UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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1941–42

SHORT PAPERS BY

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626-

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the papers for separate publication]

ILLUSTRATIONS

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STRATIGRAPHY, STRUCTURE, AND MINERALIZATION IN THE BEAVER-TARRYALL AREA, PARK COUNTY, COLORADO

A RECONNAISSANCE REPORT

BY
QUENTIN D. SINGEWALD

Prepared in cooperation with the
STATE OF COLORADO
GEOLOGICAL SURVEY BOARD OF COLORADO
AND COLORADO METAL MINING FUND

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CONTENTS

ILLUSTRATIONS

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1941-42

STRATIGRAPHY, STRUCTURE, AND MINERALIZATION IN THE BEAVER-TARRYALL AREA, PARK COUNTY, COLO.

By QUENTIN D. SINGEWALD

ABSTRACT

The Beaver-Tarryall area is 6 miles wide, extends from the Continental Divide nearly to South Park, and lies immediately east of the South Platte River. The principal rock formations comprise a sedimentary series nearly 10,000 feet thick of Pennsylvanian and Permian age and igneous intrusives of early Tertiary (?) age. Pre-Pennsylvanian rocks crop out nearby, to the west. Mesozoic sedimentary rocks—the Morrison formation (Jurassic), the Dakota sandstone (Cretaceous), and the Benton shale (Cretaceous)—crop out only in the eastern part of the area.

The Permian and Pennsylvanian formations constitute a rapidly alternating sequence of clastic rocks ranging from very coarse conglomerate to shale, with a few thin beds of limestone. The rocks of the lower portion are prevailingly gray, but they contain some red shale, and they grade upward into a prevailingly red series. Even the limestones can rarely be traced very far. Two limestone zones, however, seem thicker than others and fairly persistent, and they have accordingly been used as boundaries for a threefold division of the series. Only approximate correlations can be made between the divisions in the Beaver-Tarryall area and those of other districts.

Igneous rocks occur chiefly as ordinary and laccolithic sills. They have been classified into three mappable units—quartz-poor monzonite porphyry of Mount Silverheels, quartz-rich monzonite porphyry, and quartz-rich monzonite containing large orthoclase crystals, here and elsewhere designated Lincoln porphyry. The first unit preponderates in the central and eastern parts of the area, the second in the central-western part, and the third in the extreme western part. A huge stock lies along the eastern border of the area, and the apex of a smaller one crops out in Montgomery Gulch.

As the area lies east of the Sawatch arch of central Colorado, the regional dip is eastward. Two major longitudinal folds occur, respectively, close to the eastern and western margins of the area, and a transverse shear belt crosses the central-northern part. Other structure anomalies are purely local or are due to warping or rupture during igneous intrusion. Within the transverse shear belt occur the Montgomery Gulch stock and also the greatest aggregate thickness of sills.

Surrounding the small stock is a zone of intense contact metamorphism, which grades outward into unmetamorphosed rocks. The metamorphosed zone coincides with the area of principal mineralization. The ore deposits consist of (1) veins and veinlets along fissures, (2) replacement bodies in metamorphosed limestone adjacent to fissures, and (3) countless veinlets in exten-

sively fractured porphyry or other brittle rock. An early stage of mineralization caused widespread deposition of epidote and chlorite, accompanied locally by garnet, magnetite, specularite, and other minerals. Zoning away from the stock is indicated by the distribution of magnetite and specularite and by the relative coarseness of garnet crystals. A later stage caused deposition of pyrite and quartz throughout the mineralized area. At the end of effective deposition the temperature of the ore-forming solutions was still too high to permit deposition of sphalerite or other later sulfides except at two places.

The ore-forming solutions, in the absence of master channels, spread into innumerable small fissures, and the resulting deposits, though abundant, are small and scattered. Very small amounts of gold accompany pyrite and quartz. The most favored places for prospecting have been at the intersections of veins with limestone beds.

The area is not a favorable one for prospecting. Small ore shoots may perhaps be located by following some of the stronger veins to their intersections with limestone beds, but the thickest and most persistent limestone, at the base of the middle division, is too far from the source of mineralization to be productive along its outcrop and too deep for prospecting in most of the mineralized area. Prospecting at depth for deposits in the Leadville limestone or Dyer dolomite member of the Chaffee formation (Blue limestone of the Leadville and Alma districts) is out of the question.

The placers of Tarryall Creek and its tributaries as well as the relatively unimportant ones in the upper part of Beaver Creek derive their gold from the mineralized area around the Montgomery Gulch stock. This can be proved by physiographic evidence and substantiated by the fineness of the gold. The greatest production in the Tarryall drainage system comes from deposits within the terminal moraine of the Montgomery glacier and from outwash gravel downstream. Other placers are likewise closely related to the glacial deposits.

The gold in placers of the South Platte Valley and of the lower part of Beaver Creek came from mineralized areas of the Alma district, west of the area. In these valleys also glaciation has controlled the distribution of placer gold.

INTRODUCTION

The recent large increase in gold production from the Alma district has greatly stimulated interest in territory immediately to the east, where placers have yielded more than a million dollars in gold and where many small gold-bearing veins have been discovered. Consequently, as a cooperative project of the United States Geological Survey and the State of Colorado, 7 weeks in 1938 were devoted to reconnaissance work to determine the origin of the placer gold and the possibilities for discovering valuable lode deposits either near the surface or at depth.

The area, about 6 miles wide, extends southward a distance ranging from 5 to 11 miles from the Continental Divide between Hoosier Pass and Boreas Pass, in northwestern Park County. The latitude and longitude are shown on the geologic map (pl. 1). Tarryall Creek and its tributaries constitute the main drainage system. Beaver Creek, to the west, ranks next in size, but between them lie Crooked Creek and Trout Creek. All the streams flow into South Park, though eventually they reach the South Platte River, which constitutes the western margin of the area that has been mapped.

The topography is rugged, with altitudes ranging from 10,000 to nearly 14,000 feet. Curiously enough the highest peak, Mount Silverheels, is not on the Continental Divide. A great deal of the terrane, particularly in the north, lies above timber line, whose altitude is about 11,500 feet. The portion below timber line is mostly covered by a dense growth of pine and aspen.

Alma and Como are small towns in the extreme southwest corner and a mile east of the southeast corner of the area, respectively. The remainder of the area is uninhabited except for a few prospectors and placer miners. Both towns have bus connections with Denver. A State highway extends up the Platte Valley from Alma to Hoosier Pass, and poor roads, intermittently maintained by prospectors, wood cutters, or sheep ranchers, extend at least part way up each of the principal gulches except Trout Creek.

Previous geologic observations in 1873 by Peale,[1] in 1886 by Emmons,[2] and in 1925 by Muilenburg[3] were too meager and generalized to be of service in the present work, but Muilenburg's petrographic descriptions, chiefly of the igneous rocks, have been utilized. The first and major task, therefore, was to determine in as great detail as the available time permitted the sequence and structure of the sedimentary rocks and the form, character, and distribution of the igneous rocks over the entire area. The broad picture thus obtained is an essential framework to the local observations at known ore deposits and prospects, for when the two are fitted together, the answers to practical questions concerning potential ore bodies become clear. To accompany the discussion, the bedrock geology has been depicted on plate 1, with accompanying cross sections, plate 2.

The helpful suggestions of Mr. B. S. Butler, who made a preliminary inspection of the area during 1937, spent several days with the writer during 1938, and had general supervision of the project, is gratefully acknowledged. The writer also is grateful to G. F. Loughlin, W. S. Burbank, and J. S. Williams, of the United States Geological Survey, for suggestions during preparation of the manuscript; to John Singleton, of Fairplay, for information concerning the placer gold; and to several prospectors and miners for many courtesies. The report has been prepared in cooperation with the State of Colorado, the Geological Survey Board of Colorado, and the Colorado Metal Mining Fund.

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[1] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, pp. 212–222, 1874.

[2] Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, pp. 83–84, 104–107, 1886.

[3] Muilenburg, G. A., Geology of the Tarryall district, Park, County, Colo.: Colorado Geol. Survey Bull. 31, 1925.

PRE-PENNSYLVANIAN ROCKS

Rocks older than Pennsylvanian crop out only to the west of the Beaver-Tarryall area. Their eastern boundary, taken from the Alma map, is shown on plate 1. The nearest exposures are on the east ridge of North Star Mountain near Hoosier Pass. From that locality they trend southward, diverging west at a small angle from the Platte River.

The sequence for the northern part of the Mosquito Range may be summarized as follows:

Generalized section of pre-Pennsylvanian rocks in Alma district

	Feet
Mississippian:	
Leadville limestone: Blue to black massive-bedded dolomite; maximum	170
Devonian:	
Chaffee formation:	
Dyer dolomite member: Fairly thin-bedded dense-textured blue and white dolomite; maximum	80
Parting quartzite member: Cross-bedded and conglomeratic quartzite and sandy limestone; maximum	55
Ordovician:	
Manitou limestone: Thin-bedded white to medium-blue siliceous limestone; maximum	130
Cambrian:	
Sawatch quartzite:	
Peerless shale member: Upper part mainly thin-bedded limestone, lower part mainly shale; approximate	100
Lower member: Fairly thick-bedded white quartzite; approximate	100
Pre-Cambrian: Gneisses, schist, and granite.	

The Leadville and Dyer together constitute the well-known †Blue limestone [4] of miners and contain the chief ore zone in Leadville, Alma, and other districts in central Colorado. Their aggregate thickness is only about 50 feet in Platte Gulch south of Hoosier Pass and on North Star Mountain, whereas it is 160 feet on Mount Lincoln, 2 miles farther west. This eastward thinning, the result of pre-Pennsylvanian erosion, suggests that the †Blue limestone will not be found at depth except in the extreme western part of the Beaver-Tarryall area. It is even possible that the entire section of pre-Pennsylvanian sedimentary rocks is missing in the eastern part of the area, for these rocks do not exist either at Breckenridge, 8 miles to the north, or near Hartsel, 20 miles to the south.

The pre-Cambrian basement complex, of course, extends continuously eastward at the base of the sedimentary column.

[4] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the Geological Survey.

ROCKS OF POST-MISSISSIPPIAN AND PRE-JURASSIC AGE

REGIONAL CLASSIFICATION

The rocks of paramount interest in this study are the sedimentary beds stratigraphically between the Leadville limestone and the Morrison formation. These beds are widespread in central Colorado, where they attain a maximum thickness of about 10,000 feet.

The earliest regional subdivision of this series was made by A. C. Peale,[5] of the Hayden Survey, who gave numerous sections to accompany his descriptions of the general geology. The stratigraphic data were in part summarized and compared with those of other regions in a later report.[6] Peale's divisions apparently were based partly on color, partly on lithologic character, partly on the fossils present, and partly on relative thickness. He obviously noted the scarcity of red beds in the lower part of the series, the abundance of dull-red and maroon strata in the middle part, and the prevailingly brick-red color in the upper part; but he also recognized that the color change is progressive and so could not be used to establish clear-cut boundaries. Furthermore, fossils (Pennsylvanian) at different horizons within the lower, prevailing non-red strata permitted the bulk of them to be classified as of Coal Measures age. The lowermost several hundred feet of the non-red strata, however, were assigned to the underlying division, which also included the present Leadville limestone. The dull-red to maroon color and the presence of gypsum seem to be the most pronounced characteristics of the division overlying the Coal Measures. Emphasis on gypsum is a bit curious, for as pointed out by Girty,[7] gypsum is not mentioned in any of the detailed sections from which the generalized section for the Park Range was compiled. Both Peale and Stevenson,[8] however, report gypsum in the Eagle River region. A few plant remains from the lower part of this division on the Eagle River were referred by Lesquereux to the Permian, but Stevenson at about the same time found invertebrate Carboniferous fossils; consequently Peale labeled the division "Permian or Permo-Carboniferous." No fossils whatever had been found in the upper or "red beds" portion. In the absence of definite lithologic or paleontologic boundaries, Peale must have taken relative thicknesses into account in compiling his generalized section, presumably assigning

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[5] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, pp. 212–266, 1874; Ann. Rept. for 1874, pp. 114–124, 1876.

