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A DIGEST OF U.S. GEOLOGICAL SURVEY
PROFESSIONAL PAPER 219

GEOLOGY AND ORE DEPOSITS OF THE LA PLATA DISTRICT COLORADO

By
EDWIN B. ECKEL WITH SECTIONS BY J. S. WILLIAMS, AND F. W. GALBRAITH AND OTHERS
Digest prepared by F. D. Trauger.

Editors *Note: This digest* of Professional *Paper* 219 (out of *print)* has *been included in* the guidebook so that *conferees will have available* the *important* facts concerning *an* area that *will engage* our *attention* during much of the first day of *the conference.*

E. B. *Eckel, principal* author of Professional Paper 219 was unable, because of a heavy work load, to prepare a summary *paper* for our guidebook but he graciously authorized preparation of this *digest* and has *given it* his *approval.*

Professional Paper 219 is *detailed, definitive, and a* tightly *written* work of some 179 pages; it is not amendable to more *than* slight reduction *without serious impairment* of *its value as an* authoritative *reference.* To *achieve the* drastic *reduction* here *presented* has *required* the *omission* of nearly *all* substantiative data and most of the *numerous and detailed* discussions that *led* the authors to the many conclusions *made.* It is sincerely hoped that no erroneous *impression* of the thoroughness or accuracy of their work will result from this condensation. *If* any *person has* doubts *concerning the* conclusions as stated in this digest *it is* suggested that he first obtain *and read an unabridged* copy of the *paper before voicing* objections.

All footnotes and references have been *deleted* as *have* all maps *and* most other illustrations with the *exception* of a few photographs. *Detailed* paleontological, petrographic, *and mineralogic* descriptions also have been *deleted as have all measured* sections and much other *interesting and informative material.* What remains are *"bare bones"* that, while they *reveal the* skeletal structure, should *not be construed* as *an accurate* picture of the *living critter.*

INTRODUCTION

The La Plata mining district, also known as the California district, lies within the La Plata Mountains in southwestern Colorado, 8 to 20 miles northwest of Durango. The only settlements in the district arc the old mining town of La Plata, locally known as La Plata City, which had a population of 33 in 1930, and Mayday which is about the same size. Mayday is near the site of Parrott, which was the first settlement in La Plata County and was once the county seat. The principal supply point is Durango, which had 5,400 inhabitants in 1930, [10,530 in 1960] but Mancos with a population of 646 [839 in 1960] serves the East Mancos sector.

The La Plata Mountains lie about 20 miles southwest of the main San Juan Mountain front. The intermediate space is a region of rugged hills carved from sedimentary rocks of Paleozoic and early Mesozoic age. The mountains rise abruptly on the west, south, and southeast from the comparatively level Colorado Plateau.

All the principal peaks of the La Plata Mountains lie within a 9-mile circle centering in the valley of the La Plata River near the mouth of Tirbircio Creek. The lesser summits and outlying ridges fall within an oval area from 12 to 15 miles in diameter. The higher peaks are situated along the narrow divides on each side of the La Plata River or on spurs extending from these divides. The lowest point in the area is 7,250 feet above sea level, but 79 percent of the area is above 9,000 feet and nearly 19 percent is above 11,000. The highest peak is Hesperus Peak, which rises to 13,225 feet, but Mount Moss, Babcock Peak, and Spiller Peak are nearly as high, and several other summits exceed 12,000 feet.

Except in the outlying parts of the mountain group most of the slopes are steep, and many of those above timber line are extremely rugged.

The mountains have resulted from the dissection by erosion of a domal uplift. Consequently the drainage system radiates in general from the central part of the group. The master stream, the La Plata River, has cut almost through the north rim of the mountains by headward erosion. The La Plata flows south from the mountains and empties into the San Juan River in New Mexico.

The eastern parts of the mountain group are drained by Hermosa, Lightner, and Junction Creeks. Bear Creek drains the north-central part of the mountains. All the western part is drained by tributaries of the Mancos, of which the East and West branches are the largest.

In the rigor of its climate the area here described resembles the mining camps of the San Juan Mountains, hut the La Plata Mountains, because of their exposed position on the edge of the Colorado Pleateau, probably receive even more rain and snow than the main San Juan Mountains.

The winters in the district are long, and in the mountainous areas they are generally characterized by heavy snow. Snowbanks remain in many protected places to the end of July or August, and a few of them, particularly in the upper part of Tomahawk Basin, often survive from one year to the next.

The first snow usually falls in late September or early October. It is often followed by a month or more of clear, crisp weather, the boasted Indian summer of the Colorado Rockies; not infrequently, however, winter weather sets in immediately after the first snows.

Precipitation and snowfall at stations near La Plata district

Place	Altitude (feet)	Years of record	Snowfall (inches)	Precipitation (inches)
Durango	6,589	38	67.0	19.98
Terminal Dam	8,300	24	145.4	26.30
Rico	8,824	29	164.5	26.12
Silverton	9,400	24	157.7	26.69
Savage Basin	11,522	16	400.2	38.05

The spring months, especially May and June, are generally the driest of the year. Precipitation during the summer commonly comes in the form of sudden and more or less local thundershowers, but in some years there are many days of almost continuous rain.

A large part of the district is more or less heavily timbered. The lower slopes, especially in the southern and southwestern parts of the mountains, are largely covered with thick stands of Rocky Mountain white oak (scrub oak) intermixed with some dwarf maple, western chokecherry, and western service-berry. These trees give way upward to comparatively pure stands of aspen. On the higher parts of the mountains the deciduous trees give way to evergreens, of which Douglas and white fir, Englemann and blue spruce, and western yellow pine are the most abundant species.

Grass-covered slopes and open parks are comparatively rare below timberline, which ranges from 10,000 to 12,000 feet in altitude; but many large areas above timberline are covered with grasses, sedges, dwarf willows, and alpine flowers.

GENERAL GEOLOGY

The La Plata Mountains have been long known as an example of the laccolithic type of mountain group. They were carved from a domal uplift of sedimentary rocks into which numerous stocks, dikes, and sills of igneous rock were intruded.

In general the strata, which range in age from Pennsylvanian through Upper Cretaceous, dip away from the central higher areas. A horsehoe-shaped hinge fold along which the dips are very steep nearly encircles the central part of the mountains. On both sides of this fold the dips are relatively flat. Several faults of rather large displacement cut the outer parts of the dome, and in the main body of the dome there are many other fractures and small faults.

The igneous rocks vary widely in composition and in form, but all of them can be grouped in two general types —porphyritic and nonporphyritic. The most abundant igneous rock in the district is diorite-monzonite porphyry. The rock occurs as essentially contemporaneous sills, stocks, and dikes, which were emplaced largely by forcible intrusion. The nonporphyritic rocks, in general younger than the porphyry, consist of syenite, monzonite, and diorite and occur as irregular stocks associated with many dikes. The extensive metamorphism of the sedimentary rocks in the central part of the district is related to these stocks. The stocks were formed in large part by replacement or assimilation of the older sedimentary and igneous rocks.

The most productive of the ore deposits are veins and replacement bodies that yield gold and silver tellurides, but there are also deposits of pyrite and chalcopyrite enclosing native gold, of base-metal sulfides, and of chalcopyrite enclosing platinum. Many of the deposits are clearly related to the hinge fold and associated faults mentioned above.

PRE-CAMBRIAN BASEMENT ROCKS

The precambrian basement rocks beneath the La Plata Mountains are buried under 3,000 to 8,000 feet of later rocks. The nearest exposure of the Precambrian complex is on the Animas River 13 miles east of the center of the mountains. The Precambrian rocks there consist of schists and gneisses, with several large bodies and many dikes of coarse granite. The only actual clue to the character of the Precambrian rocks beneath the La Plata Mountains is afforded by the inclusions in the later igneous rocks. Most of the inclusions that were seen consist of coarse granite or of hornblendite.

SEDIMENTARY ROCKS

The sedimentary rocks exposed in the La Plata Mountains range from the Hermosa Formation, of Pennsylvania age, to the Mancos Shale, of Upper Cretaceous age. Only the uppermost layers of the Hermosa Formation are exposed within the district, but these are underlain by more than 2,000 feet of Hermosa beds and by several hundred feet of Cambrian, Devonian, and Mississippian sediments.

In the central part of the district intense metamorphism makes it difficult to distinguish some of the formations, or, in places, to determine whether a rock is of igneous or of sedimentary origin. The prevailing red colors have lightened to pale purplish and greenish tints or to gray, shale has been altered to hornfels, and sandstone to dense quartzite, and bedding has locally been obliterated. Contact-metamorphic minerals such as garnet, epidote, hornblende, specular hematite, and magnetite, have been formed in the calcareous beds. Fortunately all the formations occur unmetamorphosed in their normal sequence not far outside the district and these could be correlated with their metamorphosed equivalents within the district thus making it possible to distinguish the formations with some degree of certainty, even where they were strongly metamorphosed.

PRE-HERMOSA ROCKS

The sedimentary rocks that lie between the pre-Cam-brian complex and the base of the Hermosa Formation are buried so deeply beneath younger beds in the La Plata area that they arc of little economic interest. They include the Upper Cambian Ignacio Quartzite, the Upper Devonian Elbert Formation and Ouray Limestone, the Mississippian Leadville Limestone, and the Pennsylvanian Molas Formation.

The Molas Formation lies between the Leadville Limestone and the base of the Hermosa in the Needle Mountains and Engineer Mountain quadrangles. It apparently pinches out toward the southwest, however, and was not recognized during the present investigation.

PENNSYLVANIAN SERIES

Hermosa Formation

The Hermosa Formation east of the La Plata Mountains consists chiefly of several thousand feet of interbedded sandstones, grits, limy shales, and limestones, with some black shale and gypsum. Many of the limy beds contain abundant Pennsylvanian fossils. The limestone beds of the Hermosa almost certainly underlie the whole of the district, and they are the chief ore-bearing beds in the neighboring camp of Rico.

The uppermost Hermosa beds crops out not far from the center of the dome, along the bed and lower valley walls of the La Plata River and extend up Lewis Creek a little more than a mile. The formation here consists in large part of more or less highly silicified mudstone and sandstone indistinguishable from much of that in the overlying Rico and Cutler Formations, but two or three beds of light-gray limestone, which have a maximum thickness of about 5 feet and contain characteristic Hermosa fossils, are exposed in several places along Lewis Creek.

Many of the limestone beds are surprisingly free from alteration considering the marked silicification of other beds in the section, and in at least one place on the road up Lewis Creek determinable fossils occur in a limestone bed at its contact with the top of a porphyry sill.

The highest fossiliferous horizon was mapped as the top of the formation, but where no exposures of fossiliferous beds were found, the top of the formation was taken to lie just above a thick bed of arkosic sandstone similar to that which occurs near the top of the Hermosa along the Animas River.

A diamond-drill hole that was sunk in search of ore at the mouth of Madden Creek in 1913-14 gives additional information as to the character of the upper part of the Hermosa Formation. The complete core from this hole is on display in the Colorado Museum of Natural History at Denver.

The "quartzites" noted in this log are largely silicified sandstones and grits, although they doubtless include some metamorphosed mudstones and siltstones. Most of the mudstones and shales recorded are mottled in color, more or less thoroughly silicified, and similar in most respects to the same rocks where seen in surface exposures. The "limestone" probably includes beds that once were limy shale, but much of it consists of marble and represents true limestone. Whether or not the correlations are correct, the log shows clearly that a part at least of the district is un derlain by more limestone than is anywhere exposed on the surface, and by even more than is known to occur in the type section of the Hermosa.

