive removal from the magma of the phenocrysts actually found in the rocks would yield a series of rocks identical with those of the magma series. The magmatic differentiation of a magma series is therefore believed to be due to crystal fractionation.

THE SUCCESSION OF EVENTS

In middle Miocene time, after a long interval during which the crust was stable and there were no volcanic eruptions, magma moved into the San Juan area and was erupted about as fast as it moved in. The Lake Fork quartz latite, San Juan tuff, and Silverton volcanic series were erupted. There were intervals during which no magma moved in and no magma was erupted. During these eruptions the crust suffered little deformation but after the eruptions of the rocks of the Silverton volcanic series the crust subsided, probably because of removal of magma. There followed a long interval without eruptions or major deformation, and the surface was reduced to a mature stage.

Probably at a somewhat different time, a different magma—monzonitic—moved into the eastern part of the area and furnished the material for the pre-Postosi rocks of that area.

The period of quiet following the eruption of the Silverton volcanic series was ended by movement into the area of the Potosi magma—granodioritic—and its eruption without much differentiation yielded the dark rocks of the Conejos quartz latitite. A short interval without eruption allowed the deep-seated magma to differentiate by crystal settling until the upper part was rhyolitic. Magma again moved in and forced out some of the upper siliceous magma to form the Treasure Mountain rhyolite. Perhaps because of some special movement, the dark part of the magma was then abruptly extruded and yielded the dark rocks of the Sheep Mountain quartz latite. Another interval without eruptions allowed differentiation to take place again.

The Alboroto rhyolite was then erupted, followed as before by the dark quartz latite of the Huerto. A third interval without eruptions was followed by the Piedra rhyolite. This was followed by a somewhat longer interval without eruptions, and then the Fisher quartz latite of intermediate composition were erupted.

The central part of the mountains was again greatly depressed, probably because of withdrawal of magma. A long time without movement or eruptions followed and the San Juan peneplain was eroded.

In Pliocene (?) time a magma—monzonite—again moved into the area and the Hinsdale rocks, derived from the parent magma without much differentiation, were erupted on the peneplain. Their eruption was followed by the doming of the mountains to their present form. This doming is believed to have been due to the intrusion of a large mass of magma.

During the eruption of the groups of dark rocks, such as the Conejos quartz latite, local bodies of rhyolitic rock were erupted. These rhyolites are believed to have come from local pockets of differentiated magma. During the eruption of the rhyolitic rocks local eruptions of dark rocks took place and these are believed to be due to local tapping of the underlying dark part of the layered magma.

In general, short intervals during which the magma was stagnant occur during the eruption of a magma series, and they are commonly followed by the eruption of rhyolitic rocks. Longer intervals accompanied by withdrawal of magma followed the eruption of a major series. Movement of a large mass of magma into the area may characterize the end of a major magmatic cycle.

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