[6] U. S. Geol. and Geog. Surv. Terr. Ann. Rept. for 1875, especially table, p. 77, 1877.

[7] Girty, G. H., Carboniferous formations of Colorado: U. S. Geol. Survey Prof. Paper 16, p. 82, 1903.

[8] Stevenson, J. J., U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, pp. 363–372, 1875.

to each division more or less the same proportions of the total thickness from each section.

Subsequent to the Hayden Survey, detailed work in local districts has added important information. In the Crested Butte area,[9] Eldridge's divisions are based on essentially the same lithologic and color criteria as had been used by Peale, and so the boundaries are indefinite. At Aspen, the color boundary between the Maroon formation and the beds assigned by Spurr[10] to the Triassic is likewise indefinite. A lithologic zone, however, "the gray calcareous member," was assigned as the base of the Maroon. In spite of many local variations in lithology and in thickness, this zone apparently could be traced with reasonable assurance over at least part of the district, but it could not be used for correlation with other districts. At Tenmile[11] (see table), color, lithologic character, and particularly the abundance and composition of the limestones, played major parts in the correlation. The fairly definite boundaries of the Robinson and Jacque Mountain limestone zones were assigned respectively to the bottom and top of the Maroon, but the boundary between †Weber shales and †Weber grits was indefinite. At Monarch,[12] a formation boundary was placed at the lowest of many conglomerates in the upper half of the series. At Salt Creek[13] (see table), the lowest and the uppermost beds of a zone containing the only conglomerates within a 10,000-foot thickness of strata were used for two of the boundaries, and a sandstone for the third.

Thus at no place in central Colorado have division boundaries been established that may with confidence be applied to other areas. In fact, nearly all boundaries, even in local areas, are either indefinite or placed at some bed or zone whose thickness and lithologic features vary within relatively short distances. Probably the most distinctive boundaries are those of the limestones at Tenmile, but even there, according to recent detailed work by Wells,[14] one cannot be sure he is following precisely the same bed for any great distance.

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[9] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.

[10] Spurr, J. E., Geology of the Aspen mining district, Colo.: U. S. Geol. Survey Mon. 31, pp. 30–39, 1898.

[11] Emmons, S. F., U. S. Geol. Survey Geol. Atlas, Tenmile folio (No. 48), 1898.

[12] Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colo.: Colorado Geol. Survey Bull. 4, pp. 66–74, 1913.

[13] Gould, D. B., Stratigraphy and structure of Pennsylvanian and Permian rocks in Salt Creek area, Mosquito Range, Colo.: Am. Assoc. Petroleum Geologists Bull. 19, pp. 971–1009, 1935.

[14] Wells, F. G., oral communication.

Classification of post-Mississippian and pre-Jurassic rocks in three districts in central Colorado

Emmons, 1898 Tenmile district (U. S. Geol. Survey, Geol. Atlas, Folio 48)	Gould, 1935 Salt Creek, Mosquito Range (Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 971-1009)	Singewald, 1939 Beaver-Tarryall area (this report)
		Upper Jurassic series: Morrison formation.
		Age not known: Nonmicaceous strata, chiefly red shale 200 feet.
†Wyoming formation: Arkosic and micaceous sandstones and conglomerates with subordinate shales, all brick red. Limestones are rare. Archean material common in the conglomerates. Boulders in one bed as much as 2 feet in diameter. 1,500 feet.	Maroon formation: Pony Springs siltstone member: Gray to light-red siltstone with interbedded gray-green sandstone and gray shale. 5,931 feet.	Permian and Pennsylvanian series: Upper division: Red beds. Upper part micaceous and prevailingly fine-grained, with very rare limestones. Lower part micaceous and ranges from coarse arkosic conglomerate to shale; thin limestones rare except near base. 4,000± feet.
Maroon formation: Coarse gray and red arkosic [and micaceous] sandstones and conglomerates; red and black shales; and fairly numerous light bluish-gray nonmagnesian limestones. Jacque Mountain limestone is the top, Robinson limestone the base. 1,500± feet.	Chubb siltstone member: Gray to red-brown siltstone, argillaceous and calcareous near base, with sandstone in upper portion. 1,827 feet.	Middle division: Strata range from coarse arkosic conglomerate to shale, all micaceous, with numerous thin limestones. Upper three-fourths mainly red, lower one-fourth mainly gray. Prominent limestones at base and top. 3,500± feet.
Weber grits: Coarse micaceous and arkosic sandstones and conglomerates, subordinate shales, and a few thin and nonpersistent dolomitic limestones. 2,500± feet.	Coffman conglomerate member: Arkosic conglomerate with shale and sandstone. 20-1,000 feet.	Lower division: Chiefly gray micaceous strata ranging from coarse arkosic conglomerate to shale. Numerous layers of dark, nonmicaceous shale, especially in lower part. Limestones rare except in a zone a few hundred feet above the base. 2,000 (?) feet.
Weber shales: Shales and quartzose sandstones; most shales carbonaceous; some shales grade into impure limestones. 300± feet.	Weber (?) formation: Dark-gray to black shale with interbedded limestone in basal part and sandstone in middle and upper parts. Newett limestone at 330 feet above base. 1,725 feet.	

NOTE.—A dagger (†) indicates names abandoned or rejected for use in the classification of the United States Geological Survey.

PERMIAN AND PENNSYLVANIAN SERIES IN BEAVER-TARRYALL AREA

GENERAL CHARACTER AND CLASSIFICATION

The strata above the Leadville limestone and below the Morrison formation, except the uppermost 200 feet, are classified as Permian and Pennsylvanian and referred to the Weber (?) and Maroon formations in adjacent areas. In the Beaver-Tarryall area these beds range from about 8,500 to 9,500 feet in thickness. They consist of interbedded and rapidly alternating clastic rocks of several types—boulder and pebble conglomerates, siltstones, and shales, with a few intercalated limestones that rarely exceed a few feet in thickness. Nearly all the clastic rocks are conspicuously micaceous, and nearly all the conglomerates and sandstones contain conspicuous amounts of feldspar.

Most of the individual beds are thin and lenticular. The most noticeable vertical change is in color. The lower part of the series everywhere is prevailingly gray, with minor quantities of red, confined to shales; the upper part, on the contrary, consists of typical red beds with only local layers, masses, or splotches of greenish gray. The change is transitional however, and probably does not everywhere occur at the same stratigraphic position.

Any classification in the Beaver-Tarryall area presents the inherent difficulties found elsewhere in Colorado. Muilenburg[15] has divided the rocks into the Upper and Lower Tarryall formations, the lower, slightly brighter red than the upper, but the indefinite boundary between them has no value for structural mapping. The most logical procedure, therefore, is to consider the entire series a stratigraphic unit and to map individual beds or zones as far as they can be traced. The prevailing absence of fossils, the lenslike character, and the rapid alternations in coarseness of grain render the clastic strata of no value as horizon markers. The limestones are of some value in this respect, and for that reason all those of any prominence have been mapped. The decree of success with which they could be traced is readily seen by inspecting the geologic map (pl. 1). None could be carried with complete confidence over the entire area, but there are two horizons that are traceable with fair assurance over considerable distances. These accordingly furnish a convenient basis for a threefold local division of the sequence as represented in the table.

LOWER DIVISION

An erosional unconformity separates the Pennsylvanian strata from underlying rocks, but no evidence of an angular discordance in dip has yet been found; in fact, the actual contact is very rarely seen except in mine workings. According to Riley,[16] detailed work in the London mine has revealed a bed of chert conglomerate at or very close to the base. At many places the lowest bed is a yellow shale, locally containing angular chert or limestone pebbles.

Black carbonaceous shale is probably the predominant rock in the lowest several hundred feet, but considerable quantities of quartzite and conglomerate, as well as yellow, gray, greenish-gray and purplish-red shales are interbedded with it. The basal sandstones are mostly fine-grained and contain little or no feldspar, but higher in the section they rapidly become increasingly abundant, conglomeratic, and feldspathic.

The black shales commonly are somewhat limy, and some grade into impure limestones. They weather to dark gray, but others, which

[15] Muilenburg, G. A., Colorado Geol. Survey Bull. 31, pp. 17–23, 1925.
[16] Riley, L. B., oral communication.

are more sandy, weather to rusty brown. The most conspicuous limestone on North Star Mountain is about 350 feet above the base, which is approximately the same stratigraphic position as Gould's Newett limestone at Salt Creek.

The lower, predominantly shaly portion of the division, which corresponds with Emmons' Weber shales at Tenmile, grades upward into beds that correspond in position with Emmons' Weber grits. The strata form an interbedded series of rapidly alternating rocks grading from very coarse conglomerate to shale, with few lenticular limy beds. The prevailing color is gray, but some shales have other colors including dull red. Black shales, like those of the lower portion, occur intermittently throughout the division. All beds except the black shales and the rare limestones are conspicuously micaceous. The sandstones and conglomerates are feldspathic.

Conglomerates are particularly prominent because their outcrops stand out in relief. In good exposures they are seen to be cross-bedded and to consist of alternating lenses of coarse- and fine-grained materials, in some places quartzitic, in others rather friable. The coarser-grained lenses contain pebbles or scattered boulders of quartz, feldspar, and pegmatite, which in the upper beds attain 6 inches in diameter. Few individual beds are more than 15 feet thick, yet about 200 feet below the top of the division there is a persistent sandstone-conglomerate zone, more than 100 feet thick, that contains almost no shaly partings. The shales, sandy shales, and shaly sandstones probably in the aggregate are as thick as the sandstones and conglomerates, yet because they are soft and easily eroded they are rarely exposed.

The thickness of the lower division cannot be ascertained, for everywhere the interval between the Leadville limestone and the middle division of the Permian and Pennsylvanian series is crossed by the Hoosier Pass-Windy Ridge major longitudinal fold. (See pp. 25–27.) A minimum stratigraphic thickness of 1,700 feet is represented on North Star Mountain between the Leadville limestone and the western margin of this fold. The highest beds here are doubtfully correlated with the sandstone-conglomerate zone close to the top, and so a thickness of 2,000 feet is provisionally assigned to the division.

MIDDLE DIVISION

The most distinctive limestone member in the entire series crops out on the west bank of Beaver Creek at the southern margin of the area. Its base is taken as the base of the middle division. On a fresh surface it is white to light gray, and it weathers to light-gray or pale-yellow, extremely pitted blocks. The texture is prevailingly dense though locally it becomes medium-grained and crystalline. Invariably siliceous, it has either an irregularly streaked appearance or, less commonly, pronounced ribbing. Rarely it contains angular quartz pebbles. Its maximum thickness is 50 feet. It may be traced northward from Beaver Creek by walking along either this bed or one of the limestone beds close above it to a point a short distance south of Scott Gulch. Throughout this distance it is either a continuous bed or a series of lenses at about the same stratigraphic position. Immediately south of Scott Gulch it is covered by glacial moraine and rock slide, but a thick limestone bed of identical character crops out where it would be expected in the stream bed. Farther north numerous outcrops of what appear to be the same limestone continue as far as Hoosier Pass. Within this distance it becomes somewhat thinner and slightly shaly northward but retains its light-gray color. In a general way also the number and prominence of limestone beds in the overlying 300 feet decrease from south to north.

Above the basal member there is an interbedded series composed mainly of micaceous clastic strata that range from very coarse feldspathic conglomerate to shale in numberless alternations, but numerous thin limestone beds are also present. The clastic strata closely resemble those of the lower division in all lithologic details except color. Gray continues to predominate in the lowest 1,000 feet, but the higher strata are prevailing red.