Log of *diamond-drill* hole at *mouth of Madden Creek*
(Formation names indicate probable approximate correlation)

	Thickness (feet)	Depth (feet)
Cutler Formation:		
Fractured quartzite	70	70
Variegated mudstone, shale, and quartzite	140	210
Gray to mottled, fine-grained quartzite	180	390
Variegated mudstone and shale with 33-foot bed of quartzite near top	208	860
Porphyry	335	1,195
Rico Formation:		
Mudstone, shale, and quartzite	168	1,363
Porphyry	42	1,405
Quartzite, partly coarse grained	23	1,428
Impure limestone	1	1,429
Dark quartzite with some shale and mudstone	26	1,455
Hermosa Formation:		
Gray quartzite and shale	18	1,473
Impure limestone	8	1,481
Shale, mudstone, and impure limestone	13	1,494
Porphyry	11	1,505
Gray quartzite, with a little shale at top and bottom	69	1,574
Sandy limestone, with 1 foot of pink quartz-ite and a little shale	47	1,621
Dark shale and mudstone	15	1,636
Sandy limestone	11	1,647
Shale, mudstone, and quartzite, with *a* little coarse pink sandstone	44	1,691
Sandy limestone, with several 1-foot to 5-foot beds of shale	63	1,754
Shale, mudstone, and quartzite	18	1,772
Variegated impure limestone	48	1,820
Shale and mudstone, with some quartzite	74	1,894
Porphyry	92	1,986
Quartzite	20	2,006

PERMIAN SYSTEM

Rico Formation

The Rico Formation is about 300 feet thick and is made up chiefly of dull-red, maroon, or chocolate-colored sandstones, arkoses, and conglomerates and includes a minor proportion of interbedded shales and sandy or shaly fossilifcrous limestones. It is transitional between the Hermosa and Cutler beds, but resembles the Cutler more closely than the Hermosa. The top of the Rico at the type locality is defined by the highest known occurrence of Rico fossils and not by any recognizable lithologic or stratigraphic break. The base of the Rico was taken to lie just above the highest beds that were found to contain Hermosa fossils. Exposures of the formation are poor; many of its beds are more or less thoroughly silicified, and the occurrence of fossils is decidedly discontinuous.

The Rico Formation is here classified as Permian, in accordance with previous Geological Survey reports on this area. The rocks mapped as Rico locally form a readily recognizable lithologic unit, characterized by red colors and by thin beds of impure limestone that contain a more or less characteristic assemblage of fossil forms. Recognition of this unit has been of much value in working out the structure of the La Plata dome.

Comparison of the overlapping parts of sections brings out strongly the marked and rapid changes in lithology that characterize the Rico Formation wherever it is known. Several layers of dark-gray to black shale containing abundant Rico fossils are exposed along the Junction Creek road near the mouth of Flagler Fork. No such accumulation of fossils was found at the places where sections were measured.

Cutler Formation

The Cutler Formation, of Permian age, consists of 1,400 to 2,200 feet of typical redbeds made up of unfossiliferous mudstone, shale, sandstone, grit and conglomerate. It apparently thins rather rapidly toward the west and north. Its estimated thickness along Junction Creek is about 1,700 feet. It is 1,500 feet thick along the La Plata River, and in the Rico district, 20 miles to the north, it is only about 1,100 feet thick.

Where the rocks are not metamorphosed the alternations of shaly and sandy beds generally produce step like topographic forms. In the central part of the district, where the rocks are metamorphosed and almost equally hard and durable, the slopes are more uniform and are commonly steep.

It has the broadest distribution of any of the sedimentary formations in the La Plata district, being almost continuously exposed in the central and eastern parts of the district, except for its interruptions by many bodies of intrusive igneous rock.

The contact between the Rico and Cutler Formations is arbitrarily placed at the top of the highest fossiliferous horizon. The Dolores-Cutler contact commonly was drawn at the base of the limestone conglomerate and associated gray flaggy sandstone which characaterize the lower Dolores.

The total thickness of a Cutler section, exclusive of porphyry sills, measured on a ridge east of Babcock Peak, is about 1,505 feet

The Cutler is characterized by a succession of massive grits and conglomerates, which are interbedded with finer-grained sandstone and with shale and mudstone. Dull-red and maroon colors prevail in the fresh rocks, though some beds are brown or greenish gray. In general there is a tendency toward a gradation upward from dull red near the base toward the brighter reds of the overlying Dolores. No beds of true limestone are known, but most of the shaly beds are limy, and in many places the lime carbonate is segregated into nodular masses of relatively pure limestone. Nearly all the beds are micaceous.

Grits, sandstones, and conglomerates are more abundant in the lower half of the formation, but there are two or more rather persistent layers near the top.

PALEONTOLOGY OF THE LEADVILLE, HERMOSA, AND RICO FORMATION

By JAMES STEELE WILLIAMS

Invertebrate fossils were collected from the Leadville Limestone, the Hermosa Formation, and the Rico Formation. Only the last two were recognized in the La Plata quadrangle itself. Because many of the beds are there highly metamorphosed and unfossiliferous, unmetamorphosed beds were studied, and a section of them measured, along the Animas River in the Durango quadrangle, which adjoins the La Plata quadrangle on the east. The identifications of the species were made in 1941, and cahnges in species names made since that date are not shown in this report.

Collections from the Leadville Limestone

Several collections were made from the Leadville Limestone along the Animas River, in an effort to locate the Mississippian-Pennsylvanian contact in the section measured.

The following species were identified:

Schuchertella? sp. indet., fragment
Cranaena subelliptica hardingensis Girty?
Spirifer centronatus Winchell var. A

This collection is clearly Mississippian and probably of the same age as the Madison limestone.

Collections from the Hermosa Formation

Collections from the Hermosa Formation were made along the Animas River in the Durango quadrangle, and along Lewis Creek, below Ashland Gulch, within the La Plata quadrangle.

One of them contains a species that definitely restricts it to a Des Moines or older age, the age of the Hermosa in the typical area. This one collection contains the trilobite *Sevillia? trinuclesta (Herrick)* .

Collections from the Rico Formation

Fossils were collected from beds referred to the Rico in two areas in the La Plata quadrangle: along upper Lewis Creek and its tributaries, and along Lucky Strike Gulch.

The age of the Rico Formation has long been and still remains a matter of disagreement and uncertainty. The advisability of even recognizing the Rico as a formation has been questioned. It seems useful, however, for purposes of mapping and of deciphering structure, to recognize the Rico Formation as a lithologic unit, characterized by red or maroon shales, grits, and thin limestone distinct from the typical Hermosa.

The collections made suggest that the exposures designated as Rico along Junction Creek are either of late Pennsylvanian or of early Permian age. The collections from Lucky Strike Gulch are not distinctive. Few of the invertebrate fossils collected are restricted in range, and some of those that are supposedly restricted have been obtained so seldom, and from so few areas, that it is impossible to be certain that their stratigraphic ranges as published are really established.

Recognition of the Rico as a formation must be based mainly on its lithologic uniformity and characteristics and on its general stratigraphic position.

JURASSIC (?) AND UPPER TRIASSIC ROCKS

Dolores Formation

The Dolores Formation is made up of soft redbeds. It

can be distinguished locally from the Cutler by the presence of characteristic limestone conglomerates, which contain vertebrate fossils, and by the absence of coarse grits except at the base.

The formation ranges from about 400 to more than 700 feet in thickness. Along the Animas River it is about 660 feet. According to unpublished detailed field notes made by W. H. Emmons in 1904, the formation is only 440 feet thick along Falls Creek west of Trimble. A section on Junction Creek shows a thickness of 610 feet. Along the East Mancos River it is about 550 feet thick.

The formation crops out in a belt that nearly encircles the central and northeastern part of the district and it ranges from a few hundred feet to more than a mile in width.

The Dolores is almost perfectly exposed in a cliff on the west side of Junction Creek, 1.3 miles below the mouth of Castle Creek. This exposure may be considered typical of the Dolores Formation as it occurs in the La Plata district.

The Dolores is made up in large part of mudstone, siltstone, and shale, with a few beds of sandstone and several lenses of limestone conglomerate. The color of the unaltered rock is distinctly brighter, in general, than that of the underlying Rico and Cutler beds, ranging from salmon pink through various shades of red and purplish red to maroon. A few beds are gray. In most places there is a gradation from dull colors near the base to bright brick red and vermillion red near the top.

The most distinctive feature of the Dolores is the presence of thin beds and lenses of limestone conglomerate, made up of round to rather angular pebbles and pellets of dense bluish-gray limestone, set in a matrix of earthy, sandy limestone or of limy shale. Small flattened pebbles of shale are commonly present, and a few pebbles of quartzite, granite, and other rocks occur in places. Fragments of bones and fairly well preserved teeth of belodont crocodiles and megalosauroid dinosaurs have caused the enclosing rocks to be called "saurian conglomerates."

The lower half of the formation contains much more sandy material than the upper half, which is made up predominantly of mudstone and siltstone. The lowest 25 to 60 feet of the formation is characterized in most places by light-gray, micaceous, slabby sandstone, which contains several beds and lenses of limestone conglomerate. Poorly preserved plant remains occur locally in the sandstone.

Entrada Sandstone

The Entrada Sandstone, formerly known as the lower part of the La Plata Sandstone and still called the "lower La Plata Sandstone" locally, is from 150 to 265 feet thick within and near the La Plata district. It is one of the most distinctive and easily recognized formations in the district and contains valuable ore deposits in several places. It is well-exposed in a narrow but almost continuous band extending around the south and east sides of the mountains. Remnants cap Slide Rock Mountain, two of the ridges near the main forks of Lightner Creek ,and Deadwood Mountain. Along the Animas River it is 262 feet thick, on Junction Creek 235 feet, and on Jackson Ridge about 275 feet. Near the forks of Lightner Creek it is only 100 feet thick, and in the vicinity of the May Day and Idaho mines it ranges in thickness from 150 to 225 feet. The Entrada characteristically weathers to form sheer cliffs or smooth faces of bare rock, which present a striking contrast to the more rounded or terraced slopes assumed by the redbeds below it.

The lowest 40 to 50 feet of the formation consists in places of somewhat slabby buff to grayish-white or pinkish-white fine, even-grained sandstone. Elsewhere the slabby structure is poorly defined and the beds are massive and cross-bedded. The remainder of the formation is made up of massive, somewhat friable sandstone that is strikingly cross-bedded. Locally there are a few very thin partings of shale. The sandstone is mostly light gray or white, but in places it is pale cream to buff.

A distinctive feature of the Entrada is that all but the bottom and topmost beds are largely made up of well-rounded, relatively coarse grains of glass quartz, in the interstices of which are much finer sand grains.

The upper limit of the Entrada is marked almost everywhere in the La Plata Mountains by the basal Pony Express Limestone member of the Wanakah (La Plata Limestone of former reports).

Wanakah Formation

Throughout the district and the surrounding area the formation as now defined consists in most places of two easily recognized members, the Pony Express Limestone and an overylying thicker marl member, which is unnamed. A thin sandstone member, the Bilk Creek Sandstone, lying between the marl and the limestone, can be distinguished in a few places, and the limestone is locally absent. The two lower members are too thin to be shown separately.

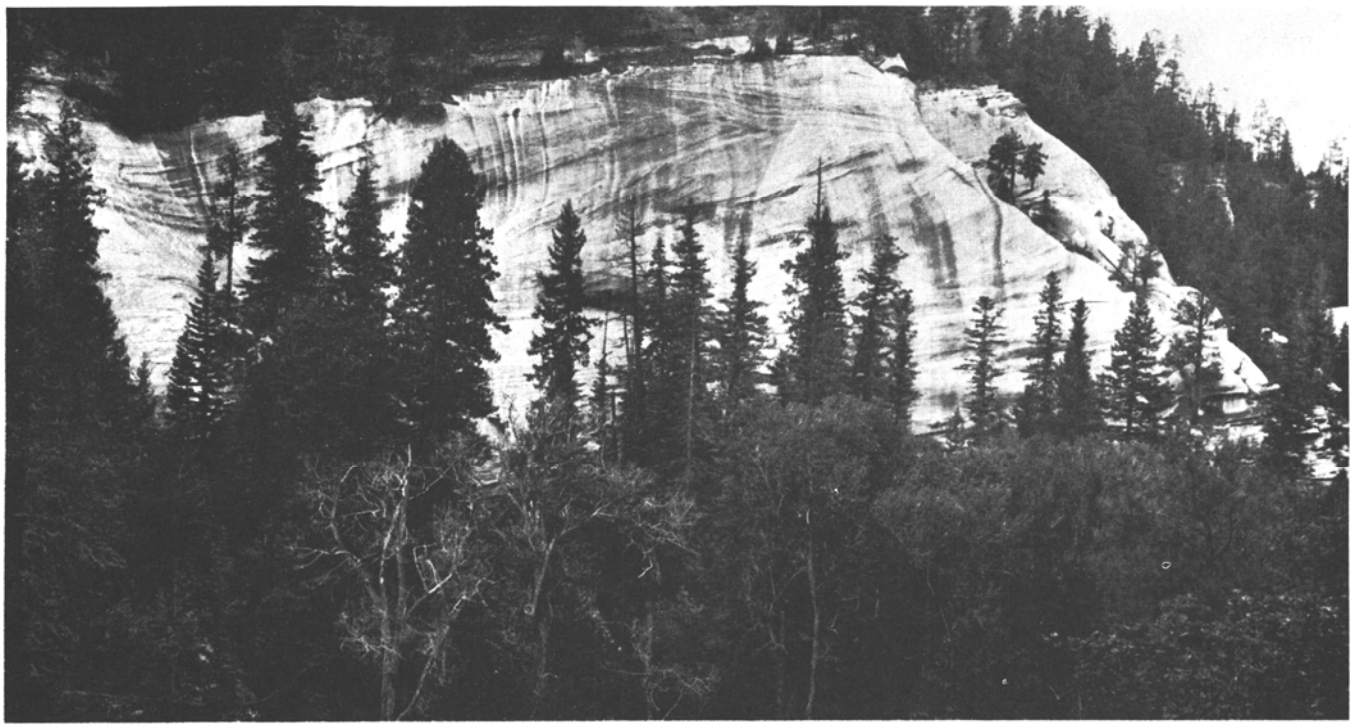
The formation as a whole is 25 to 150 feet thick. Its main belt of outcrop, which is 200 to 1,000 feet wide, skirts the southeastern and southern edge of the mountains and thence follows the west side of the East Mancos River and Bear Creek.

The Pony Express Limestone Member, at the base of the Wanakah (locally called the "La Plata Limestone") is one of the most important stratigraphic units in the district. It is a thin stratum of dense dark-blue or gray to nearly black relatively pure limestone.

In places the limestone consists of a single massive bed, but elsewhere it comprises three or more beds, each about a foot thick. In these places the upper beds are commonly massive and the lower ones thinly laminated. The top and bottom of the member are everywhere sharply defined. In some layers there is a suggestion of oolitic or pisolitic structure, but this feature is by no means widespread and nowhere well-defined. Some, if not all, of the limestone is bituminous and gives forth a noticeable fetid odor when freshly broken.

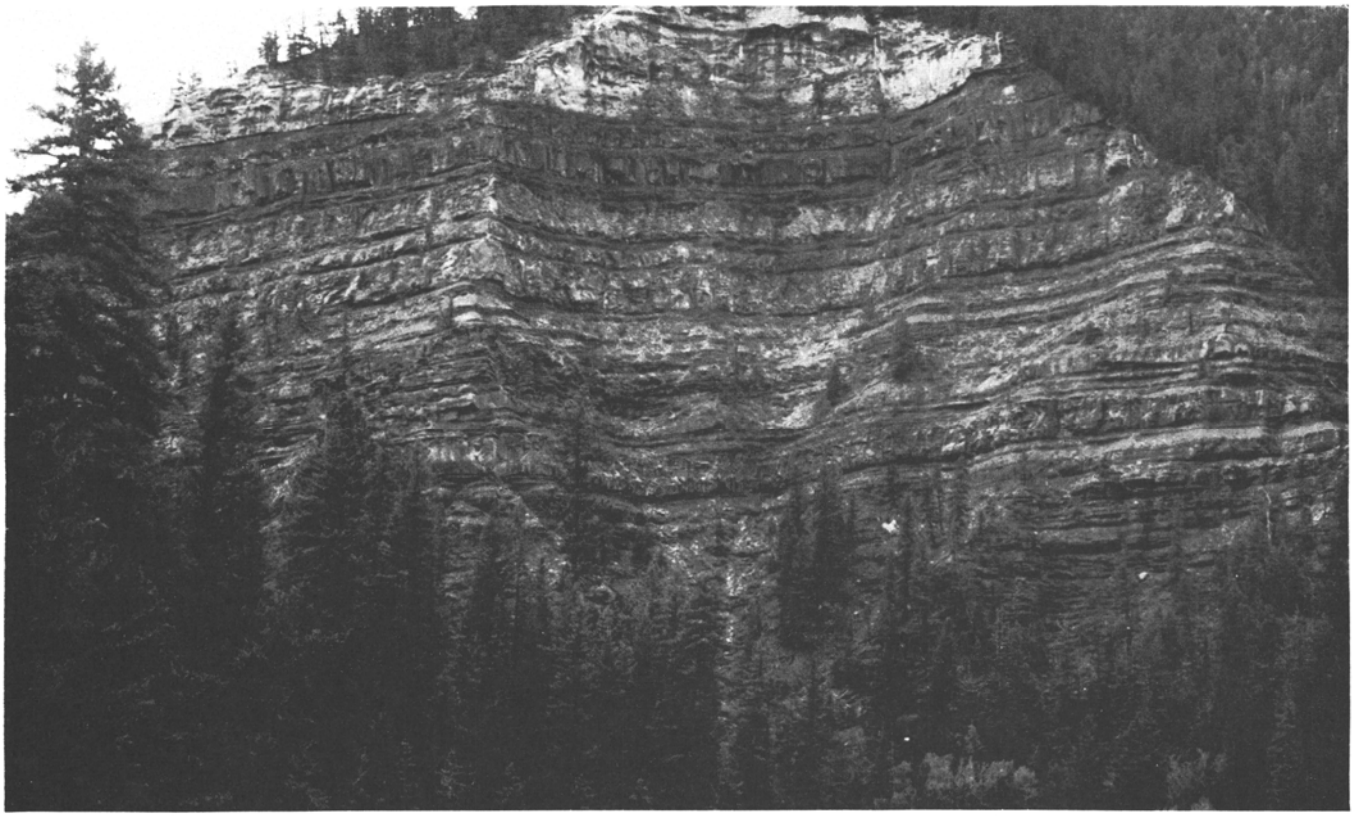
The only place where the member is known to be more than 10 feet thick is on the ridge between the forks of Lightner Creek, where it is 25 to 30 feet thick.

The Bilk Creek Sandstone is a succession of sandy beds, generally about 20 feet thick, rather soft, with prevailingly horizontal and locally nodular bedding; it is finer grained



A. VIEW OF TYPICAL EXPOSURE OF ENTRADA SANDSTONE ON WEST SIDE OF JUNCTION CREEK.

The thin Pony Express limestone member of the Wanakah formation caps the sandstone. This view also shows the character of the vegetation in much of the La Plata district. View 2½ miles below mouth of Castle Creek.



B. VIEW OF DOLORES FORMATION ON WEST SIDE OF JUNCTION CREEK

The white cliff at the top is Entrada sandstone. This is the best exposed section of the Dolores in the district and is described in the text. View 1.3 miles below mouth of Castle Creek.

NOMENCLATURE OF UPPER JURASSIC FORMATIONS

La Plata district, this report		La Plata district, local usage	La Plata district, 1936, Eckel		La Plata Quadrangle, 1899, Cross, Spencer, and Purington		La Plata Mountains, 1941, Goldman and Spencer		San Juan region, 1936, Baker, Dane, and Reeside
Morrison formation.		McElmo formation.	Morrison formation.	Local names used for members.	McElmo formation.		Morrison formation.		Morrison formation.
Junction Creek sandstone.		Upper La Plata sandstone.			La Plata sandstone.	Upper sandstone.		Junction Creek sandstone member.	
Wanakah formation.	Marl member.	Middle La Plata shale.				Middle calcareous member.		Wanakah marl member (restricted).	
	Bilk Creek sandstone member.	Not named.						Bilk Creek sandstone member.	
	Pony Express limestone member.	La Plata limestone.						Pony Express limestone member.	
Entrada sandstone.		Lower La Plata sandstone.	Entrada sandstone.			Lower sandstone.	Entrada sandstone.		Entrada sandstone.

than the Entrada. The uppermost layer, about 1 1/2 to 2 feet thick, is a hard calcareous sandstone, generally containing grains of red chert, scattered through it to some extent but more characteristically on its upper surface.

The marl member is 25 to 100 feet thick and consists of light pinkish-red to greenish-gray marls, mudstones, and sandstones in lenticular beds. Some of the marly beds are concretionary, and in places these beds contain thin lenses of relatively pure limestone. Flakes of bright-green shale, small grains of carnelian, and concretions of red chert thinly coated with material of a rich dark-green color, are all characteristic of this member, as they are of the Morrison. It is difficult, therefore, to distinguish the marly member of the Wanakah from the Morrison Formation (McElmo Formation of former reports), except by noting its relation to the intervening Junction Creek Sandstone (upper La Plata Sandstone of former reports) or to the diagnostic cherty layers and the "carnelian sandstone" at the top of the Bilk Creek Sandstone, as described by Goldman and Spencer.

The division between the Bilk Creek Sandstone and the marl member of the Wanakah is defined as the top of the "carnelian sandstone." From 10 to 15 feet above this sandstone there is usually found the "green chert" layer, containing a concretionary zone of authigenetic chert coated with associated dark-green glauconitic mineral. This relation is so nearly constant throughout the region from the San Miguel valley south to the La Plata Mountains that it is unquestionably diagnostic of the type "middle La Plata shale" sequence of Cross.

Junction Creek Sandstone

The Junction Creek Sandstone ("upper La Plata sandstone" of former reports) ranges in thickness from 200 to nearly 500 feet and is made up in large part of massive white cross-bcddcd sandstone closely resembling the Entrada. In most places the sandstone forms smooth cliffs, but they are rarely as steep or as prominent as those formed by the Entrada Sandstone. Outcrops along Junction Creek and the East Mancos River are marked by a multitude of spires and pinnacles of various shapes and by jumbles of great detached blocks of rock.

The greater part of the formation is typically composed of massive white to light bluff friable sandstone, which is strikingly cross-bedded. Thin lenticular beds of arkosic sandstone occur throughout the section, being especially numerous in the somewhat slabby uppermost part. Thin partings of greenish-gray or light-red shale are numerous in some places but absent in others.

Apart from stratigraphic position, no certain means of distinguishing between this sandstone and the Entrada have been found. Numerous local minor differences exist, however, and taken in combination they are often helpful.

Morrison Formation

Above the Junction Creek Sandstone lie the shales and sandstones of the Morrison Formation, formerly known as the McElmo Formation or as the uppermost member of the Morrison. The formation as now defined is 400 to 625 feet thick and is made up of thin alternating layers of varicolored shales and sandstone. Flakes and lenses of brilliant-green shale are widespread and locally abundant and serve to distinguish the Morrison from all other units except the marl member of the Wanakah. The sandstone beds are light-colored and are similar in most respects to the Junction Creek sandstone. They are all lenticular, and some, like those on the lower East Mancos River that merge with the sandstone member, are rather thick.

UPPER CRETACEOUS SERIES

Dakota (?) Sandstone

The Dakota (?) Sandstone has little relation to the known ore deposits of the district and was not studied in detail. It crops out in an irregular band near the south edge of the mapped area and it is almost continuously exposed along the western and northwestern sides of the dome. The Dakota (?) is only about 100 feet thick within or near the district.

The formation consists of conglomeratic sandstone with several layers and lenses of shale and impure coal. In general the lower part consists of a layer, from 5 to 50 feet thick, of white to gray or brown medium-grained to coarse-grained, cross-bedded, pebbly sandstone. This basal Dakota (?) Sandstone is overlain in most places by 8 to 15 feet of carbonaceous shale. Above this coaly parting is a bed of sandstone 25 to 40 feet thick that resembles the lower sandstone. Above the sandstone is a layer, 30 to 40 feet thick, of interbedded shale and sandstone with a little coal; the lower half of this layer is more shaly than the upper.

Mancos Shale

The Mancos Shale, which is the youngest formation that occurs within the La Plata district, is extensively exposed in the northwestern part of the area and also crops out along its southern edge. Within the La Plata quadrangle the Mancos Shale is about 1,200 feet thick. It is an almost homogeneous body of soft dark-gray to nearly black clay shale. It contains a few thin layers, lenses, and concretions of shaly fossiliferous limestone, especially near the base and top. The concretions are characteristically yellow brown in color. A few thin beds of gray sandstone occur in places.

QUATERNARY DEPOSITS

Unconsolidated deposits of Quaternary age obscure the bedrock in large parts of the La Plata area. They consist of glacial till and outwash gravels, landslide debris, talus, and alluvium. None of these deposits were studied in detail.

In the La Plata Mountains, as in the main San Juan Mountains, there were three glacial stages during Quaternary time, but the first of them is not represented by any known deposits. The floors of many of the basins in which the streams head contain masses of stony till left by the Wisconsin ice. These masses are now largely buried beneath talus and alluvium.

The small terminal moraine of the La Plata glacier is near Mayday. It dammed the valley and forced the stream to cut a narrow trough along its eastern edge. About a mile below Mayday the front of the moraine is bordered by the outwash gravel of a valley train, whose surface is about 30 feet above the modern flood plain of the river.

Small landslides have occurred in many places throughout the mountains, but the most conspicuous one is on the north side of Hesperus Peak.