Although quantitatively comprising only a very minor part of the series, the limestones have particular interest as possible marker beds and as possible ore containers. Those in the lower, prevailingly gray portion are mostly thin, dark gray to black, dense-textured, and prevailingly rich in magnesia. Locally two or more thin beds coalesce to form a massive stratum as much as 25 feet thick. Locally, also, the color becomes light gray. Some beds, particularly near the base, are siliceous. Individual beds are lenticular, grading laterally into limy shale. They occur at almost any stratigraphic position, yet certain zones are favored. The lowest limestone zone, extending some 300 feet upward from the base, is best developed in the southern part of the area. The next zone is at about 800 feet above the base and it contains from one to several beds that may be traced for 2½ miles northwestward from the southern margin of the area. What presumably is the same zone reappears at the head of Scott Gulch, whence it may be traced to the Continental Divide.

Typical limestones of the upper, prevailingly red portion decidedly differ from those beneath. Each limestone generally is red at the base but grades upward into gray-blue rock that weathers to smoothly rounded fragments. They likewise are lenticular and may occur at any horizon, but they become increasingly abundant near the top. Moreover, these limestones are prevailingly low in magnesia.

On the Continental Divide the red beds contain two thick limestones which are 400 feet apart stratigraphically. The lower limestone is a bed about 100 feet thick, pure white and coarse-grained near the base, and a banded or mottled (in part brecciated-looking) mixture of light and dark bluish-gray, medium- or fine-grained rock above. Locally the texture is vaguely oolitic. The upper limestone is really a group of several beds that locally coalesce to form a single one as much as 50 feet thick. These beds have typical grayish-blue color at most places but locally may resemble the lower limestone. The upper limestone can be traced more than a mile southeastward, but toward the Montgomery Gulch stock it is contact-metamorphosed.

In the southern part of the area the greatest amount of limestones above the limestone of Beaver Creek occurs at approximately the same stratigraphic interval above the base of the middle division as on the Continental Divide. From the southern margin of the area on Crooked Creek limestones that form a zone ranging from 10 to more than 100 feet in thickness may be traced northwestward for 3 miles, but beyond they appear only sporadically. This limestone zone occupies nearly if not precisely the same stratigraphic position over the entire distance of 3 miles.

The top of the middle division has been placed at the top of the limestone zone of Crooked Creek and its approximate equivalent on the Continental Divide. At both localities thin limestone beds are fairly abundant just above this horizon, and so the upper boundary of the middle division is transitional and less sharp than the lower boundary.

Under normal conditions the principal limestones tend to stand out with considerable prominence, but where the other beds have been greatly hardened through contact metamorphism, as around Mount Silverheels, the limestones become inconspicuous. Thus where they are most needed for structural detail they are the most difficult to find and trace.

The computed thickness of the middle division, excluding porphyry sills, along the three geologic sections (pl. 2) ranges between 3,360 and 3,550 feet, and its inferred average is about 3,450 feet, though it may be 150 feet, more or less.

UPPER DIVISION

Beds overlying the middle division for an interval of 2,000 feet are very similar to the red beds below, except that limestones are less abundant. All the clastic rocks, ranging from very coarse conglomerate to shale, are micaceous, and the coarser-grained ones are feldspathic. This portion of the series is well exposed on the Continental Divide, where very coarse conglomerate beds range from 1 to 40 feet in thickness and occur from a few to 70 feet apart in a more or less thin-bedded series of sandy shale, shaly sandstone, sandstone, fine-grained conglomerate, and shale. Grayish-blue limestone and light-gray limy shale form intercalated beds nowhere more than 3 feet thick.

The rocks of this interval grade upward into about 2,000 feet of a decidedly finer-grained facies that contains very few conglomerates, none of which are very coarse. Limestones also are rare. Mica remains abundant to the top but because of its fineness of grain is less conspicuous than lower in the section.

The total thickness of the upper division on the Continental Divide is 4,200±300 feet. Conglomerates are abundant in the lowest 2,200 feet, less abundant in the overlying 1,000 feet, and exceedingly rare in the upper 1,000 feet. A zone of bleached and epidotized rock 3,000 feet above the base suggests a slightly higher limy content there than anywhere else except close to the base. The division maintains or slightly increases its thickness southward from Boreas Pass as far as Mount Silverheels, where it begins to thin. Section *C–C′*, plate 2, shows a thickness of 3,800 feet or less, and at the southern margin of the area the thickness was calculated to be less than 3,400 feet. These variations doubtless are due to erosion prior to deposition of the overlying rocks.

METAMORPHOSED FACIES

In the general vicinity of Mount Silverheels the red beds of both the middle and upper divisions have been extensively bleached or rendered green as a result of contact metamorphism. The outlines of the areas of metamorphosed rocks are shown on plates 1 and 3, but as the change is gradual the best position for the boundary is a matter of personal judgment.

Where metamorphism was weakest only the conglomerates are bleached. Where it was slightly more intense the sandstones and shaly sandstones are bleached, hardened, and slightly epidotized and chloritized, but the shales remain red. The shale where partly metamorphosed has a banded appearance, with alternating films or thin layers of gray or green intercalated with red. Where metamorphism was strongest all the rocks have lost their red color and are very hard. The laminated, splintery shales range from light gray to green according to their epidote and chlorite content, which varies from one band to the next. Although most of the epidote is disseminated through the rocks, many films and nests have been formed. Variations in epidote and chlorite content doubtless are on the whole concomitant with variations in the original limy content. Where all the clastic rocks are bleached, the limestones have been transformed into masses of epidote, garnet, and coarse-grained calcite, generally accompanied by magnetite or specularite and locally by amphiboles.

Similar metamorphism of red beds have been observed at Crested Butte, Aspen, Monarch, and Tenmile.

CORRELATION

The section at Tenmile (see table, p. 7), because of its proximity, is the most appropriate one with which to correlate the Beaver-Tarryall rocks. Emmons states that the Maroon contains "three principal groups or series of limestone strata." The lowest, named by him, the Robinson limestone member, includes two or three beds within a stratigraphic interval of about 200 feet; the second, his White Quail limestone member, includes from one to several beds in about the middle of the formation; and the highest, the Jacque Mountain limestone member, is "at most places only a single bed * * * and this has frequently an oolitic structure." The lack of precision as to thickness and particularly as to number of beds in the descriptions suggests that each of the principal limestones at Tenmile consists, as observed in the Beaver-Tarryall area, of lenticular beds at approximately the same horizon. The remaining limestones of the Maroon are thin, variable, and nonpersistent.

Limestones in the strata assigned to the Weber at Tenmile, as represented in geologic section, are mainly in the upper part. On the whole, they are thin and nonpersistent, but in the northwestern part of the district one of them locally attains a thickness of 60 or 80 feet.

As the Morrison and younger formations have been completely eroded in the Tenmile district, it may be presumed that part of the †Wyoming formation has also been eroded. Consequently, its original thickness, though unknown, must have been greater than the maximum listed in the table.

In the Tenmile district the Jacque Mountain is the only limestone described as locally oolitic; in the Beaver-Tarryall area the only limestones locally exhibiting even vaguely oolitic texture are at the top of the middle division and in a zone 400 feet lower. Moreover, the estimated stratigraphic interval from the base of the Pennsylvanian and Permian series to the top of the oolitic limestones is at least 4,300 feet at Tenmile (Emmons) and 5,200 feet in the Beaver-Tarryall area; and recent work by Wells[17] indicates that the Maroon formation at Tenmile is about 500 feet thicker than was estimated by Emmons. Because of the oolitic character and because a variation in stratigraphic thickness of no more than 1,000 feet

[17] Wells, F. G., oral communication.

within a distance of several miles can readily be expected, the top of the middle division in the Beaver-Tarryall area is tentatively correlated as approximately the equivalent of the top of the Maroon formation at Tenmile (see table on p. 7).

The considerably greater thickness of the middle division in the Beaver-Tarryall area than of the Maroon at Tenmile and the position of the approximate base of prevailingly red color in the two sections suggest that the limestone at the base of the middle division in the Beaver-Tarryall area is not equivalent to the Robinson limestone at Tenmile but is nearly 1,000 feet lower in the section. Perhaps the Robinson limestone is represented by the moderately persistent limestone zone 800 feet above the base of the middle division in the Beaver-Tarryall area. If so, the prevailingly magnesia-rich limestones of the lowermost 800 feet of the middle division in the Beaver-Tarryall area would correspond with the similarly magnesia-rich limestones of the upper †Weber grits at Tenmile, whereas the prevailingly magnesia-poor limestones of the uppermost 2,600 feet of the middle division in the Beaver-Tarryall area would correspond with the prevailingly magnesia-poor limestones of the Maroon at Tenmile.

The section at Salt Creek, though only about 25 miles distant, represents a much finer-grained series than has been reported anywhere else except at Aspen and so cannot be readily correlated with the Beaver-Tarryall section. Red color seems to be abundant in Gould's Chubb siltstone member of the Maroon (see table), and so its base may be approximately equivalent to the base of the Maroon as originally defined at Tenmile; on the other hand, Gould describes the Chubb siltstone as being "calcareous near base," and the basal Chubb siltstone, therefore, may be equivalent to the basal part of the middle division in the Beaver-Tarryall area. This correlation would make Gould's Coffman conglomerate member (see table) approximately equivalent to the prominent conglomerate zone about 200 feet below the top of the lower division in the Beaver-Tarryall area and would assign nearly equal thicknesses to the lower part of the section at the two localities. Such a correlation is too intangible, however, to be regarded as more than a speculation.

For further information regarding regional stratigraphic details and correlations, the reader is particularly referred to a paper by Girty.[18]

AGE

In a general way throughout central Colorado fossils become increasingly scarce upward in the section, and none have yet been found

[18] Girty, G. H., Carboniferous formations of Colorado: U. S. Geol. Survey Prof. Paper 16, 1903.

in the upper part. In the publications on local areas previously cited Pennsylvanian fossils are reported to have been found in the Weber formation at Tenmile and at Salt Creek, as well as in the Garfield formation of Crawford at Monarch. Pennsylvanian fossils have also been found at different horizons, including some in shale immediately below the Jacque Mountain limestone member, in the Maroon formation of Tenmile; on the other hand, Gould reports that a few fossil plants from his Pony Spring member at Salt Creek (see table) were tentatively referred by David White to the Permian.

Present knowledge, accordingly, indicates that the lower part of the series, definitely Pennsylvanian, grades upward into strata that may be as young as Permian.

ROCKS OF UNKNOWN AGE

On the Continental Divide west of Boreas Pass are exposed non-micaceous strata about 200 feet thick lying between the micaceous red beds and the basal sandstone of the Morrison. The section is as follows:

Section on Continental Divide west of Boreas Pass

	Feet
Morrison sandstone.	
Concealed	40±
Gray to slightly red-weathering limestone conglomerate	2
Red shale, which weathers platy to nearly fissile, with intercalated layers of gray marl	90±
Nearly fissile-weathering shale of black, chocolate-brown, and red colors, with three beds of pebbly nonfeldspathic conglomerate, each less than 2 feet thick	60±
Top of micaceous beds in the Permian and Pennsylvanian series; red, slightly micaceous shale, sandy shale, etc.	

If these rocks are present elsewhere in the area, they are concealed. They have some resemblance to Triassic rocks of the region,[19] but as they cannot be traced away from this one locality, they have not been mapped separately from the uppermost part of the Pennsylvanian and Permian series.

ROCKS OF JURASSIC AND CRETACEOUS AGE

MORRISON FORMATION

The Morrison formation may be divided into three general zones, whose approximate thicknesses at Red Hill Pass are:

	Feet
Variegated shales	250
Limy zone	150
Basal sandstone	80

[19] Reeside, J. B., oral communication.

The basal sandstone forms prominent ridges at many places, but at others it is inconspicuous. It is a medium-grained quartzose rock with fairly well-defined or obscure bedding planes. Locally, where the grain size increases, there is faint cross-bedding. The normal color is white, but, probably because of infiltration of red coloring matter from rocks above and below, it commonly becomes pink.

Beds immediately overlying the sandstone are nowhere exposed. They are presumably shale. Above them comes a group of limy beds with interbedded shale. At some places grayish-blue limestones, about 6 inches thick and containing shell fragments, are numerous; elsewhere the limestones are whiter, more shaly, and less numerous. Wherever well exposed the limy beds are cut by fractures into rectangular blocks that weather with rounded tops.

The upper zone consists of the variegated red shales typical of the Morrison throughout Colorado.

No suggestion of appreciable discordance in dip has been found between the Morrison and underlying rocks in the Beaver-Tarryall area.

DAKOTA SANDSTONE

The Dakota sandstone provides an excellent horizon marker, though in the absence of exposures above and below it may be difficult to distinguish from the sandstone of the Morrison. It is a white medium-grained quartzose rock that is fairly thin and well bedded and has a few partings of dark shale. Like the Morrison, it becomes obscurely cross-bedded as the grain size locally increases. In places the rock is slightly friable, but throughout most of the area it has been hardened to a quartzite. The thickness is about 180 feet.

BENTON SHALE

Only the basal part of the Benton is exposed in this area. Typically it is a dark-gray laminated shale containing numerous concretionary layers. The shale normally weathers to dark-gray, bluish, or moderately light-gray fragments, most of which are rather fissile, although some do not split readily.

On the northeast slope of Little Baldy Mountain is a low knob of slightly metamorphosed Benton shale. Here it is hard and brittle, has been bleached to a bluish gray, and breaks into splintery fragments and blocks that conspicuously reveal the textural laminations.

TERTIARY (?) IGNEOUS ROCKS

STOCKS

Igneous rocks, abundant throughout most of the area, occur in the form of sills, laccolithic sills, and stocks. The largest body, which extends northward from South Park beyond the Continental Divide, was arbitrarily chosen as the eastern boundary for most of the area mapped. Its prevailing rock, according to descriptions by Muilenburg,[20] is porphyritic quartz monzonite composed of orthoclase, quartz, plagioclase, biotite, hornblende, and accessories; however, diorite occupies a large area southeast of Boreas Pass.

The apex of a much smaller stock, not shown on earlier maps, was found in Montgomery Gulch. Its outline, which is not readily apparent on plate 1, is shown on plate 3. The margins are prevailingly quartz-poor monzonite or diorite, whereas the interior is mainly quartz-rich, yet the two facies interfinger. In places the quartz-rich variety contains large crystals of pink orthoclase. In texture it is decidedly granular at many places, though elsewhere it is porphyritic like the sills. A profusion of aplite veinlets was noted at several places near the margin, transecting both the stock and the adjoining sedimentary rocks.

At many places the stock fingers outward and upward into sill-like bodies, and dikes extend from it on the north face of Mount Silverheels. Direct relations between the stock and the main group of sills, nevertheless, could not be established because of inadequate exposures. A genetic relation between them is evident from lithologic similarities, but the bulk of the sills were doubtless intruded prior to the stock, as happened elsewhere in central Colorado.

SILLS

DISTRIBUTION

A great number of sills, some of which approach laccoliths in form, have been intruded throughout the sedimentary series. They are most profuse within a nearly east-west belt, about 2 miles wide, that also includes the Montgomery Gulch stock. On the southern margin of the belt, as shown in section *B–B′*, plate 2, sills within the middle and upper divisions of the Permian and Pennsylvanian series have an aggregate thickness of 4,000 feet. Two miles farther south, as shown by section *C–C′*, the thickness has decreased to 800 feet; and at the border of South Park almost no sills remain. A corresponding though less abrupt decrease occurs northward; for example, section *A–A′*, in spite of being partly along the northern margin of the belt, shows an aggregate thickness of less than 2,000 feet. The sills represent additions to the section, for the sedimentary strata clearly maintain either constant or uniformly changing thickness regardless of the intrusives.

Individual sills range in thickness from a few inches to 1,000 feet. The thickest ones are continuous bodies that terminate along the strike by abruptly thinning and fingering out into the country rock. Many

[20] Muilenburg, G. A., Colorado Geol. Survey Bull. 31, pp. 32–37, 38–42, 1925.

terminations are so intricate and ragged that a definite contact is difficult to assign. In general, those less than 100 feet thick are very lenticular. Commonly, however, groups occupying approximately the same stratigraphic positions form persistent zones, between which the number and thickness of sills are less.

It was necessary to map the sills diagrammatically rather than precisely, for outcrops are so widely spaced that the sills had to be traced mainly by following debris or "float," and at many places it was impossible to decide from which of several possible sills the debris was derived. Even the more persistent zones could not be traced with assurance across poorly exposed areas. On the whole, the intrusives depicted on plate 1 represent porphyry zones containing intercalated sedimentary layers. At a few places, such as Palmer Peak, the porphyries within a zone coalesce into a single laccolith-like body containing few or no sedimentary inclusions.

CLASSIFICATION

The porphyries are classified according to composition into three types, which at most places can be readily distinguished from one another. The most widespread type was formerly designated the †Silverheels porphyry,[21] a name first proposed by Cross, but more recently it has been included in the Gray porphyry group of Leadville.[22] The rock is quartz-poor monzonite porphyry of light, slightly greenish gray color. Profuse phenocrysts range in different varieties from moderately coarse to minute. The visible minerals are white, altered feldspar and chloritized hornblende and biotite, with little or no quartz. Hornblende prisms, though distinctly subordinate in quantity, are everywhere conspicuous. The dense-textured groundmass, according to descriptions of Cross and of Muilenberg, consists chiefly of microscopic orthoclase, quartz, and hornblende, with accessory magnetite, apatite, zircon, allanite, and pyrite.

A second type is here designated quartz monzonite porphyry. As implied by the name, it contains considerable amounts of visible quartz, whose grain diameter varies from small in some facies to half an inch in the so-called "bird's-eye porphyry." In composition and in range of facies, it is identical with the quartz monzonite porphyry of the Alma district. The larger content of quartz and the smaller content of hornblende prisms constitute the only visible difference from quartz-poor monzonite porphyry of Mount Silverheels. In fact, the two types not only grade into each other but in some oc-

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[21] Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, p. 83, 1886.

[22] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U. S. Geol. Survey Prof. Paper 148, pl. 11, 1927.

currences are intimately associated, and at a few localities the designation of one or the other becomes arbitrary.

The third type is the Lincoln porphyry, which is readily recognized, here as elsewhere in central Colorado, by its very large pink orthoclase crystals. In other respects it closely resembles the coarser-grained facies of the quartz monzonite porphyry.

The general distribution of the three types is shown on plate 1. The quartz-poor monzonite porphyry greatly preponderates in the entire central and eastern parts of the area, where the few occurrences of other types are too negligible to be recorded. The quartz-rich monzonite porphyry, on the other hand, greatly predominates in a belt immediately to the west. The Lincoln porphyry is abundant only in the extreme western part.

QUATERNARY DEPOSITS

The Quaternary deposits, all unconsolidated, consist of glacial moraine, stream alluvium, slide rock, and residual soil. The principal areas of the first three are shown collectively on plate 1, and moraines of two glacial stages individually on plate 4, which also shows the maximum area covered by glacial ice and the location of placers.

The glacial moraines are of at least two ages. Those of the latest glacial stage have been distinguished wherever possible from older ones. As the valleys had not been scoured to as great a depth during the early glaciation as during the later, the early glaciers were correspondingly thinner, broader, and longer. The older moraines, therefore, are found downstream from and higher on the slopes than the younger moraines, for elsewhere they have been swept away by later ice and by streams of the interglacial stage. The older moraines, having been partly eroded, at most places form only a thin veneer over the bedrock and in some places are represented only by scattered boulders; in fact, at places, as indicated on plate 4, the bedrock shows well-developed hummocky topography from which the moraine has been entirely removed. The best example, shown on plate 4, lies between the north and middle forks of Tarryall Creeks. Another example occurs along the east side of the South Platte valley. These places, incidentally, have important scientific interest in clearly showing that hummocks are developed in the bedrock and are not simply dump heaps of moraine.

The stream alluvium consists of (1) material deposited after the melting of the ice within glaciated areas, (2) glacial outwash and later material deposited downstream from the glaciers, and (3) products of long erosion in unglaciated valleys.

The slide rock is coarse debris that has accumulated rapidly at the base of bold cliffs formed by ice erosion.

STRUCTURE

REGIONAL SETTING

The dominating structural feature of central Colorado is the northward-trending Sawatch arch, which, as pointed out by Butler,[23] is part of an anticlinorium that extends in an arc across the entire State. For miles to the east the regional dip in a general way causes successively younger beds to crop out away from the axis. The picture is complicated, however, by other structural features of major proportions, trending more or less parallel to the arch. The nature of the structure on the east limb has been determined by detailed studies in several districts, but because of proximity those of the Mosquito Range have particular interest in this report.

In the Mosquito Range there are many major faults of north to northwest trend, with upthrow on the east, that have ruptured the steep west limbs of long, narrow anticlines. The largest, the Mosquito fault, according to published information[24] is in part a normal fault with steep westerly dip and in part a reverse fault; according to Behre[25] its reverse character is more continuous than was formerly supposed. All the other faults of this group are reverse, with dips ranging from steep to gentle. Several of the faults have displacements so large that the entire rock sequence, including the pre-Cambrian, has been raised to or above the present surface on the east side, thus completely counteracting the effect of the regional easterly dip. The easternmost exposure of pre-Cambrian rock is along the east side of the London fault in the Alma district. Although smaller reverse faults and related flexures are present farther east, they do not counteract the regional dip to any great degree, and successively younger formations are exposed as the Beaver-Tarryall area is approached, until within this area no pre-Pennsylvanian rocks appear at the surface.

Besides the reverse faults and associated folds there is in the Mosquito Range a profusion of minor faults that have had much to do with the abundance and distribution of ore bodies. Those of one type are closely related to the major reverse faults. They include longitudinal and transverse fractures with small displacements, which were produced in great numbers by strains auxiliary to those that caused movements along the main faults. Very few faults of this type can be shown on areal geologic maps, yet, because they served as channels for the circulation of ore-forming solutions, they have

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[23] Butler, B. S., Relation of ore deposits of the southern Rocky Mountain region to the Colorado Plateau: Colorado Sci. Soc. Proc., vol. 12, pp. 30–33, 1930.

[24] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district: U. S. Geol. Survey Prof. Paper 148, p. 80, 1927.

[25] Behre, C. H., Jr., Preliminary geologic report on the west slope of the Mosquito Range in the vicinity of Leadville, Colo.: Colorado Sci. Soc. Proc., vol. 14, No. 2, pp. 69–70, 1939.

special interest to the miner. They are known to be numerous in the most productive part of the Leadville district and along the London fault in the Alma district, where they are well exposed in underground workings. Poor exposures and lack of any underground workings preclude any statement concerning their abundance in the Beaver-Tarryall area.

The second type of minor faults, perhaps on the whole somewhat later in origin than the major reverse faults, bears no areal relationship to the major faults. These minor faults probably are due to regional shear caused by differential stress. They are most profuse within a belt trending northeastward from Leadville to North Star Mountain. South of this belt they become less abundant in the Mosquito Range, though they have been found to be fairly numerous wherever detailed mapping has been done. Although most individual faults continue only short distances horizontally and vertically, and although they have small displacements, they likewise have great interest to the miner, for the belt as a whole has served not only to localize igneous stocks and many dikes but also many ore bodies. In spite of their abundance on both sides of the Mosquito Range, faults of this type are inconspicuous in the Beaver-Tarryall area, where analogous stress apparently produced flexing rather than breaking of the strata.