Except for the grass and flower-carpeted upland meadows, the greater part of the district above timberline consists of bare rock or of accumulations of coarse, angular talus. The talus forms a conspicuous feature of the landscape and conceals the lower slopes of most of the high basins. A boulder crashing from the cliffs, or a little avalanche rushing down a ravine, reminds one, now and again, that vigorous erosion is constantly adding to the talus.

LATE CRETACEOUS OR TERTIARY IGNEOUS ROCKS

The igneous rocks of the La Plata Mountains are of late Cretaceous or Tertiary age, all are intrusive, and all of them can be grouped in two general types—porphyritic and nonporphyritic. The porphyritic rocks, which are the more abundant, occur as more or less contemporaneous stocks, sills, and dikes. For the most part they are intermediate between diorite and monzonite in composition, but some bodies are syenitic or mafic. The nonporphyritic rocks, in general younger than the porphyries, consist of syenite, monzonite, and diorite and occur as irregular stocks accompanied by dikes. The porphyritic bodies were intruded forcibly between the layers of sedimentary rock and were thus a major factor in the uplifting of the La Plata dome, whereas the nonporphyritic rocks cut across the sedimentary formations and the sills, few of them having disturbed the preexisting attitude of the beds. There is clear evidence that the nonporphyritic rocks replaced or assimilated their wall rocks during invasion.

The intrusion of the porphyries was not accompanied by any considerable metamorphism, whereas the group of nonporphyritic stocks is surrounded by an aureole of rather intensely altered sedimentary rocks.

PORPHYRITIC ROCKS

The porphyry bodies are thickest and most numerous near the center of the dome. Fully 98 percent of the porphyry related to this center lies within an oval area 12 miles wide and 17 miles long, elongate from east to west.

Four stocklike masses of porphyry are exposed in the mountains. The one on Silver Mountain presents the largest uninterrupted exposure of this rock; it is roughly 11/2 miles in diameter and is exposed throughout a vertical range of nearly 3,000 feet .

No single large mass of porphyry is exposed in the area northeast of Lewis Mountain, but the predominance of crosscutting bodies over sills suggests that this area may contain one of the centers from which many of the sills in the northeastern part of the district were fed, and that it may be underlain by a larger stock of porphyry.

The porphyry masses that characterize the region between Burnt Timber Creek and Baldy Peak are vastly more complex than the others in the district. Most of them cut across the sedimentary layers, but some have the form of sills or small laccoliths. They range in thickness from a few inches to more than 500 feet, and in lateral extent from a few yards to at least 5 miles. Some have a nearly uniform thickness throughout; others pinch and swell and locally assume laccolithic form and proportions.

Dikes of varying thickness and extent occur throughout the district. Most of them are similar to the sill rocks in general make-up, and many can be seen to connect one sill with another. Some of them have comparatively great vertical as well as lateral extent; many reach the surface, but a few like the small one exposed in the Neglected mine have not yet been exposed by erosion. In one or two places dikes were seen to end abruptly at some bedding plane or other structural feature of sedimentary rocks.

Some of the porphyry bodies are unquestionably older than others, and in several places dikes can be seen to cut through sills or irregular intrusive bodies, but all the masses of diorite-monzonite porphyry are closely related genetically and were intruded during a single epoch.

The porphyries are older than the nonporphyritic rocks, but clean-cut relations between rocks of these two types are seen in only a few places. Many of the contacts are obscured by talus, and many of those exposed are gradational. There are reasons for believing that this gradation is due at least in part to incomplete replacement of the porphyries by the later rocks.

Porphyry bodies cut all the sedimentary beds in the district but are most numerous in the Cutler and Dolores beds and least so in the thick Entrada, Junction Creek, and Dakota (?) Sandstones. The Cutler-Dolores contact, presumably because it is marked by an unconformity, seems to have been particularly favorable to sill intrusions.

Most of the sills were intruded between the sedimentary strata and domed them upward, but some cut across the beds, and others, notably the complex sill near the mouth of Tirbircio Creek, on the La Plata River, unquestionably pushed the underlying beds downward instead of lifting the overlying beds.

Near the sides of some of the crosscutting stocklike bodies the sedimentary rocks are bent upward. In most places, however, the stocks and thick dikes have not visibly disturbed the immediately adjacent rocks.

Injection of great quantities of porphyry magma was largely responsible for the forming of the La Plata structural dome. The stresses were relieved mainly by doming of the sediments, but locally, especially in brittle beds, by faulting. Some of the fault fissures were filled with dikes of porphyry; others deflected the magmas or caused them to stop abruptly, causing differences in the shapes of the intrusive bodies on opposite walls.

Petrology

The diorite-monzonite porphyries that make up nearly all of the porphyry bodies (except those between Burnt Timber Creek and Baldy Peak) are characteristically light gray to greenish gray or brown in color and contain abundant phenocrysts of white feldspar and of dark-green to black hornblende embedded in a dense groundmass. Folia of biotite and rounded phenocrysts of quartz occur in a few places. Augite with or without hornblende is present locally.

A great variety of texture is seen even within single masses. In some places the phenocrysts are so small that the rocks appear to be almost equigranular; in general, however, porphyritic texture is well-developed, all the feldspar phenocrysts in a given rock mass being commonly from 2 to 8 millimeters in length and the grains in the groundmass very much smaller. The phenocrysts of dark minerals are generally somewhat smaller than those of feldspar and similarly restricted in range of size.

Many of the sills and dikes contain numerous angular inclusions of foreign rocks. They range from coarse granite through hornblendic schists and gneisses to dark granular masses of amphibole. Fragments of the adjacent sedimentary formations are very rare.

Labradorite and orthoclase are the most abundant minerals. Labradorite is much the more abundant of the two; to the unaided eye it may appear to be the only feldspar in the rock, for it forms phcnocrysts whereas the orthoclase is largely confined to the groundmass. The groundmass is actually a granular mixture of orthoclase with quartz and the accessory minerals, magnetite, sphene, and apatite. Of the ferromagnesian minerals, common hornblende is the most abundant in most specimens, though a few specimens contain augite with or without hornblende. Biotite, the only other dark mineral present, is absent in many bodies and rare in all of them.

Quantitatively, the rocks range in composition from those in which orthoclase and labradorite occur in nearly equal amounts to those in which labradorite is predominant. The proportion of hornblende to the feldspars varies to some extent, but most of the apparent variation is due to differences in texture rather than in composition.

NONPORPHYRITIC ROCKS

The long irregular stock in the vicinity of Spiller and Babcock Peaks and Mount Moss consists chiefly of monzonite. The mass is about 2 miles long and a half a mile to three-quarters of a mile wide and is exposed through a vertical range of 2,500 feet. In addition to larger tongues and dikes there are many smaller ones on all sides of the main stock. The main body is in general distinctly stacklike in form, but locally it spreads out in the form of sills.

The monzonite is a light-gray to pinkish-gray medium fine-grained equigranular rock. The pink tinge is due to the color of the orthoclase in partly weathered rock and is not seen in the freshest parts of the mass. Two kinds of feldspar make up the greater part of the rock as seen in hand specimen, but dark-green to black crystals of augite and a few of hornblende and biotite can also be identified. Veins and narrow dikes cut the monzonite in places. Some of these veins contain a little gold.

Two irregular stocks of diorite are exposed in the district. The typical rock is commonly finer grained and somewhat darker gray than the monzonitc and contains a slightly larger quantity of ferromagnesian minerals and more lime-soda feldspar.

The larger stock, which is about 11/2 miles in diameter and is exposed through a vertical range of 2,800 feet, extends southward and eastward from Diorite Peak to the valleys of the La Plata River and Basin Creek. The small body of diorite at the head of Fly by Night Gulch is al-

VIEW AT HEAD OF BOREN CREEK SHOWING MONZONITE STOCK.

Dashed lines show approximate boundary of stock. Spiller and Burwell Peaks are in upper left and right corners. The jagged pinnacles along the gulch in the foreground are due to erosion of strongly altered and pyritized rocks of various kinds. View looking north from the ridge east of Burwell Peak.

most certainly an offshoot from the main stock and is probably connected with it in depth. Many dikes and a few sills are associated with both stocks.

Except for the difference in color and grain size noted above, the diorite is similar megascopically to the monzonite.

Two large stocklike bodies of augite syenite crop out in the central part of the district, south of the stocks of monzonite and diorite. The rock is strongly altered in many places, is characterized by gradational contacts, and is as poorly exposed as any in the district. The larger, more westerly stock extends from near La Plata to Gibbs Peak a distance of 21/2 miles, and ranges from a few hundred feet to 11/2 miles in width. It is exposed through a vertical distance of 3,000 feet. The smaller stock on the east side of the La Plata River, between Tirbircio Creek and Bragdon Ridge, is about 11/2 miles long and as much as three-quarters of a mile wide.

In the vicinity of the Allard tunnel on Bedrock Creek the syenite is traversed by innumerable veins and dikes. The most impressive of these bodies consist of coarsely bladed dark-green augite, intergrown with microcline feldspar. Coarsely crystalline calcite, white to clear crystalline quartz, and blue chalcedony form the inner parts of many of the veins. Chalcopyrite and pyrite occur in irregular masses interstitial to the nonmetallic minerals.

The seyenite is characteristically light brown to brownish gray in color, but some of it is pinkish gray. In general, it is moderately fine-grained and nearly cquigranular, although on the outcrop the altered condition of the feldspars tends to obscure the individual grains. Some of it has a marked porphyritic texture and is therefore not readily distinguished from that of the diorite-monzonite porphyries.

Except in the border facies, most of the variation in the syenite is apparently textural rather than compositional. Feldspars greatly predominate over the dark minerals. Dark-green augite, in irregular prisms, is the chief dark mineral.

The syenite is almost everywhere more strongly altered

than the diorite and monzonite. The feldspars are sericitized, though usually not beyond recognition, and the dark minerals are altered to limonitic material.

Geologic Relations of the Nonporphyritic Rocks

As now exposed, the stocks are largely in contact with the Cutler and Dolores red beds. Three types of contact between the stocks and the enclosing rocks have been observed; sharply defined, brecciated, and gradational. In many places the contacts between the diorite and monzonite and the host rocks are sharply defined and of a character that is normal for crosscutting intrusive bodies.

In at least two places, the Little Kate mine on Basin Creek and on the east slope of Lewis Mountain, the contact of the diorite with the enclosing rocks is marked by a coarse breccia that is unlike any other seen in the district. Little Kate breccia body is 2,200 feet long and 200 to 650 feet wide and is exposed through a vertical range of more than 600 feet.

Both diorite and monzonite seem in places to grade imperceptibly into diorite-monzonite porphyry. This gradation may be observed in one large sill on the east side of Banded Mountain, and in several of the dikes and sills south of Babcock and Spiller Peaks.

Both of the syenite stocks cut many bodies of porphyry. So far as could be determined, however, all these contacts are gradational; no clean-cut contact of syenite and porphyry was seen anywhere.

Origin

Much evidence indicates that the nonporphyritic rocks made room for themselves in part by replacing or assimilating the country rocks, rather than wholly by mechanical intrusion. Preexisting structures were not disturbed by the intrusion of the syenite, monzonite, and diorite stocks as they were by the intrusion of porphyries. The effects of the two types of intrusion on the structure are shown schematically in figure 3. Many of the veinlets of ingeous rock contain crystals too large to have been forced in along the narrow fissures, and in many places the silicified sedimentary rocks contain scattered feldspar crystals. Neither of these facts can be explained as the result of simple physical intrusion; both imply chemical action.

Gradation between diorite-monzonite porphyry and syenite is clearly established, and there is much evidence of similar gradation between porphyry and monzonite or diorite. These relations, too, can best be explained by chemical replacement.

As most of the inclusions are of sandstone, and as the stocks narrow where they cut sandstone beds, it is clear that siliceous rock was not easily digested by the stock-forming magmas. The rounded pebbles of quartz and quartzite that are found in parts of the stocks could only have been derived from conglomerates such as those that characterize the Cutler Formation; the fine-grained matrix has been removed, having evidently been attacked more freely by the magmatic emanations than were the siliceous pebbles. This difficulty in digesting silica might be expected in view of thorough silicification of the country rocks that accompanied the formation of the igneous stocks.