GENERALIZED STRUCTURE OF BEAVER-TARRYALL AREA

The prevailing strike of strata in the Beaver-Tarryall area is essentially north, ranging from about N. 10° E. to N. 10° W. What may be regarded as the prevailing easterly dip ranges from about 20° to 40°. Strikes or dips not within these ranges, and especially westerly dips, may be regarded as anomalies. (See pl. 1.) Anomalies exist at many places and are due to different causes. Some occur consistently within two northward-trending zones that are regarded as major longitudinal structural features. Others, in definite but more localized areas, appear to be warpings or fractures caused by igneous intrusion. Still others, of random distribution, may be regarded as local small structural features.

Strikes and dips were taken at many localities, and the more significant are recorded on plate 1. Most of those recorded are the averages of groups of readings on bedding surfaces, but a few represent dips derived from three points on some well-defined horizon marker, usually a porphyry sill. In large portions of the area bedrock either is not exposed at all or is so poorly exposed that no dip readings could be measured; moreover, marker beds for structural mapping are very scarce, as even the limestones cannot be correlated with certainty for more than short distances. The structural data, therefore, are neither as precise nor as complete as would be desirable, yet they represent all the information that could be obtained in the absence of very detailed mapping.

An attempt has been made to depict the generalized structure on plate 1 by means of contour lines, using the base of the limestone zone along Beaver Creek as a datum. Because of insurmountable difficulties in determining the depth to any horizon, the positions of the structure contours must be considered as merest approximations. Even so they serve a useful purpose. A marked discrepancy between the trend of these contour lines and the strike is due to the lensing of porphyry sills outward in each direction from the east-west belt through the Montgomery Gulch stock.

BOREAS PASS-LITTLE BALDY MOUNTAIN FOLD

The Boreas Pass-Little Baldy Mountain fold is the eastern of two northward-trending zones interpreted as major longitudinal structural features of the district. This eastern fold extends from Little Baldy Mountain northward beyond Boreas Pass. It is here interpreted as an unsymmetrical anticline with a faulted west limb, but several parts of it have been complicated or even obliterated by later igneous intrusion, although the associated structure west of the fault is preserved. More than any other fold in the Beaver-Tarryall district, it closely resembles the major structural features of the Mosquito Range. Not enough exposures exist, however, to indicate the structure precisely, and therefore it seems desirable to record the more important observations that could be made. They will best be understood by close attention to the geologic map (pl. 1).

At the southeastern margin of the area, the Morrison and Dakota formations crop out continuously along a hogback that extends northward to Trout Creek. To the east are scattered outcrops of Benton shale and porphyry sills, with no repetition of the Dakota or older rocks. For a mile north of the hogback there are no exposures whatever. Still farther north intermittent outcrops of the Morrison permit it to be mapped with assurance as far as the alluvium along the Middle Tarryall Creek. Undoubted outcrops of the Dakota sandstone in normal position with respect to the Morrison extend from the saddle at the west base of Little Baldy Mountain almost without interruption northward to the slope near Middle Tarryall Creek. Southward from the saddle the Dakota can be traced only a short distance before it disappears beneath slope wash. The Benton shale, as shown on plate 1, was found in two small areas immediately east of the Dakota. In the northern one, near Middle Tarryall Creek exposures are excellent, whereas in the southern one, on the saddle west of Little Baldy Mountain, the Benton was found only in one prospect pit. Thus, from the saddle northward to Middle Tarryall Creek a belt showing the normal sequence of Morrison, Dakota, and locally Benton can be definitely established. Immediately east of this belt, however, are scattered outcrops that indicate a second belt of the Morrison. None of these outcrops are good enough to permit determination of dip, but they imply the presence of a fault between them and the Benton shale. Still farther east, on both sides of Middle Tarryall Creek, several placers reveal red beds as the country rock for more than half a mile, and these are followed by a third belt of Morrison that is accompanied by Dakota and Benton in normal sequence. This third belt crops out a quarter of a mile northwest of Peabody's Switch.

The southerly convergence of the second and third belts of the Morrison implies anticlinal structure, but the presence of both Dakota and Benton in discordant relation to the Morrison near the anticlinal axis show that the anticline is broken by a fault with upthrow on the east. (See sec. *B–B′*, pls. 1 and 2.) This fault is mapped as extending northward between the second belt of Morrison and the red beds, as paralleling the fault that separates the second Morrison belt from the Benton shale, and as having its upthrow on the east. Nearly vertical dips, found locally just south of Middle Tarryall Creek in the western belt of Morrison, Dakota, and Benton beds west of this fault, suggest a condition analogous to that found along the London fault in the Alma district—a buckling caused by a westward push along a narrow syncline west of a reverse or compression fault. It supports the inference that the two faults just mentioned are reverse faults caused by rupture during folding.

The large mass of Dakota sandstone that crops out on the peak and the entire southern slope of Little Baldy Mountain clearly forms an anticlinal nose plunging to the south and in line with an anticlinal fold to the north. West of the axis of the fold the dip of the Dakota sandstone and the underlying beds steepens abruptly. The relations between the Dakota sandstone on Little Baldy Mountain and on the hogback south of Trout Creek could not be determined because of the absence of exposures along Trout Creek, but what seems most probable has been depicted on the geologic map, plate 1, and in section *C–C′*, plate 2. The western of the two faults mapped south of Middle Tarryall Creek evidently extends southward along the west base of Little Baldy Mountain, but near Trout Creek it passes into a southward-plunging syncline that separates the plunging anticline of Little Baldy Mountain and the hogback.

One further complication needs mention. On the north slope of Little Baldy Mountain there is an apparent displacement of at least 1,000 feet between the Dakota sandstone on the peak and the

Dakota northeast of Peabody's Switch, but the two outcrops are separated by a wide body of the quartz-poor gray porphyry that probably extends from the huge stock farther east. Outside the limits of the porphyry body no fault can be inferred that would not transect beds whose continuity can be definitely established; consequently the displacement can be accounted for only by assuming that the porphyry mass between the two outcrops cuts diagonally across the bedding and has pushed the rocks above it up to their present position on the peak of Little Baldy Mountain. As the inferred position of the fault along the west base of Little Baldy Mountain marks the west boundary of the porphyry, the beds on the west show no displacement.

On the divide between the middle and north forks of Tarryall Creek the location of the Dakota sandstone was established by several small prospect pits and by material on the dump of a tunnel. Here also Morrison beds with an anomalous dip seem to occur east of the Dakota and to imply a fault similar to those south of Middle Tarryall Creek; but the ridge elsewhere is entirely covered by glacial drift.

Just north of Tarryall Creek the Morrison and Dakota are again exposed with normal relations, but several prospect pits show that a narrow belt of Morrison with an anomalous steep westerly dip adjoins the Dakota on the east. Next to the westward-dipping Morrison, in turn, is porphyry of the large eastern stock. The contact, nowhere exposed, is probably a continuation of the inferred fault south of Deadwood Gulch.

Both the Dakota and the porphyry can be traced continuously northward to the Continental Divide, yet, except for scattered loose fragments, nothing can be seen of the Morrison or of its structural relation to the Dakota. A short distance south of the Continental Divide the strike of both the Dakota and the underlying Morrison swings more to the northwest, permitting a wedge of Benton shale to crop out between the Dakota and the porphyry. North of Boreas Pass, in the lower cliffs of Bald Mountain, the fault is again bordered by red beds. These red beds have not been mapped, but it is readily apparent that their projected strike would carry them well above the Benton shale at the pass. Hence, again, a repetition of strata with large apparent displacement suggests a major fault comparable to many others found in the Mosquito Range.

In summary, abnormal distribution of strata seems definitely to indicate a major structural feature that extends southward from Boreas Pass and dies out south of Little Baldy Mountain. This flexure, because of certain analogies, is inferred to be an anticline with a faulted west limb, similar to many in the Mosquito Range.

The large porphyry stock, which now forms the east wall along part of the inferred fault, was intruded during or subsequent to the deformation.

STRUCTURE OF HOOSIER PASS-WINDY RIDGE AREA

A major structural feature extending from Alma northward beyond the Continental Divide is clearly indicated by a zone about a mile wide in which at many places the beds dip west, opposite to the normal easterly dip. Evidence of the structure was first obtained on the west side of the South Platte Valley, which was mapped by B. S. Butler during his work on the Alma mining district. Westerly dips found by Butler in this area are shown on plate 1. The present work proved that similar dips exist on the east side of the South Platte Valley, on the Continental Divide near Hoosier Pass, and north of the pass. Symbols on plate 1 show only localities where westerly dip readings can be made. At many other places a westerly dip is apparent, yet the exposures are not good enough to record either the amount of dip or the direction of strike. In most of the zone bedrock is entirely concealed by moraine, so that details of the structural pattern cannot be deciphered; but, as shown on plate 1, the westerly dips are mainly in the lower division of the Pennsylvanian and Permian series and the lower part of the middle division.

Along the eastern margin of the zone westerly dips seem to a certain extent interspersed with easterly dips that are less steep than those on each side of the zone. This may indicate either that subsidiary folds extend obliquely from the main zone or that the entire zone is a composite of individual folds and faults. It is interesting to note that large instrusive masses of Lincoln porphyry, perhaps for the most part laccolithic sills, occur within or adjacent to the zone, and that Lincoln porphyry is almost entirely absent elsewhere in the district.

The main features of the structure can best be understood by describing salient observations. West of the road on Hoosier Pass a small mass of Lincoln porphyry is bordered on the east by feldspathic sandstones whose dips range from steeply west to vertical. East of the road strata that include a limestone correlated with the one along Beaver Creek dip gently to the southwest, but just north of the pass limestones turn sharply downward into a zone of steep dip and become silicified. As only rocks stratigraphically lower than the limestones crop out west of the zone, a fault with downward displacement on the east must be present within the zone. The direction of displacement is contrary to what the apparent drag would suggest. (See pls. 1, and 2, especially sec. *A–A′*.) The amount of displacement, though indeterminate, need not be large.

Gentle southwest dips continue, apparently unaccompanied by noteworthy faults, from Hoosier Pass southeastward beyond Scott Gulch. South of Scott Gulch, however, a well-defined zone of steep dip, several hundred or 1,000 feet wide, is bordered on the west by a wider zone of east dip. The limestone of Beaver Creek becomes involved in this zone about a mile to the south, where a fault is revealed. The total apparent throw, up on the east, amounts to about 500 feet, but most of this is due to folding and comparatively little to faulting. The zone thence passes southward under moraine.

Between 2 and 3 miles south of Scott Gulch strata that include the limestone of Beaver Creek are sharply flexed and terminate abruptly against a large mass of Lincoln porphyry, though the contact between porphyry and sedimentary rocks is nowhere exposed. This occurrence could be attributed to the intrusion of the porphyry subsequent to the main deformation, but elsewhere in the region the Lincoln porphyry sills were intruded earlier, and the contact here is therefore probably a fault. (See pl. 2, sec. *C–C′*.) The position of the fault can be mapped rather accurately to a point about half a mile northeast of Alma, where it passes under moraine.

Two faults east of and diverging from the fault just described have been suggested, as shown on plate 1 (map and pl. 2, sec. *C–C′*), to account for the anomalous outcrops of three beds of limestone, all of which are regarded as equivalent to the limestone of Beaver Creek. The three beds of limestone occur (1) in the western part of sec. 1, T. 9 S., R. 78 W., (2) in the southwestern part of sec. 6 and the northwestern part of sec. 7, T. 9 S., R. 77 W., and (3) in the western part of sec. 36, T. 8 S., R. 78 W., and the eastern part of sec. 31, T. 8 S., R. 77 W.

West of the South Platte River westerly dips occur at all outcrops in a zone more than 2 miles long, which passes both northward and southward under a moraine cover.

From the foregoing observations and others not recorded here the deformed belt can be interpreted as a broad and relatively flat-topped fold. The margins have, at least locally, been ruptured by faults, but even along them the apparent throw is due more to flexure than to movement. All the faults known or inferred along the eastern margin have upthrow on the east. Local faults on the western margin, as at Hoosier Pass, may have upthrow on the west, yet their effect probably is small compared with the aggregate apparent displacement of the fold as a whole.

In conclusion, it may be noted that if the interpretation as outlined is correct, the Hoosier Pass fold (pl. 2, sec. *A–A′*) differs from others in the region not only in having folding predominant over faulting, but also in being wider. As a consequence of the greater width, the prevailing westerly dip in the deformed zone is no greater than the regional eastward dip, so the fold is not asymmetrical. The suggestion is ventured that where the underlying pre-Cambrian basement complex consists of relatively plastic schist a broad symmetrical fold may have resulted from stress of the same type as that which produced the London and other flexures where the basement complex is gneiss or granite.

TRANSVERSE ZONE OF SHEAR

A major transverse zone of shear in the district can be inferred with reasonable certainty. It has a maximum width of about 2 miles and trends slightly north of east, and its southern margin passes through Mount Silverheels. Structural detail within the zone remains somewhat uncertain, largely because of inadequacy of exposures but also partly because of necessary haste in reconnaissance mapping.

The broadest features of the shear zone are best shown by the structure contours of plate 1. Even after allowing for the admitted uncertainties in their positions, it is obvious that the contours both north and south of the shear zone are essentially straight, whereas across the zone they are either bent or offset. The gross effect, therefore, is an apparent displacement of about a mile, the north side being east with respect to the south side.

The precise lines of principal faulting or warping within the zone cannot be deciphered. At several localities faults of fairly large displacement are suggested either by wide zones of rusty fault gouge and breccia or by marked general dissimilarity of beds along the strike. Thus the sequence of rocks, especially limestones and porphyries, exhibited by fairly good exposures along the main ridge westward from Mount Silverheels is utterly unlike the sequence at the top of the cliffs only a few hundred feet to the north, where a greater abundance of limestones in the beds suggests that they are stratigraphically lower than those on the ridge. Limestones are somewhat more abundant in the beds on the north slope than is evident from plate 1, for several isolated outcrops of limestone are not shown because the beds could not be followed for any distance and also because addition of more lines to the map would confuse the showing of more important relations in the complex area. This structure is indicated on plate 1 by a series of question marks.

Half a mile farther north intermittent outcrops of an iron-stained breccia more than 50 feet wide reveal a prominent fault, as indicated on plate 1. Here also, the absence of marked beds precludes any statement as to the amount of displacement. In and north of the saddle between Mount Silverheels and the Continental Divide, along the watershed between Beaver Creek and Montgomery Gulch, are several additional conspicuous shear zones ranging from a few feet to more than 50 feet in width. The exposures permit only one of these to be traced for any distance, and there is question as to the continuity even of this one.

Less tangible evidence of a fault, trending eastward, exists in a saddle between the main eastern spur of Mount Silverheels and a branch spur to the north. West of this saddle, near the northwest corner of sec. 22, T. 8 S., R. 77 W. (see pl. 1), strata show marked anomalies in both strike and dip, and east of it the porphyries cannot be correlated across a narrow gulch. At other localities, only some of which are shown on the geologic map, westerly dips or marked divergences in strike can be observed.

In addition to the major displacements, there are on both sides of Montgomery Gulch innumerable minor fissures trending both parallel and normal to the main zone.

It is significant that the Montgomery Gulch stock and the thickest porphyry sills lie within the transverse shear zone.

LOCAL STRUCTURAL FEATURES DUE TO IGNEOUS INTRUSION

Certain structural features can be best explained by assuming that the strata have been warped or ruptured by the intrusion of igneous masses. These local effects, of course, are superimposed on the regional structure.

The largest area thus affected is east of the Montgomery Gulch stock. Dips of 40° or more, found consistently on the south side of Montgomery Gulch and along the ridge trending northeastward from Mount Silverheels, suggest a steepening caused both by the stock and by thick sills. For a mile northward from Montgomery Gulch the dip is even steeper, and the strike becomes more westerly as the strata curve around the north end of the stock and as the sills become thinner.

A similar steepening of the dip accompanied by curvature in strike occurs east of a huge sill complex on the northward-trending section of the Continental Divide, 2 miles east of Hoosier Pass. At other places the same phenomena may be found on a smaller scale.

At two localities intrusions apparently ruptured and displaced certain beds without displacing those above or below. One, on the north slope of Little Baldy Mountain, has already been mentioned because it is located on a major anticlinal fold. The other is on Beaver Creek, not far east of the Hoosier Pass-Windy Ridge fold. Plate 1 shows a large mass of quartz-rich porphyry cropping out mainly on the west side of Beaver Creek, close to the southern margin of the area. Intrusion of the porphyry, together with some minor transverse faulting, apparently caused displacement of the limestone of Beaver Creek from a knoll—on which is a bench mark labeled 11,262 feet—west of Beaver Creek across to a low cliff on the east side of the creek; from this cliff the limestone continues southward beyond the edge of the area. The identity of the limestones in the two outcrops is unquestionable, yet no comparable displacement occurs in higher beds whose continuity can be demonstrated by walking along them.

MINOR STRUCTURAL FEATURES

Purely local anomalies in strike or dip occur at many places, but most of them were not recorded on the geologic map. Some are doubtless associated with minor faults, but the greater number seem to indicate small-scale warping of the strata without rupture. These features are believed to represent the response of more plastic rocks to forces of the same type as those that produced innumerable minor faults in the brittle rocks of the Alma district.

LODE DEPOSITS

GENERAL CHARACTER

Numerous prospect pits in the Beaver-Tarryall area prove extensive mineralization by ore-forming solutions. The known deposits, however, are small, discontinuous, and of low grade. Although no records exist, it is certain that the total production of the district, exclusive of placers, has been only a few hundred tons of ore.

The geographic distribution of the prospects indicates several interesting relations. All the mines that may have been productive, as well as most of the prospects, lie within the area of contact-metamorphosed sedimentary rocks surrounding the Montgomery Gulch stock, which, therefore, marks the principal center of ore deposition as well as of contact metamorphism. The few remaining prospects, with exceedingly rare exceptions, lie within the transverse zone of shearing but beyond the epidotized area.

The lode deposits consist of (1) veins and veinlets along well-defined fissures in both sedimentary and igneous rocks, (2) replacement masses adjacent to mineralized fissures in limestone beds, and (3) disseminated deposits composed of a profuse network of pyritic veinlets extending throughout intensely fractured porphyry or other brittle rock.

The number of veins and veinlets within the mineralized area is tremendous. Few of them are more than 6 inches wide or more than 100 feet long. The dip is steep, and although the strike may be in any direction, the largest number trend either from about N 20° E. to N. 30° W. or from N. 70° E. to N. 60° W. Pyrite and quartz, either of which may predominate, with minerals from the country rocks, are the chief constituents. Characteristically, the pyrite and quartz occur as intermittent lenses within narrow shear zones. Nearly all contain a little gold, yet assays rarely exceed half an ounce to the ton. Apparently the best assays are obtained where the pyrite has been oxidized to limonite. There is a slight suggestion of greater gold content where pyrite is less abundant than quartz.

Hypogene minerals other than pyrite and quartz are rare. Carbonates, doubtless derived from the limestone beds, are most common. Calcite is the chief representative, but slightly ferruginous dolomite occurs at a number of places and siderite at one. Manganese stain at several prospects may also be derived from carbonates. Dark sphalerite with a purplish tone has been found in specimens from two of the principal properties but is absent or rare elsewhere. All sphalerite contains profuse microscopic blebs, mostly of chalcopyrite but partly of pyrrhotite. Small amounts of chalcopyrite can be seen megascopically in specimens from the Iron mine of Tarryall Creek (see pl. 5) and microscopically in nearly all others; azurite occurs in one prospect in Scott Gulch. Pyrrhotite is abundant at the two iron mines. Galena has not been seen on any of the dumps, although small quantities have been reported from a prospect in Scott Gulch.

The disseminated deposits in which whole masses of porphyry or other rock are extensively fractured and permeated with discontinuous veinlets of pyrite alone or pyrite with quartz are clearly associated geographically and genetically with the veins.

What seem to have furnished greatest allure to prospectors are the intersections of veins with limestone beds, where small replacement masses extend away from the veins. The limestones invariably are heavily epidotized. In addition, at many prospects garnet occurs in irregular masses or in aggregates of imperfect crystals ranging from minute ones to those more than 1 inch in diameter. Commonly associated with garnet are nests or irregular blobs of magnetite or specularite or both. Two varieties of specularite, one granular and the other platy, are frequently found in the same specimen. Platy specularite occurs not only as nests in replaced limestone, but also as streaks parallel to bedding in sandstone and shale. This second mode of occurrence is particularly evident on the north face of Mount Silverheels.

All these minerals—garnet, epidote, magnetite, and specularite—belong to an early contact-metamorphic stage of mineralization, for they clearly are older and extend for much greater distances from the fissures than pyrite and quartz. At some places, however, small quantities of epidote seem to be contemporaneous with the pyrite and quartz and therefore later than the bulk of the epidote.

A zonal distribution of certain minerals is quite evident. Magnetite and coarse-grained garnet are found only within a mile of the stock. Specularite occurs in many prospects in the outer part of the magnetite area and extends for 2 miles from the stock. The pyritic veins, on the contrary, occur throughout the mineralized area, though they are scarce within the stock itself.

IRON MINE OF TARRYALL CREEK AREA

A group of properties collectively known simply as the "Iron mine" are located in sec. 9, T. 8 S., R. 77 W., on the north fork of Little French Gulch, which is a small tributary of Deadwood Gulch. On these properties are the remains of an old mill, several dilapidated cabins, one main adit, several small adits, and numerous prospect pits. All underground workings are caved and therefore inaccessible. According to C. J. Galloway, U. S. mineral surveyor of Alma, the mine shipped small amounts of iron ore, but neither the date nor the quantity is recorded.

The principal fissure trends N. 27° W. Ore specimens on the dump consist of a sphalerite-quartz aggregate containing diverse quantities of pyrite, an iron- and manganese-bearing carbonate, and a little chalcopyrite. Magnetite may be present. Polished sections reveal chalcopyrite and pyrrhotite blebs in sphalerite. The predominant wall rock is light-colored hard, splintery shale derived by metamorphism of red beds. Epidote locally accompanied by chlorite is profuse in laminae parallel to the bedding and in irregular nests. Several specimens of coarse, sugary carbonate suggest that the vein also cuts a thick limestone, in which perhaps the ore shoot occurred. These strata belong to the upper 500 feet of the middle division of the Permian and Pennsylvanian rocks.

The lowermost adit is a limonitic gouge trending N. 40° W. Massive pyrrhotite accompanied by minor pyrite, chalcopyrite, and sphalerite alone or enclosing rock fragments is abundant on the dump, and sulphide seams extend into the quartzite wall rock.

Northwest of the main workings are scattered prospects in the uppermost beds of the middle division—a limestone thoroughly replaced by epidote, garnet, magnetite, and coarse calcite.

UTE MINE

Original work on the Ute property was done from a shaft 4,800 feet N. 65° W. of the junction of Deadwood and Montgomery Gulches. The slope of the shaft suggests a vein trending about N. 4° E. and dipping about 60° SE. Specimens on the dump contain magnetite, subordinate pyrite, and minor quartz intergrown with varying quantities of epidotized country rock. In addition, chalcopyrite is seen in polished sections. The magnetite, which forms irregular masses or knots, is commonly transected by pyrite seams. Pyrite also occurs in irregular bunches and in quartz-pyrite veinlets apart from magnetite. Many veinlets contain coarse bright-green epidote that is more or less contemporaneous with the pyrite and quartz. These specimens suggest a small ore shoot at the intersection of a mineralized fissure with a limestone bed in the lower part of the upper division of the Permian and Pennsylvanian series. The dump is one of the largest in the district.