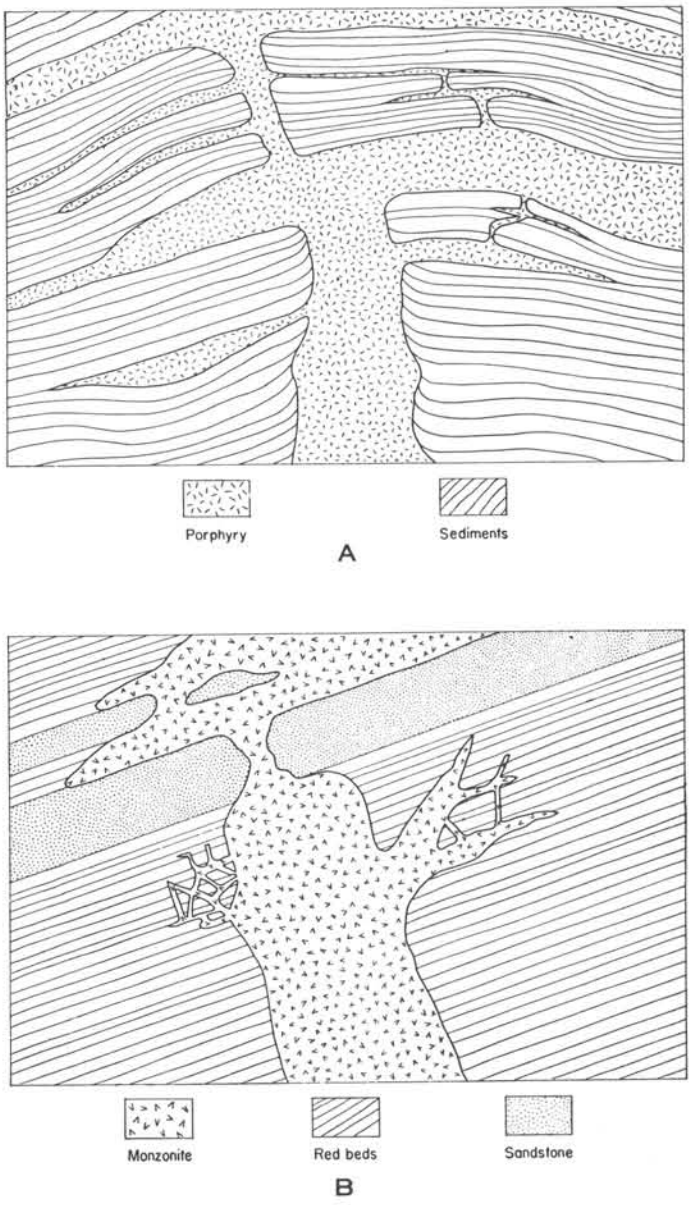


FIGURE 3.—Schematic sections showing relations of igneous rocks to structure and to country rocks.

A. Section through porphyry stock and associated sills. Beds have been dragged upward in walls of stocks and domed by sills. The sill in lower left depressed the beds beneath it.

B. Section through monzonite stock. Existing structures are not disturbed and stock narrows where it passes through thick bed of sandstone.

Metamorphism of Country Rocks

Widespread metamorphism of the country rocks accompanied the emplacement of the nonporphyritic rocks and even affected the syenite itself. Except near veins, the diorite and monzonite are very fresh, alteration being essentially confined to slight kaolinization and sericitization

of the feldspars. The syenite, on the other hand, is strongly altered in many places. Whether this alteration is due to endometamorphism during formation of the syenite or indicates that the syenite is somewhat older than the diorite and monzonite, and so has been weathered longer, is not known.

Nearly all the sedimentary rocks in the central part of the district have been strongly metamorphosed. The prevailing red colors have been lightened to pale pink, or brown gray, the rocks have been rendered hard and erosion-resistant, and many of the distinguishing features of the formations have been almost obliterated. Silicification has been the dominant process, and the sandstones have been changed to dense, hard light-colored quartzite. Shales and mudstones have been altered to hornfels made up chiefly of fine-grained quartz, intergrown with varying porportions of sericite, epidote, pyroxene, and other silicates. The carbonaceous shales of the Mancos and the coaly beds of the Dakota (?) have locally become graphitic. Limestone beds and limy nodules in the redbeds are characteristically represented by intergrowths of coarse calcite with typical "contact-metamorphic" minerals. Widespread introduction of pyrite followed the metamorphism.

That the metamorphism took place after the intrusion of the porphyries is proved by the facts that the porphyries themselves are altered, whereas, except in the central part of the district, the sedimentary rocks in contact with the porphyries are unaltered.

AGE OF IGNEOUS ROCKS

There are no means of dating the La Plata intrusive activity more closely than by saying that it took place during late Cretaceous or Tertiary time. The similarity in form and composition of the rocks in both the La Plata and the Rico domes with the late Cretaceous or early Tertiary rocks at Ouray strongly suggests that all three groups are of the same age.

STRUCTURE

The most pronounced structural feature of the La Plata Mountains is a domal uplift of the sedimentary beds, about 15 miles in diameter, which blends somewhat into the southwestern flank of the much broader San Juan uplift. This dome is partly bounded by a steep, horseshoe-shaped hinge fold, open at the south, which nearly encircles the central part of the mountains. On the south side of the hinge, and along the northern and northwestern margins of the dome, there are several strong faults along which the rocks in the central part of the dome were uplifted.

The formation of these major structural elements was contemporaneous with and resulted from the porphyry intrusions, and it preceded the emplacement of the granular stocks and the metamorphism. Numerous short, discontinuous faults of small displacement were formed during the doming process. Many of them trend east, but some radiate from the center of the dome. After the emplacement of the nonporphyritic stocks, some of these faults were reopened and other similar faults were formed, which became the loci for many ore deposits.

FOLDS

The domal structure of the La Plata Mountains is apparent from the areal distribution of the sedimentary rocks. Beyond the limits of the dome, the beds dip about 5° toward the south and southwest. This regional dip is a part of the main San Juan uplift, which centers far to the northeast.

Although the dome is nearly symmetrical in section when viewed broadly, it is not so in detail. From the outskirts of the dome, the rocks rise gradually toward the center, with dips of 5° to 20°, until they reach the steep hinge fold that is the most striking feature of the structure. The zone involved in this hinge fold is 1,000 to 3,000 feet in width, is irregular in plan but has the general shape of a horseshoe, with the open end toward the south.

Along this hinge zone the beds generally dip outward at angles of 25° to 60°. Individual beds are thus elevated as much as 1,000 feet in horizontal distances of 2,000 feet or less. Both inside and outside of the hinge the beds flatten abruptly, and locally there is a minor syncline along the outer edge. In places the rocks are sheared and brecciated along the fold and many of the ore-bearing fractures are concentrated within or near it. The hinge fold is most strikingly exposed on the ridge between Spiller and Burwell Peaks and on the east side of Lewis Mountain, but it can be made out rather clearly throughout its extent. The hinge does not continue as a structural unit along the south edge of the dome.

In general, the rocks inside the hinge fold rise gradually toward the center of the dome, which lies near the junction of Lewis Creek with the La Plata River. Within the dome, however, there are many local folds of varying degrees of magnitude. Most of them, if not all, can be attributed directly to the influence of porphyry bodies.

FAULTS

Most of the ore deposits are closely associated with faults, which arc thus of the greatest economic importance. Compared with folding, however, faulting played a minor part in the growth of the La Plata dome. In general, nearly all of the faults fall into two groups: one is classed here as "barren" and the other as "ore-bearing." Members of the first group, though mineralized in places, are not known to contain workable bodies of ore, whereas the second group contains most of the district's ore deposits. The essentially barren faults are older than the ore-bearing faults and are characterized in general by much larger displacements. They are almost entirely confined to the northwestern and southern outskirts of the dome, while the ore-bearing fractures are widely distributed.

Barren Faults

A group of strong faults extends along the northwest and north sides of the dome. The most prominent of them strike northeast to due east. Along most of them the downthrow is on the north side away from the center of the dome. Vertical displacements range from several tens to several hundreds of feet. These main faults are nearly vertical and the curving courses they show on the map are

due to actual changes in direction rather than to the influence of topography.

A series of strong faults trending nearly due east crosses the southern part of the dome and closes the open end of the horseshoe-shaped hinge fold. The most prominent members of the series fall into two parallel systems, known as the May Day-Idaho and the Parrott faults. A strong tendency toward parallel alinement here characterizes all the structural features; most of the porphyry dikes trend east and west, probably along faults of comparatively small displacement. As a group, these faults raise the beds toward the center of the dome, thus having the same general effect as the hinge fold.

The Parrott fault system is strongest and best exposed on the ridge between Parrott and Madden Peaks, where it has a downthrow on the south of about 1,000 feet and brings the Dakota (?) against the upper beds of the Dolores Formation. Two main splits can be traced westward to the divide between the East Mancos River and Starvation Creek, but the displacement diminishes rapidly in this direction, and no fault of any considerable displacement can be found along the East Mancos.

The two main splits of the Parrott fault can be traced eastward for several thousand feet from the type locality, but in this direction also the displacement diminishes greatly within a short distance. A strong shear zone that cuts the large porphyry mass along Burnt Timber Creek is probably a continuation of the Parrott system, though the displacement along it is certainly less than 200 feet.

Much of the ore produced by the Lucky Discovery mine was taken from a split of the Parrott system known as the Nettie fault. The showings of gold ore in the Kaibab and Billings properties farther west are closely related to this fault; and so, probably, is the Comstock deposit.

The May Day-Idaho fault system trends nearly due east along the south side of the La Plata dome. Most of the faults of this system are barren of ore deposits. Evidence indicates clearly that the May Day-Idaho faults are older than the ore deposits and nearly contemporaneous with the porphyry intrusions that formed the La Plata dome.

Ore-Bearing Faults and Breccia Zones

Many faults and fractures along which the rocks are displaced from a few inches to 75 or 100 feet occur throughout the district, and two broad breccia zones occur in the central part. These features are of great economic importance for, though relatively few of them contain workable deposits of ore, most of them are mineralized to some extent.

These faults and mineralized features show a slight tendency toward radial arrangement with respect to the La Plata dome. The majority trend northeast to east, though several of them, particularly in the southern part of the district, trend nearly due north, and a few on Jackson Ridge and elsewhere trend northwest.

Most of the faults of this class are considerably less than a mile long, and many of them extend only a few hundred feet. A few individual veins, such as the Black Diamond vein and several of those in the upper part of the Bear Creek Basin, can be traced for more than a mile. More commonly, however, the longer fault zones are made up of a series of overlapping fractures.

So far as can be determined no displacements of more than 100 feet are known. Most of the faults are normal, but a few are reverse faults. There is some reason to believe that the fault followed by the Columbus vein is a hinge fault, having displacements in opposite directions at the two ends, but it is possible that the ore deposit follows segments of two separate faults that cross each other at a small angle.

The ore-bearing faults cut every kind of rock that occurs in the district, but they are more numerous, and are characterized by stronger shear zones, in the harder and more brittle sandstones and igneous rocks than they are in the less competent shaly beds.

Because of the generally small displacements along these faults it is difficult or impossible to recognize them in places where they are not mineralized or where good marker beds are lacking.

Two extensive breccia zones have been observed in the central part of the district, and a smaller one is exposed in the Gold King mine. Within these zones the rocks are weakly sheared and brecciated along numerous fractures and minor faults, a few of which are very extensive. Most of them trend northeastward. Pyrite and chalcopyrite are widely distributed throughout the breccia zones, being particularly abundant in and near the fractures. Some of the fractures contain sufficient gold to be workable, at least in their oxidized parts.

Some of the most productive deposits in the district lie along the continuations of the Baker Peak-Burnt Timber Creek breccia zone. It seems likely, therefore, that this zone, and perhaps the Gibbs Peak-Spiller Peak zone, are upward extensions of major rifts in the basement rocks through which the ore solutions gained access to the higher rocks.

PHYSIOGRAPHIC HISTORY

The carving of the present La Plata Mountains from the La Plata structural dome occurred in large part during Quaternary times. By the beginning of the Quaternary, late Tertiary erosion had obliterated the greater part of whatever topographic expression the structural dome may have had. Erosion had cut deeply enough to expose some of the porphyry masses and to contribute pebbles and boulders thereof to the gravels that were spread far to the south on the gently sloping surface of the San Juan peneplain. Masses of resistant rock may have stood as monadnocks on the plain. A radiate stream system, consequent on the structural dome, had probably been initiated, and the La Plata River may already have become the dominant stream.

Early in Quaternary time a broad uplift of the entire San Juan region rejuvenated the streams and caused them to begin active downcutting, which they have continued, with interruptions, to the present day. The general form of the La Plata Mountains was probably blocked out rather early in Quaternary time, and the three glaciations only

reinforced the work of the streams without producing a new drainage pattern.

LATE GEOLOGIC HISTORY

At the close of the Cretaceous period the area was covered by 11,000 to 14,000 feet of horizontally bedded sedimentary rocks. When the ancestral San Juan dome was formed these beds were tilted upward toward the northeast.

Volcanism began either very early in the Tertiary or during the Miocene. Great quantities of diorite-monzonite porphyry magma were intruded into the basement rocks, along one or more comparatively small conduits. Upon reaching the sedimentary layers, the magma gradually spread out and pushed the sediments upward.

The intrusion of the porphyries went on slowly and in a gentle, but forceful manner. The country rocks were soft and they yielded to the intrusive forces largely by bending. On the outskirts of the dome, however, the stresses were partly relieved by faulting. Some of these faults transected soft and hard beds alike; others broke only the brittle beds and passed into local folds in the softer strata.

The aggregate effect of the porphyry intrusions, of the upward thrust of the basement, and of the faults was the formation of the structural dome that characterizes the La Plata Mountains. Apart from the effects of erosion, this dome had essentially the same shape and size at the close of the period of porphyry intrusion that it has at present.

Soon after the intrusion of porphyry had ceased, or possibly even a little before it had ceased entirely, stocks of diorite, monzonite, and syenite began to form. They were guided in large part to weak places that had developed along the sharp hinge line of the dome.

The emplacement of the holocrystalline stocks was accompanied by silicification, baking, and metamorphism of the surrounding country rocks. The shape and size of the metamorphic aureoles were largely controlled by the stocks themselves, but in most places the hinge line of the dome limited its area. The pyritic-gold deposits of Jackson Ridge and elsewhere and the disseminated platinum-bearing copper deposits of Copper Hill appear to have been formed during the general metamorphism of the rocks in the central part of the district.

Toward the close of the igneous cycle hydrothermal solutions rose along many of the fractures, and quartz deposited early in this process was sheared and brecciated by renewed fault movements, thus leaving open channelways for the ore-bearing solutions. Slight movement took place along some of the veins after the ores had been deposited, and a few new minor faults were formed.

The Quaternary history of the La Plata Mountains was essentially the same as that of the San Juan Mountains, since both ranges were affected by the same series of up lifts. Many of the ore deposits in the La Plata district may have been enriched by downward-circulating waters during late Tertiary and early Quaternary time, but the glaciers which carved many of the present features removed nearly all of the weathered ore and even cut deeply into the primary deposits.

ECONOMIC GEOLOGY

HISTORY AND PRODUCTION

Spanish explorers visited the La Plata Mountains in the 18th century and reportedly found mines already in operation. There is no other record of the early history but placer gold was found on the Animas River in 1861, near the present site of Durango. Mining in the La Plata district itself began in 1873. In that year, placer gold was discovered along the La Plata River and the Comstock vein was discovered. On June 22, 1874, Captain Moss and Harry Lightner located the South Comstock lode, and A. K. Fleming, Almarion Root, and Robert James located the North Comstock lode and millsite. In 1875, Moss bought Fleming's interest for $5,000 and then sold both claims to Tibircio Parrott for $10,000.

By 1885 two unsuccessful attempts at milling the ores had been made. Freeman mentions the original 5-stamp Cumberland mill and an arrastre mill, the location of which is not known. The Cumberland mill was designed for extraction of free gold, although the Cumberland ore yielded only ruby silver.

Between 1897 and 1901 attention was temporarily diverted from the high-grade telluride deposits to the low-grade pyritic-gold deposits on Jackson Ridge and at the heads of Bedrock and Boren Creeks. At the turn of the century, many of the mines had produced some ore, but not one of the mines opened before 1900 had then produced as much as $100,000.

With the coming into production of the Neglected mine in 1901, the district entered upon a new era of real discoveries. The Valley View or Idaho vein was located in 1902 and the May Day deposits in 1903. These mines began production in 1904, reached a peak about 1907, and, in spite of many legal and other difficulties, remained the leading mines for many years. The Incas deposit was discovered in 1909 and yielded $260,000 within 3 years. No other large deposit was found until about 1923, when the Gold King vein, an extension of the old Eureka-Bulldozer vein, was uncovered. In 1933 the sensational Red Arrow discovery was reported.

More than half of the nearly $6,000,000 total production of the camp was taken from two mines, the May Day and the Idaho, and four others, the Neglected, Gold King, Incas, and Red Arrow, have together yielded more than $1,000,000 worth of ore. More than two-thirds of the district's production has thus come from six mines.

Production of gold, silver, lead, and copper from La Plata district, 1878-1937, in terms of recovered metals[1]

Lode gold	Silver		Copper		Lead		
(value)	Fine ounces	Value	Pounds	Value	Pounds	Value	Total value
$4,362,792	2,003,497	$1,289,238	283,876	$ 45,590	715,183	$ 38,095	$5,741,711

1. Gold valued at $20.67 + per ounce 1873-1932, at $25.56 for 1933, at $34.95 for 1934, and at $35 for 1935-37.

MINERALOGY

By F. W. GALBRAITH

The following is a list of minerals reported associated with the ore deposits of the district. A question mark indicates that presence of the mineral in the district has not been definitely established. In addition to the listed minerals, a few are believed to occur in particles too small for positive identification.

Aikinite (?)	Copper (native)	Orthoclase
Amalgam (?)	Cosalite (?)	Palladium (native?)
Andradite	Covellite	Pearceite (?)
Anglesite	Dickite	Petzite
Ankerite	Enargite	Platinum (native?)
Argentite	Epidote	Polybasite (?)
Arsenopyrite	Fluorite	Pyrargyrite
Augite	Galena	Pyrolusite
Azurite	Gold (native)	Pyrite
Barite	Gypsum	Realgar
Benjaminite (?)	Halloysite	Quartz
Bornite	Hematite	Roscoclite
Calaverite	Hessite	Siderite
Calcite	Krennerite	Silver (native)
Cerargyrite (?)	Limonite	Stephanite
Cerussite	Magnetite	Sylvanite
Chalcanthite	Malachite	Tellurium (native)
Chalcocite	Marcasite	Tetrahcdrite
Chalcopyrite	Mercury (native)	Tourmaline
Chlorite	Miargyrite	Tremolite
Cinnabar	Muscovite, var. sericite	Troilite (?)
Coloradoite		

Digest Note: Descriptions *and* occurrences of *all* the *minerals* listed above are *given in* the *original* paper. The *need for brevity permits* only *brief mention* of a few *in* this digest.

Gold, Au.—Native gold is the only valuable product of some of the mines. Finely divided free gold is associated with pyrite in the Doyle "blanket" and in many veins. It is also associated with pyrite and chalcopyrite in contact-metamorphic deposits.

The most notable occurrence of free gold is at the Red Arrow mine, which has produced much coarse gold in crystals, wires, and irregular masses. The largest "nugget" found weighed more than 5 pounds. This gold is associated with quartz, coarsely crystalline barite, ankerite, chalcopyrite, tetrahedrite, and pyrite. Some of it is intergrown with tetrahedrite, minute crystals of which are perched on gold crystals in one specimen.

Native gold was seen in polished sections of ores from the Bessie G., Durango Girl, Neglected, Lucky Discovery, and Eagle Pass mines. It is relatively abundant in several parts of the Gold King vein. In nearly every section the gold is intimately associated with the tellurides of gold, silver, and mercury and is of hypogene origin. In one section from the Bessie G. mine, native gold occurs with cinnabar deposited in vugs lined with very late quartz. This occurrence probably represents the final stage of hypogcnc mineralization.

In a section of ore from the Eagle Pass vein much of the gold fills tiny fractures and follows minute capillary cracks along the cleavage of hessite. This is the only occurrence of native gold believed to be of supergene origin that was observed in the polished sections. Several occurrences of gold in association with native mercury and amalgam have been reliably reported, however, and free gold is said to have been abundant in the near-surface workings of the Neglected, May Day-Idaho, Comstock, and other mines.

Free gold is said to be associated in small quantity with the ruby silver ores of the Cumberland and other mines, but as none of it was seen in the specimens examined the relation of gold to the silver minerals is not known.

Silver, Ag.—Native silver has been reported only as an oxidation product in some of the copper mines on Bear Creek, but it may have been present in the oxidized parts of other deposits; it is scarce throughout the district.

Copper, Cu.—Native copper has been reported from the Copper Age and Bonnie Girl mines and from several of the mines along Bear Creek.

The most interesting occurrence of native copper is in a recent swamp deposit on the west side of the La Plata River, just below the town of La Plata. Here the soil in a depression half an acre or so in extent is kept moist in part by surface waters from Boren Creek and in part by small seep springs in the immediate vicinity of the swamp. All of this water drains through or over rocks that contain appreciable quantities of disseminated chalcopyrite. The black muck of the swamp, which is 5 feet thick or more in places, contains many irregular nodules and grains of native copper, the smallest of which are less than a millimeter and the largest more than a centimeter in diameter.

Platinum, Pt. and palladium, *Pd.—Small* quantities of platinum and palladium are associated with chalcopyrite-bearing rock on Copper Hill, between Boren and Bedrock Creeks. The platinum metals were discovered and proved by chemical methods.

Galena, PbS.—Galena is widely distributed through the La Plata district, both in the telluride and the sulfide ores, but it is abundant in only a few of the deposits studied, the Gold King, Jumbo-Morovoratz, and Puzzle being almost the only mines that have produced it in commercial quantity.

Argentite, Ag.,S.—Small quantities of argentite are associated with sphalerite, tetrahedrite, pyrite, and ruby silver minerals in the coarse-grained galena of the Daisy mine. Argentite has also been reported from the Hidden Treasure mine. It is not known to occur elsewhere in the district and is almost certainly rare.

Chalcocitc, Cu_2S.—Aside from the copper deposits along Bear Creek (p. 70), the only known occurrence of chalcocite in the district is in the Red Arrow Extension prospect.

Sphalerite, ZnS.—With the exception of pyrite, the most abundant sulfide mineral in the La Plata district is sphalerite.

Sphalerite has been deposited in open vugs and fissures in quartz, and it also has replaced quartz, pyrite, and carbonate gangue. Sphalerite and chalcopyrite are essentially contemporaneous, tiny blebs of chalcopyrite being contained in much of the sphalerite.

Chalcopyrite, $CuFeS_2$.—Chalcopyrite is recognizable in about half the ores studied. In most of them it is scarce, very little being present in the ores that contain telluride minerals. It is the most abundant sulfide, however, in the vicinity of Copper Hill and Bedrock Creek.

Sylvanite, (Au, Ag) Teo.—According to most of the published descriptions of the district sylvanite is by far the most widespread telluride mineral in the La Plata deposits and is commoner there than any other telluride. However, it is actually very rare in the many polished sections of representative ores that have been studied.

Hessite, Ag_e Te.—Hessite is by far the most abundant telluride of the La Plata district and occurs in considerable quantity in the ore of the Bessie G., Durango Girl, Gold King, Idaho, Lucky Discovery, and May Day mines. It is intimately associated with the other tellurides in contemporaneous hypogene intergrowths.

Coloradoite, HgTe.—Coloradoite, heretofore unreported from the district, is more abundant there than any telluride except hessite, and is probably a constituent of all ores that contain tellurides.

Miargyrite, $Ag_2S.S13_2S_3$, *and* Pyrargyrite, $3Ag_2S.S132S3$.—Pyrargyrite was identified only in ores from the Gold King and Texas Chief mines, and miargyrite only in ore from the Gold King mine. These minerals, however, with proustite ($3Ag_3S.AsoS_3$), are doubtless among the principal ore minerals in the Cumberland, Muldoon, Kennebec, and other mines of the belt that crosses the northern part of the district.

Cuprite, Cu_20.—The red copper oxide cuprite has been found only along Bedrock Creek, where it forms veins and veinlets that cut the metamorphic rocks in the border zone of the syenite stock.

Hematite Fe_20_3.—Specular hematite is a prominent constituent of many of the "contact-metamorphic" bodies that have been formed by replacement of limestone beds and nodules. The only places where these bodies have been worked as ore are in the Bay City, Gold Farm, Lady Eleanora, and Silver Falls mines.

Magnetite, $FeO.Fe_20_3$.—Magnetite has the same general distribution as hematite. On the northeast slope of Diorite Peak the "La Plata" limestone has been entirely replaced by massive granular magnetite over a comparatively large area.