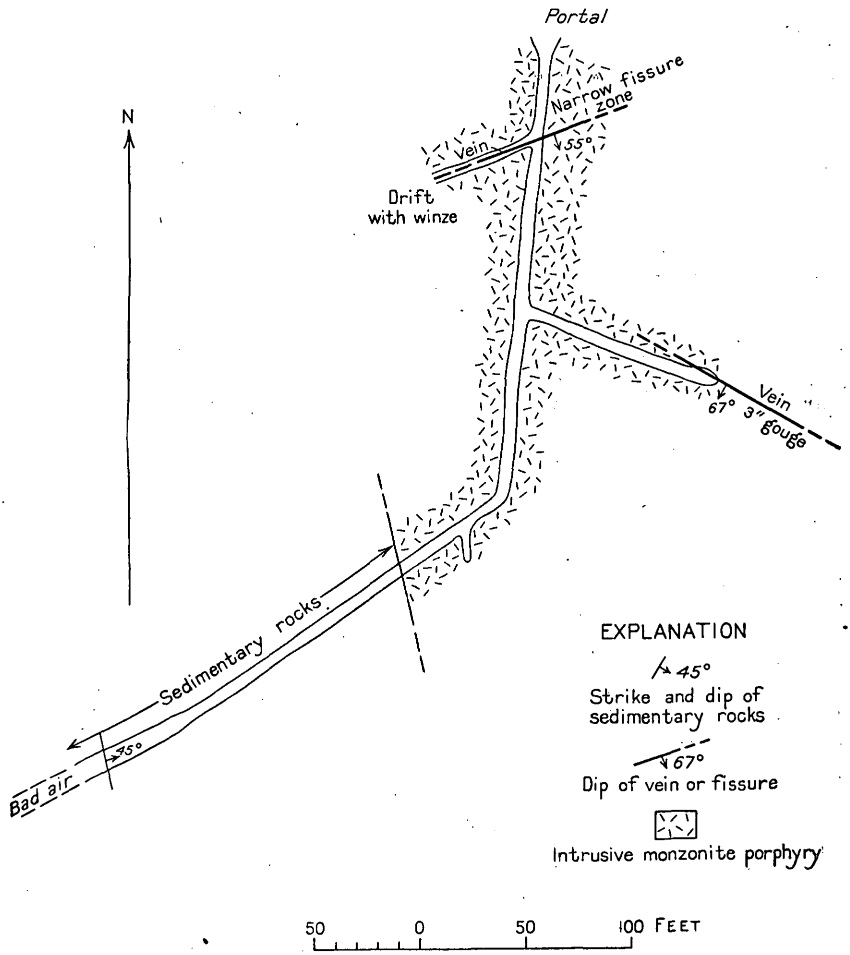

FIGURE 1.—Geologic map of Ute tunnel, Deadwood Gulch.

In order to get under the older workings, an adit was later driven westward from Deadwood Gulch. The portal is about 3,300 feet upstream from the intersection with Montgomery Gulch. In 1938, most of the adit was inaccessible because of bad air, but part was mapped as shown in figure 1. Two prominent sulphide veins are reported beyond the portion mapped. They consist, according to specimens on the dump, of dark sphalerite (containing numerous chalcopyrite blebs and scarce pyrrhotite blebs) and pyrite in nearly equal proportions, minor amounts of calcite and quartz, and diverse proportions of altered sedimentary country rock. Neither vein was sufficiently rich in gold to be exploited.

LINK PROPERTY

A small production is reported from two adits on the Link property. These workings are in the lower part of the upper division of the Permian and Pennsylvanian series. The lower adit is 4,100 feet S. 41½° W. of the intersection of Montgomery and Deadwood Gulches. Ore was sent on track tram to a mill in Montgomery Gulch.

Each of the adits extends nearly due west. Small ore shoots apparently were localized where veins transect a thin limestone bed. Stock piles show heavily epidotized rock, containing much coarse calcite and minor amounts of fine-grained garnet and permeated with magnetite, pyrite, and a little platy specularite and quartz. Chalcopyrite was seen only in polished sections. The magnetite, in part lodestone, forms rounded to irregular masses, some of which are several inches in diameter. Specularite occurs in smaller nests. Pyrite is thickly disseminated in the rock and also forms nests, veinlets, and films. The pyrite is later than all other minerals except perhaps quartz and late epidote. A minor feature of interest is late epidote along cleavage cracks in the recrystallized, coarse-grained calcite.

OXIDE MINE

The Oxide workings are on the west slope of a ridge forming the watershed of Montgomery Gulch and Beaver Creek between Mount Silverheels and the Continental Divide. The alinement of the three adits suggests a fissure trending N. 80° E. The largest adit is in a dark shaly limestone, about 25 feet thick, in the lower part of the middle division of the Permian and Pennsylvanian series. The mine is reported to have produced small quantities of oxidized gold ore during the early days of the area. Specimens on the dump are intensely oxidized, yet occasional grains of magnetite and specks of pyrrhotite may be found in polished sections.

IRON MINE OF BEAVER CREEK

The name "Iron mine" is used not only for the property in Deadwood Gulch, already described, but also for a mine located nearly 2,000 feet south of the Oxide mine, at the head of Beaver Creek, from which small quantities of iron ore for use in smelting have been shipped. The ore was a mixture of limonite with original pyrrhotite accompanied by pyrite, magnetite, chalcopyrite, and gangue. Apparently the sulphide minerals formed veinlets, nests, bunches, and disseminated grains in a thin limestone bed and in clastic rocks adjacent to the limestone. The wall rocks are in the lower part of the middle division of the Permian and Pennsylvanian series.

ALMADEN TUNNEL

The Almaden tunnel is 6,900 feet S. 64½° W. of the intersection of Montgomery and Deadwood Gulches. It is the most extensive underground working now accessible. The map (fig. 2) is therefore of interest in showing the general distribution and direction of fissures and veins, even though none of the veins are commercially productive where cut. The sedimentary rocks belong to the lower part of the upper division of the Permian and Pennsylvanian.

CONCLUSIONS

INTERPRETATIONS

The foregoing data permit certain conclusions regarding mineralization, which in turn serve as a basis for inferences regarding future possibilities.

The epicenter of mineralization quite obviously was the Montgomery Gulch stock. The first mineralizing solutions that reached the present surface were so hot that they formed garnet and magnetite within a mile of the stock and specularite as far as the margins of the entire area. As mineralization proceeded and the temperature decreased, the solutions deposited large quantities of pyrite and somewhat less quartz. Gold, which is closely associated with pyrite and quartz, perhaps was deposited during a final stage of mineralization. Deposition of pyrite and quartz took place wherever there were available openings throughout the area of former contact metamorphism.

The normal sequence, which accompanies a gradually decreasing temperature, for the common sulfides is pyrite, sphalerite, chalcopyrite, galena. Considerable quantities of sphalerite were found at only two localities, chalcopyrite at one, and galena at none, although traces of chalcopyrite as a microscopic constituent are widespread. Consequently it may be inferred that the temperature at the cessation of effective deposition still remained too high for any of the common sulfides later than pyrite, except at three localities. The alternate hypothesis, that zinc, copper, and lead were entirely absent in the ore solutions, is far less reasonable on the basis of analogies from other districts throughout the world. The preferred interpretation implies that sphalerite, chalcopyrite, galena, and prob-

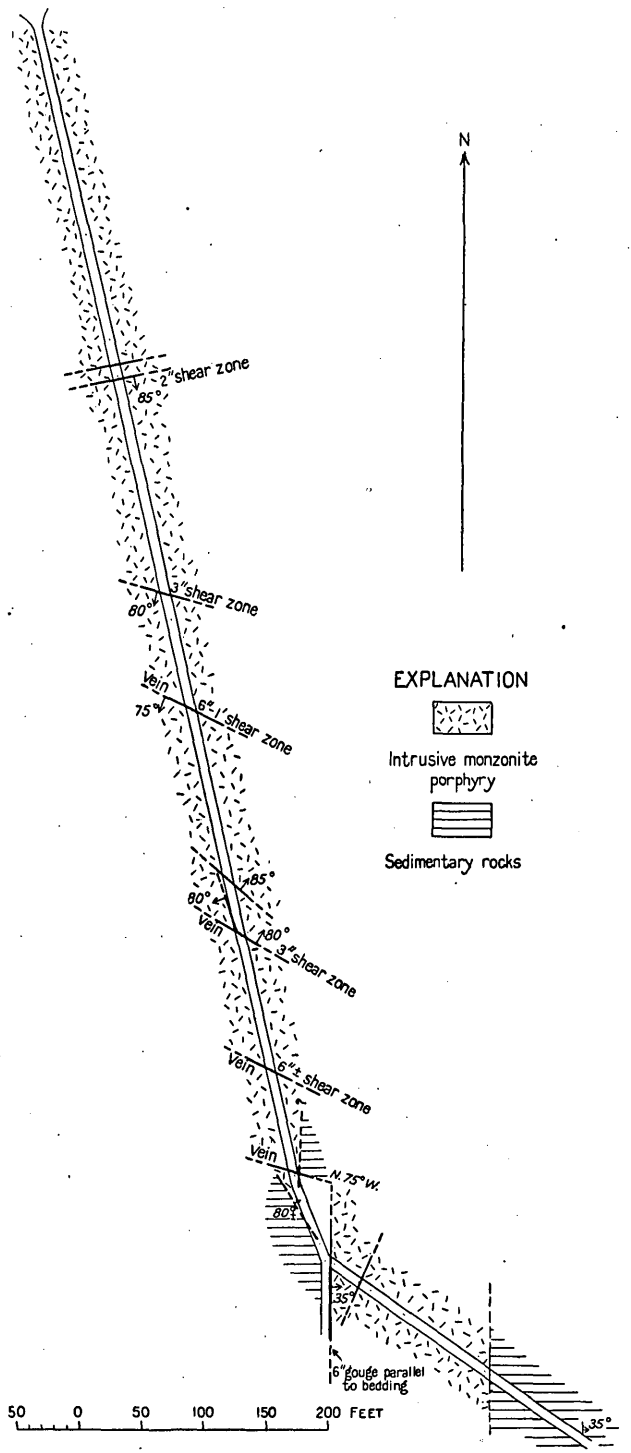

FIGURE 2.—Geologic map of Almaden tunnel, Montgomery Gulch.

ably other metallic minerals were deposited farther upward and outward from the stock, where at least the bulk of them have now been removed by erosion.

The structure of the area resulted in the scattering of the ore-forming solutions through a very great number of faults and fractures within the transverse belt of shear instead of their concentration in a few main channelways; consequently, the deposits are numerous but lean and small, and no place in the district can be suggested where there may be more continuous structural features along which larger or richer deposits might be expected.

Past prospecting within the mineralized area has shown a decided preference for the intersection of veins with limestone beds. This is attested not only by the abundance of small pits and adits at such intersections, but also by the relative abundance of materials in the larger dumps. It might be concluded, therefore, that the intersections were richer and larger than other parts of the veins, but no records or assays are available as proof. It is entirely possible, though less probable, that the presence of "contact-metamorphic" minerals, especially magnetite or specularite, might have given a misleading impression of greater mineralization at the intersections, even though there was no enrichment in gold or other of the later ore minerals.

SUGGESTIONS FOR PROSPECTING

It is obvious that the area is not a favorable one for lode prospecting. None of the known workings give promise for the discovery of large ore shoots. The best that can be expected would be small shoots that might be encountered by following the stronger veins to their intersections with limestones. Throughout the area of principal mineralization thin limestone beds may be expected at intervals ranging from a few feet to about 1,000 feet in a direction at right angles to both the strike and the dip. Limestones more than a few feet thick, however, will rarely be encountered except within a narrow belt near the top of the middle division of the Permian and Pennsylvanian series.