Calcite, $CaO.0O_2$.—Calcite is fairly widespread but is generally not abundant as a gangue mineral. By far the greatest concentration of calcite seen occurs along the eastward extension of the May Day-Idaho fault system, in the general vicinity of the Oro Negro prospects, where there are solid bodies of white calcite 10 to 20 feet in width.

Ankerite, Ca0.(Mg.F00.2CO3—Carbonate minerals are present in many ores throughout the district and are relatively abundant in some of them. Most of the carbonate approaches ankerite in composition, but some of it is probably closely allied to rhodochrosite; much ore contains so much manganese that it is stained black when weathered.

Roscoelite, $2H_20$ .Ko0 .3 (AI,V) ,$0.6SiO_2$.—The green vanadium-bearing mica, roscoelite, is a widespread associate of the telluride minerals. It commonly occurs in small quantities in microscopic intergrowth with fine-grained quartz, to which it imparts a dull-green color. This green quartz is an almost certain indication of high-grade ore, even where no telluride minerals are visible to the naked eye.

Barite, $BaO.S0_3$.—Barite is rather widely distributed as a gangue mineral in the veins of the district but is everywhere subordinate to quartz in abundance. Deposition of barite followed that of quartz and early pyrite and preceded the main period of sulfide mineralization.

SEQUENCE OF HYPOGENE ORE MINERALS

The main stages in the history of ore formation are deposition of (1) quartz and pyrite, (2) barite and ankerite, (3) vein sulfides in the order pyrite and arsenopyrite, sphalerite and chalcopyrite, tetrahedrite and galena, (4) tellurides, all believed to be of contemporaneous origin, (5) native gold, and (6) cinnabar and native gold.

There are many exceptions, however, to this order. The most variable relations are exhibited by the sulfides. The relations most commonly observed indicate the order of deposition given above, but the occasional replacement of sphalerite by pyrite, of tetrahedrite by chalcopyrite and sphalerite, and of galena by sphalerite suggests an overlapping sequence of deposition.

The tellurides are clearly later than the sulfides. Tetrahedrite is the mineral most extensively replaced by them, although pyrite, sphalerite, chalcopyrite, and galena are all replaced in lesser degree. No evidence of the replacement of one telluride by another was observed in any of the polished sections studied, so that the tellurides are believed to have been formed contemporaneously.

SUPERGENE ALTERATION

Little alteration of the primary ores by surface waters has taken place. Limonite is the most abundant supergene product, especially in ores containing much pyrite. Anglesite and cerussite in small amount were formed from the alteration of galena, a little covellite replaced chalcopyrite and tetrahedrite, and supergene bornite filled capillary cracks in chalcopyrite. Native gold is believed to have replaced a little of the hessite.

ORE DEPOSITS

More than 98 percent of the production of this district has been gold and sliver. The district is best known for its veins and replacement deposits of gold-bearing and silver-bearing telluride ores, from which the greater part of the production has come. In addition to them, however, it contains a surprising variety of types of ore deposit within a small area. They include deposits of disseminated platinum-bearing chalcopyrite, gold contact-metamorphic deposits, deposits in which base-metal sulfides or pyrite and native gold predominate, and deposits characterized by the ruby silver minerals. They include disseminations and bed replacement bodies as well as veins. Some of these various classes of deposits are relatively unimportant commercially, and none of them probably will ever approach the telluride veins in total production. From the scientist's viewpoint, however, they form an interesting group, and some of them

bear promise of having greater economic value in the future than they have had in the past.

Classification of ore deposits of La Plata district is as follows:

1. Disseminated chalcopyrite with platinum and palladium.
2. Gold with sulfides:
   a. Contact-metamorphic replacement bodies.
   b. Gold-bearing pyrite:
      Veins.
      Replacement bodies.
      Breccia bodies.
   c. Mixed sulfides with silver and free gold.
3. Chalcocite veins.
4. Ruby silver veins.
5. Telluride deposits:
   a. Veins.
   b. Replacement bodies.
6. Gold placers.

Disseminated Chalcopyrite with Platinum and Palladium

Disseminated deposits of chalcopyrite, rich enough in a few places to constitute copper ore, are associated with both of the syenite stocks in the central part of the district. As a result of Eckel's study small amounts of palladium and platinum were found to be associated with the chalcopyrite in one of these deposits on Copper Hill, and the general similarity of all the deposits of this type in the district made it seem possible that these precious metals are present in other places.

Contact-Metamorphic Deposits

Most of the limy beds in the highly metamorphosed central part of the district have been altered to minerals commonly regarded as products of contact metamorphism. Many of these deposits contain a little gold, and a few have yielded workable bodies of ore. Their most abundant and widespread minerals are andradite, garnet, augite, magnetite, and hematite, that have nearly or quite replaced the original limy material of the country rocks.

Gold in small quantities is widespread in these deposits. Most of it is probably contained in the sulfides, but according to reliable reports some bodies of essentially pure magnetite and of garnet contain appreciable quantities of gold.

Gold-Bearing Pyrite Deposits

Many deposits in the central part of the district contain pyrite and minor quantities of quartz almost to the exclusion of other minerals. Sericite, chlorite, and kaolin found at some places in the wall rocks appear to be genetically related to the ores. Finely divided gold is commonly associated with the pyrite, but in only a few places is it sufficiently abundant to render the primary deposits workable by present methods of mining and metallurgy.

Veins

Examples of the pyritic gold veins are to be seen in the Century, May Rose, and Monarch mines and in the Timberline workings of the Doyle mine. The veins generally follow narrow, steeply dipping shear zones, in which the rocks are broken or brecciated along series of closely spaced overlapping fractures. Some of these zones have sharply defined walls, but others have gradational limits.

The chief minerals in most of them are fine-grained massive pyrite and granular to coarsely crystalline quartz, pyrite being commonly much more abundant than quartz.

The vein minerals were deposited largely in open spaces; they fill interstices between breccia fragments or form veins and veinlets within the shear zones. A few veins, notably those of the Monarch mine, were formed by replacement of the country rocks.

Replacement Bodies

Two places are known where gold-bearing pyrite has extensively replaced a bed or layer of rock, and only one of the resulting deposits is of economic importance. This is on the south side of Jackson Ridge and constitutes the "blanket vein" of the Doyle mine. The other deposit was worked in the Peerless mine.

Little is known of the Peerless deposit, but it apparently consisted of a nearly horizontal tabular body of pyrite, arsenopyrite, and chlorite at the contact between the Dolores Formation and the Entrada (lower La Plata) Sandstone. This body probably replaced a lens of limestone.

Breccia Deposits

The district contains several extensive breccia zones in which pyrite is widely distributed but almost nowhere abundant. All these zones contain a little gold, but none of them, with the possible exception of the Little Kate deposit in Tomahawk Basin, seem rich enough to constitute a workable ore body under present methods of mining and milling.

Mixed Sulfides with Gold and Silver

All but one of the known deposits of this class consist of irregular veins that range in thickness from less than an inch to about 5 feet and that occupy steeply dipping breccia zones. The zones range from a few inches to more than 10 feet in width and less than 200 feet to more than 1,000 feet in length. In the Lady Maurine prospect however, the ore minerals are scattered throughout a 40-foot breccia zone.

The deposits are characterized by the relative abundance of base-metal sulfides. Pyrite, chalcopyrite, galena, and sphalerite are the most abundant and widespread metallic minerals, but gray copper (tetrahedrite) is conspicuous in many places.

Chalcocite Veins

The copper deposits are without exception associated with the monzonite porphyry dikes. The chief ore mineral is chalcocite, but native silver is reported from the Bell Hamilton mine, and a little pyrite is locally associated with the ore.

The copper deposits are limited to the lower part of the Dolores Formation and lie within 40 feet of the borders of the monzonite porphyry dikes. Where the dikes penetrate formations other than the Dolores, the rocks appear to be entirely barren.

The grade of ore produced in the past was variable, depending largely on the degree of sorting that was done.

Ore that was carefully hand-picked contained as much as 25 to 30 percent of copper, but shipments of unsorted ore are reported to have contained 4 to 5 percent. No records arc available as to the silver content of the ore.

Ruby Silver Veins

A class of deposits that is relatively distinct, both geographically and geologically, from all other deposits in the district consists of the ruby-silver bearing veins. They lie along a belt 3 miles long and less than half a mile wide, that extends eastward from the central part of Cumberland Basin to Fassbinder Gulch. The Cumberland mine contains the best example of the ruby-silver deposits—the only one, indeed, that is sufficiently developed and accessible to provide an adequate picture.

The ore consists mainly of the ruby silver minerals, proustite and pyrargyrite, but contains stephanite, argentite, and probably other sulfides and sulfosalts of silver, and most of the veins contain a little gold. Most of the gold is probably free, though tellurides are reported from the Cumberland.

Telluride Veins and Replacement Bodies

The telluride veins and replacement bodies are by far the most important commercial ore deposit in the La Plata district and have yielded more than 95 percent of its total production. With the exception of the Red Arrow, all of the mines that have yielded more than $100,000 worth of ore are in deposits of this class.

Although known telluride deposits, large and small, are scattered throughout the district, they are most numerous, in three rather localized areas. One of them is in the northeast part of the central mountain mass, centering near Lewis Mountain and extending from near Baker Peak to Snowstorm Peak. A second area lies south of Madden Peak and Deadwood Mountain, near the south edge of the district. A third group of deposits, somewhat different from most of the others, centers about Diorite Peak, in the north-central part of the district.

With certain exceptions, no deposits of any commercial importance occur within the central metamorphic core of the mountains, two of the main groups of deposits lie along and near the hinge fold that encircles this core while the third, most southerly group, lies within the belt of east-west faults that takes the place of the hinge fault across the south edge of the La Plata dome.

Telluride veins occupy parts of many of the "ore-bearing" faults and fractures. In general the deposits consist of irregular and commonly discontinuous veins and veinlets that traverse the breccia and sheared rock composing most of the fault zones. Some of these veins and veinlets merely fill interstices in the sheared country rock; others follow fractures or replace the country rock, as is shown by the presence in the vein matter of rounded masses of "ghosts" of the original rock fragments.

All the known replacement deposits are in the Pony Express (La Plata) Limestone member of the Wanakah Formation, and all are closely associated with productive veins. Few of them extend more than 50 feet on either side of the veins, and the values in them commonly de crease rather uniformly away from the veins. In the May Day and Idaho mines, the replacement bodies, like the productive portions of the related veins, are close to intersections of the latter with strong barren faults.

The ore minerals, which comprise the tellurides and native gold with minor amounts of sulfides, arc apparently scattered through the carbonate gangue, but locally they are concentrated, and solid masses of mixed tellurides several feet in diameter have been found.

Placer Deposits

The first gold discovered in the district was in the form of placer deposits along the La Plata River. Considerable attention was given to placer mining in the early days of the camp; several placer claims were patented and a little gold was produced.

With one exception, that of the Gold Bar, the known placer deposits are stream gravels in present stream beds. They range from a few inches to 80 feet or more in thickness and are made up of sand, gravel, and boulders; some of the boulders are very large. The gold is relatively coarse and rough in most places and is unevenly distributed, although as usual it is commonly most abundant at or near bedrock. Some cracks and fissures in the bedrock contain appreciable quantities of gold.

Gold Bar, which extends southward from Mayday to Hesperus, is composed in large part of glacial outwash gravels. No thorough tests have been made of the Bar. Available information suggests, however, that it is the largest and perhaps the most promising placer deposit in the district.

FUTURE OF THE DISTRICT AND SUGGESTIONS FOR PROSPECTING

The known vertical range of ore deposits in the district as a whole is far greater than that of the ore shoots hitherto developed in any one mine, and the lower limits of the productive zone arc not yet known. Favorable conditions for ore shoots are produced by a large variety of geologic conditions, many veins contain several ore shoots, separated by nearly barren stretches, and some ore shoots do not crop out at the surface. The outlook for discovery of new ore bodies is therefore promising, providing the exploratory work is intelligently undertaken.

Not only may new shoots be found in known deposits, but new deposits may be discovered. New discoveries have occurred at widely separated intervals and there is no reason for believing that 1933, the year the Red Arrow was found, marked the end of the discovery period for new ore bodies.

Except in the vicinity of Diorite Peak the distribution of known deposits offers little encouragement to further exploration within the central metamorphic area. Outside this area further exploration would appear to be justified. Most of the veins that characterize the hinge fold have probably been found, but much of the exploration has been only superficial, and many ore shoots may remain undiscovered. The strong faults in the southern and northwestern parts of the district deserve more exploration. The faults themselves are commonly barren; search for ore

should be confined to intersections of the faults with mineralized veins.