The belt in which the topmost limestones of the middle division crop out both north and south of the transverse zone of shear is considered unfavorable territory in the absence of any evidence of appreciable mineralization. Moreover, the moderately thick limestones at the base of the middle division crop out too far from the epicenter, even where they cross the shear zone. It is possible that these rocks at depth, as they approach the epicenter, become mineralized. The most favorable place to look for ore bodies would be beneath Beaver Creek, close to the margin of the area of metamorphosed rocks shown on plates 1 and 3. Even here, however, the many uncertainties of deep prospecting make the hope of an ultimate profit exceedingly slim. and farther east the depth would be prohibitive. The approximate depth to the most favorable horizons at any place can be obtained by subtracting the altitude indicated by the structure contours from the surface altitude.

Subsurface prospecting for ore bodies in the Leadville limestone beneath the Pennsylvanian and Permian series is unwarranted, for several reasons. In the first place, the formation is not likely to be present beneath the known mineralized area. Secondly, even if it is present, its depth beneath the mineralized area would range from 3,000 to 12,000 feet. Thirdly, the temperature relations, discussed above, suggest that either no deposition at all or else only the deposition of very high temperature minerals with no gold would have taken place at that depth. The last two considerations apply also to all other pre-Pennsylvanian rocks.

It has been asked whether any methods of geophysical prospecting would aid materially in the search for deep ore bodies, especially replacement bodies in limestone. It is very unlikely that the assemblage of rocks and minerals in this district would afford to such methods any results of definite significance, and even if they did, the depth to the limestones, as shown above, renders the cost of prospecting prohibitive.

PLACER DEPOSITS

GENERAL DISTRIBUTION

The gold in placer deposits originated in lodes which have been partly or wholly eroded and from which it became redistributed by agents of transportation and deposition. The location of placers, therefore, is closely related to the physiographic development of the area.

The general pattern of the present topography dates back to a long erosion period prior to glaciation. During the Pleistocene epoch great masses of ice accumulated in the higher reaches, moved down the valleys, and eventually melted. The moving ice not only swept away all unconsolidated materials in its path but even gouged out the solid rock, thereby deepening and widening the valleys. Materials picked up by the ice were deposited as outwash by streams isuing from it, as terminal moraines at the lower ends of glaciers, as lateral moraines along their sides, as medial moraines between two lobes or between coalescing glaciers, and as recessional moraines where slight readvances or stillstands took place during the period of recession. As all the valleys that contain placers have been glaciated, the distribution of gold in them has largely been controlled by glacial and postglacial processes.

As mentioned in the section on Quaternary deposits, there were at least two stages of glaciation. Hence much of the detrital gold has been twice redistributed. It was first deposited in moraines and outwash gravel deposits of the earlier stage, some of which still remain in areas outside the limits of the later glaciers. Most of the older moraines, however, were swept away and their materials redeposited either by streams that deepened valleys during the interglacial stage or by the later glaciers, which scoured the deepened valleys and accounted for the new moraines and outwash gravel in the present valleys. Water issuing from the glaciers during their retreat to some extent reassorted material previously dropped directly by ice in the stream channels.

As might be expected, the most extensive placers occur within and downstream from terminal moraines of the latest glaciers. The stream gravel, whether original outwash or reassorted morainal material, has proved richer and less expensive to work than the moraines. Smaller though in places valuable placers occur in recessional or lateral moraines of the latest stage and also in moraines of the earlier stage. The principal pay streaks are invariably adjacent to bedrock, but in moraines there are pay streaks above bedrock in slightly assorted layers that interfinger with unassorted, more clayey debris and cause a somewhat erratic distribution.

TARRYALL CREEK

Tarryall Creek and its tributaries were credited by R. W. Raymond, as quoted by Henderson,[26] with a production of about $1,000,000 between 1859 and 1872. Production in Park County between 1872 and 1904 cannot be divided among individual districts. According to United States Bureau of Mines records, furnished by C. W. Henderson, the production from 1905 to 1937 has been 4,971 ounces, or about $140,000. The aggregate production, therefore, is believed to be about $1,250,000. The average fineness of gold produced each year since 1905 ranges from 0.803 to 0.967, the mean being about 0.900.

The early glaciers of Tarryall, Deadwood, and Montgomery Creeks all coalesced into a single sheet whose front at the time of maximum advance lay approximately 1½ miles east of Peabody's Switch. Moraine deposited by this ice is well exposed in the cut of the former railroad along the west bank of Tarryall Creek and is further repre-

[26] Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, p. 187, 1926.

sented by scattered boulders and swamp above the cut. The later glaciers did not extend so far downstream. Their maximum advance is shown by a well-developed terminal moraine, indicated on plate 4, at the junction of the middle and north forks of Tarryall Creek. At its farthest advance the ice from the upper part of Deadwood Gulch coalesced with ice from Montgomery Gulch. The North Tarryall glacier, however, probably terminated about 1,000 feet before reaching the Middle Tarryall glacier, for at that point there is a prominent terminal moraine, and farther downstream there is no later moraine along the east bank. The larger glacier of Middle Tarryall Gulch developed several secondary terminal moraines upstream from its point of maximum advance, owing perhaps to stillstands but more probably to readvances. As two of the former ice stands are particularly prominent and have economic significance, they are indicated on plate 4. One took place a mile downstream from the junction of Montgomery and Deadwood Gulches; the other took place just upstream from the junction and therefore is represented by separate moraines in each gulch.

The principal placers from which gold has been won are in the general vicinity of the junction of the middle and north forks of Tarryall Creek, where they clearly are related to the termination of the Middle Tarryall glacier. They extend half a mile up North Tarryall Creek along the margins of the moraine, a mile up Middle Tarryall Creek within the moraine, and a mile downstream in outwash gravel. Recent prospecting suggests that rich gravel may yet be worked downstream from these older diggings.

Next, though far less in economic importance, are the placers within and downstream from the secondary terminal moraines of the last major ice stand of the Montgomery and Deadwood Glaciers. These placers are shown on plate 4 as a continuous group in Deadwood Gulch from a point just below its junction with Montgomery Gulch to a point a mile upstream. Of still less importance is the group associated with the secondary terminal moraine 1½ miles farther downstream. Other minor placers are shown on plate 4. Nearly all lie in moraine of the later Middle Tarryall glaciation, either within the present drainage basins of these gulches or where the ice spilled over the divide into Tarryall Creek. Only the three placers on the east bank of North Tarryall Creek in the vicinity of Selkirk Gulch are not related to the Middle Tarryall glaciation, and they have no commercial significance.

All the placers above mentioned are within the mountains. About 5 miles southeast of Como, in South Park, there is a fairly large placer in Park Gulch and there are several insignificant ones in Slater Creek (north branch of Park Gulch). The gold, which has a fineness of about 0.920, was derived from preglacial terraces of Tarryall Creek.

SOUTH PLATTE VALLEY

Placer production in the immediate vicinity of Fairplay prior to 1874 was estimated by R. W. Raymond and quoted by Henderson[27] as about $1,000,000. The bulk of this gold came from the South Platte River and a subordinate amount from Beaver Creek. The Alma placer apparently was started about 1870 and produced $19,000 during the first 3 years. Records of the United States Bureau of Mines, furnished by C. W. Henderson, credit the Fairplay placers with 25,767 ounces of gold, or about $500,000, and the Alma placer with 8,776 ounces, or about $250,000, during the period 1904–37. Thus the aggregate production from the South Platte River near Fairplay must be about $1,500,000 and at Alma $250,000. The yearly average fineness of gold since 1904 ranged at Fairplay from 0.705 to 0.828, with a mean of about 0.800, and at Alma from 0.823 to 0.830.

The early South Platte glacier, fed by tributaries from Buckskin and Mosquito Gulches, extended down the valley to a point beyond the town of Fairplay and about 2 miles beyond the south boundary of the area shown in plate 4. About half a mile north of latitude 39°15′ the ice spilled over the eastern ridge into Beaver Creek. Moraine material deposited during the early glaciation remains on both sides of the valley near Fairplay. The later South Platte glacier, like the Middle Tarryall glacier, did not extend downstream as far as the earlier one. Its maximum advance is shown by a conspicuous terminal moraine half a mile north of Fairplay. During its maximum advance the ice of the later glacier also spilled over the divide into Beaver Creek, but soon after retreat began it was confined to its own valley. The South Platte glacier, like the Middle Tarryall glacier, also deposited several secondary terminal moraines, two of which are especially prominent. Part of the border of the lower one is shown on plate 4, but the remainder lies south of the area mapped; the border of the upper one forms an arc around the town of Alma, and its counterpart in Mosquito Gulch lies just upstream from the junction of Mosquito Creek with the South Platte River.

The Fairplay placers are located in gravel deposits that extend several miles downstream from the terminus of the latest glacier and in gravel beds and unassorted material in the terminal moraine. All these, which have been the most productive localities in the region, are south of the area shown on plate 4. Another group of placers, also included with Fairplay in production records, lie on the Snow-

[27] Henderson, C. W., op. cit., p. 187.

storm property, in a moraine on the east slope of the valley; the northernmost are shown on plate 4.

The Alma placer is in the secondary terminal moraine of the last major ice stand, and scattered minor placers are shown on the map.

BEAVER CREEK

Henderson[28] quotes R. W. Raymond as stating, in 1874, that Beaver Creek "was in the early days a noted creek, but owing to high cost of working it has lain idle for many years." The placer production from 1904 to 1937 amounted to 1,133 ounces of gold, worth about $30,000, or about one-fifth the production from Tarryall Creek.

An early glacier in Beaver Creek was about 4 miles long, as shown on plate 4; its presence is attested by a moraine and by a hanging valley near its termination. The latest glacier, however, must have been little more than an ice field at the head of the valley, for it has left no well-defined moraine, and the stream flows more than a mile in a V-shaped gorge west of Mount Silverheels.

Small placers, none of them of great importance, are scattered along the upper part of Beaver Creek as shown on plate 4. Nearly all are in stream gravel. The gold averages 0.900 or more in fineness, thus resembling that of Tarryall Creek.

By far the most productive placers of Beaver Creek are south of the area mapped, where the stream issues into South Park. These occur on the lower margin of the moraine from the South Platte Glacier and in the outwash gravel beyond. Smaller placers extend intermittently upstream in the channel and on the west bank as far as the moraine continues. Hence, the gold has been derived from the South Platte Valley. This conclusion is substantiated by the fineness of the gold, which ranges from about 0.820 to 0.837.

SOURCES OF PLACER GOLD

The mineralized zone surrounding the Montgomery Gulch stock clearly was the source of all gold in Tarryall Creek and its tributaries and in the upper part of Beaver Creek. Montgomery and Deadwood Gulches head within and drain most of this zone, and placers are abundant in the Middle Tarryall. North Tarryall Creek, on the contrary, heads outside the mineralized area and therefore contains no productive placers above the point where ice from the Middle Tarryall Glacier spilled into it. Beaver Creek, which drains a margin of the mineralized area, contains only small placers in its upper part. All these placers contain gold whose fineness is uniformly high. Not only does this point to a common source, but it con-

[28] Henderson, C. W., op. cit., p. 190.

forms with the type of gold to be expected from deposits formed at fairly high temperature.

All placers in the South Platte River and those of Beaver Creek below the point at which the South Platte Glacier spilled over its eastern ridge are derived from mineralized areas in the Alma district, west of the Beaver-Tarryall area. Mineralized areas in the Alma district have been shown in another report.[29] The lode deposits in all of them were formed at lower temperatures than those in the Montgomery Gulch area, and the placer gold derived from them has lower fineness.

[29] Singewald, Q. D., and Butler, B. S., Suggestions for prospecting in the Alma district, Colo.: Colorado Sci. Soc. Proc., vol. 13, No. 4, p. 104, 1933.

INDEX

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