The eastern part of the district is heavily covered with vegetation and has been less thoroughly explored than any other part. The widespread distribution of known telluride deposits within this area offers hope that other deposits remain undiscovered.

Most of the district's deposits are small and "pockety." It is therefore expensive and difficult to explore and develop them completely, and unless a vein is developed by mine openings that are very closely spaced both horizontally and vertically, worth-while ore shoots may be entirely missed. Few single mines will repay large company operations. Consolidation of several deposits with a single overhead to cover management and technical guidance might prove profitable.

Dumps appear to warrant examination and sampling. The mines from which they came were operated when ores that contained less than $50 to the ton could not be handled at a profit, and much ore of moderate grade was wasted. Random sampling of dumps indicate the presence of much easily accessible material that should yield a profit under modern methods of treatment.

MINES

Digest note: *Professional Paper* 219 describes 104 of the *principal mines,* prospects, *and claims* of the district. This digest *includes* information for only the Gold King mine *and the May Day Idaho* group of *mines* and claims *which were the most successful* in the district.

Gold King

The Gold King mine is situated on the north bank of Lewis Creek, at an altitude of about 10,500 feet. A fairly good road and an aerial tramline connect it with the Gold King mill on the La Plata River, less than 2 miles to the southwest.

The Gold King mine produced 12,137.45 ounces of gold, 141,349 ounces of silver, 440,900 pounds of lead, and over 155,000 pounds of zinc from its discovery in 1921 through 1943. The mine was worked through a 600-foot crosscut adit, which connects with the east-west Main level about 350 feet below the surface. Two long drifts above the Main level four shorter drifts below the Main level were worked through a 400-foot winze. Including principal raises and winzes there are about 6,000 feet of workings in the mine. At the time of examination the two lowest levels were under water, and the Water tunnel and most of the 100-foot level were inaccessible because of caved ground.

The sedimentary rocks exposed in the mine are interbedded shales, mudstones, sandstones, and grits, which dip 2° to 20° W. The main adit of the mine lies above the base of the Rico formation. The contact of the Rico and Hermosa Formations must lie not far below the Main level, but it has not been recognized in the lower workings. One small exposure of red sandy and shaly limestone containing Rico fossils was found on the footwall of the No. 2 level but no fossils were found in the hanging wall. All available evidence indicates that most of the ore came from the Rico Formation, though some was found in the lower Cutler and some almost certainly in the uppermost Hermosa beds. The rocks are relatively unaltered along most of the vein.

Several porphyry sills, from 1 foot to nearly 200 feet thick are exposed; most of them are irregular in shape and swell out or cut across the sedimentary strata.

A body of breccia is exposed near the main adit on all accessible levels but the No. 2. The breccia is composed of angular fragments of sedimentary rocks. It is thoroughly silicified, and pyrite is abundant between the breccia fragments. Contacts with the adjacent sedimentary strata are gradational in some places, but elsewhere they are marked by fairly well defined fractures. The breccia mass is 75 to 230 feet wide and appears to trend north, at right angles to the course of the Gold King vein. Its walls are nearly vertical, and according to miners who worked in the lower parts of the mine it extends at least as far down as the 300-foot level. The porphyry sills appear to be later than the breccia and to cut through it.

The Gold King vein follows a fault that strikes nearly due east and dips 35° to 85° N., its average dip being about 60°. The outcrop has been traced northwestward from Lewis Creek as far west as Amethyst Creek.

The amount and even the direction of displacement along the Gold King fault have not been determined, because the only recognizable marker bed, the one containing fossils, could not be found on the hanging wall. The writer believes that the fault is probably a small one.

In summary, the sequence leading to the formation of the vein seems to have been about as follows: Formation of the breccia mass and of an eastward-trending fracture zone; silicification of the wall rocks, particularly of the breccia; intrusion of porphyry; renewed movement along the east-west fault zone; deposition of ore and silica.

Ore minerals.—The principal ore minerals of the Gold King mine are tellurides of gold and silver and native gold. The rather high ratio of gold to silver in most of the ore mined suggests that gold-bearing tellurides (krennerite, calaverite, and perhaps sylvanite and petzite) are more abundant than in the specimens examined. In them hessite is by far the most abundant, but one large specimen is rich in krennerite, and small quantities of calaverite and coloradoite are widespread.

Other metallic minerals are native tellurium, pyrite, sphalerite, tetrahedrite, galena, chalcopyrite, myargyrite, pyrargyrite, and cerussite. The gangue is largely white to dark green or gray quartz, accompanied by small quantities of barite, calcite, ankerite, and fluorite. Small veinlets and irregular masses of free gold have been found even on the lower levels. Galena is abundant in places, particularly in the flat ore shoot above the No. 2 level.

Ore shoots.—Most of the ore that has been produced was found in an ore shoot closely associated with the breccia mass. Above the Main level this shoot was 250 to 350 feet long and at least 200 feet high. A smaller ore shoot, which has yielded ore containing more lead and somewhat less gold has been exploited above the No. 2 level, east of the breccia mass. This shoot was only 60 to 150 feet high but was about 900 feet long.

Tenor.—Few detailed records of the tenor of the ore

produced are available. The average gross value of all the ore mined to the end of May 1935 was $13.46 to the ton (gold valued at $35 to the ounce). Some of the ore was much richer than this; for example, one 25-ton carload of sorted crude ore shipped in the spring of 1935 yielded a net smelter return of $9,952. The mill record for 1935 shows that 3,284 tons of ore milled contained 0.11 ounce of gold and 1.00 ounce of silver to the ton, 0.44 percent lead, 0.40 percent zinc, 0.85 percent iron, and 85.0 percent insoluble. This ore yielded 103 tons of concentrates containing 2.95 ounces of gold and 25.40 ounces of silver to the ton, 12.1 percent of lead, 12.0 percent of zinc, 23.0 percent of iron, and 15.9 percent of insoluble. Ore from the smaller shoot that was being milled toward the close of operations in 1937 had a gross value of $5 to $10 per ton.

May Day and Idaho

The Idaho, or Valley View mine, and the adjoining May Day are more favorably situated for economical operation than most in the district. They are, together, responsible for more than half the total production of the district. At the end of 1943 the Idaho had produced 47,962.23 ounces of gold and 383,004 ounces of silver since its discovery, and the May Day had produced 74,914.92 ounces of gold and 758,984 ounces of silver. It is generally believed locally that both mines should also be credited with large quantities of gold that were "high-graded" from time to time. Production of copper and lead was insignificant.

The principal workings total well over 5 miles in length. Except for their lower parts, which were caved or filled with water, and for the stopes, most of the workings were open for examination in 1935-37. Most of the ore deposits have been worked through four long crosscut adits, connected by drifts, raises, and winzes.

The southward-dipping sedimentary rocks in this area are cut by a series of barren east-west faults, which drop the beds to the south and apparently also displace them eastward on the south side of the faults. Several northward-trending ore-bearing veins follow faults of small displacement, and these veins, together with closely associated replacement bodies in limestone, constitute the ore deposits of the two mines. It is believed that the barren faults are pre-ore and that the heavy gouge zones that characterize them guided the ore solutions as they rose along the veins.

The sedimentary rocks range from the Dolores Formation through the Morrison (McElmo of former reports) . The thicknesses as determined from the mine maps, are as follows: Entrada Sandstone, 180 to 225 feet; Pony Express Limestone Member of Wanakah Formation, 1 foot to 10 feet; marl member of Wanakah, 65 to 100 feet; Junction Creek Sandstone, 250 to 350 feet; shale of Morrison Formation about 500 feet. The rocks are unaltered in most places, but near porphyry dikes and along some of the veins and faults the sandstone and shales are silicified and the Pony Express Limestone is locally replaced by ore minerals.

Irregular dikes and sills of porphyry are exposed in the mine workings and on the surface. The most continuous of these bodies follows the Idaho fault for at least half the length of the fault; it is made up of diorite-monzonite porphyry, but it is nearly everywhere sheared and strongly altered. Though known as the Idaho dike, it is highly irregular in form, and most of its exposed contacts are faults marked by more or less abundant gouge.

May Day-Idaho fault system.—The sedimentary rocks dip 10° to 55° S., their average dip being between 20° and 30°. The most important structural feature is the May Day-Idaho fault system. This system, which is most strongly developed in and near the mines, strikes nearly due east along the southern base of the La Plata dome. The system at its type locality comprises two strong eastward-trending reverse faults, the Idaho and the May Day, each with downthrow on the south. The total vertical displacement along the two faults is 350 to 475 feet; marker horizons, such as the Pony Express Limestone, show an apparent horizontal displacement of 1,000 to 2,000 feet to the east on the south side of the fault system.

Locally the displacement follows a single fracture plane; elsewhere it is distributed through several splits. The two faults can be traced only a few hundred feet east of the May Day workings.

Vein systems.—Besides the strong eastward-trending faults of the May Day-Idaho system, there is also a series of normal faults that trend northward and dip steeply eastward. These faults, which have displacements of 10 to 30 feet, contain the principal ore deposits They are discontinuous, and stop abruptly, in most places, at their junctions with the major faults.

Interpretation of structure.—The writer believes that the main movement along the May Day-Idaho faults system took place before the introduction of the ore deposits, and that it was nearly contemporaneous with the porphyry intrusions and the formation of the La Plata dome.

Later earth movements that followed the formation of the barren faults and the intrusion of the porphyry resulted in the formation of northward-trending fractures, which gave access to ore-bearing solutions. These solutions rose along the barren faults, and deposited ore in places where the country rocks were favorable to the formation and survival of strong breccia zones, or where they were easily replaceable.

The beliefs just outlined differ from thos held by several geologists and engineers who have examined the mines. It is held by them, and by some of the miners, that the May Day and Idaho faults are post-ore and that they displaced the ore-bearing veins horizontally. The Idaho, Valley View, and "810-foot" veins are thus regarded as segments of the same vein.

This hypothesis that the faults are post-ore fails to explain the concentration of ore at intersections of veins with the "barren" faults, the absence of "drag" ore in the fault planes, and the mutual relations of the Idaho dike and fault.

The strong east-west faults appear to be closely related to the hinge fold that encircles the central part of the district, which was formed early in the structural history of the La Plata dome.

If, as is believed by several engineers and mining men,

the Brooklyn and May Day veins on the one hand and the Idaho, Valley View, and "810-foot" veins on the other, are segments of two veins that have been dislocated, the displacement along the barren fault system was essentially horizontal, the south wall having moved east somewhat more than 1,000 feet. There is little evidence that supports this correlation. There are no known means of either proving or disproving the correlation between the various segments, and there are no correlatable bodies of igneous rock in the different fault blocks. The horizontal slickensides indicate that the last movement along the system was horizontal, but they prove nothing as to the direction of the main displacement.

Clearly, no clean-cut solution is possible at this time. The barren east-west faults are almost certainly older than the ore deposits. The principal northward-trending veins may represent segments of two main fissures that were displaced horizontally by the May Day and Idaho faults. It seems equally possible that most of the movement on the barren faults was more nearly vertical and that the ore-bearing fissures never extended beyond their present limits. The writer is inclined to favor a third hypothesis that each of the veins may be more extensive than is now apparent, and that unrecognized segments of any or all of them may exist.

Classification.—Two related classes of ore deposits are known in these mines—veins and limestone replacement bodies. Both of them yield telluride ores of gold and silver. A third class, which consists of altered and mineralized porphyry, is known but has not yet been exploited. The replacement bodies have yielded richer ore than the veins but the veins probably are responsible for the greater part of the total production.

Veins.—Three veins, the May Day, the Valley View, and the Idaho, have yielded most of the ore that has been produced, but some ore has also been taken from the Brooklyn, Gertrude, "810-foot," and other veins. The distance between vein walls ranges from a few inches to about 10 feet.

The Idaho vein is known only to the north of the Idaho fault. It strikes a few degrees west of north and in most places dips eastward. The main ore shoot is clearly related to the Idaho fault. Some of the ore taken from this vein came from between walls of the Dolores Formation (redbeds) or from the Pony Express Limestone, but by far the greater part of the ore produced was found where one or both walls were of Entrada Sandstone.

The Valley View vein, 300 feet east of the Idaho has yielded much of the ore credited to the Idaho mine and some of that credited to the May Day mine. It has been explored only between the May Day and Idaho faults. Other segments, if they exist, have not been identified. Most of the ore was taken from or near the Pony Express Limestone.

The Gertrude vein strikes north and is nearly vertical. It is said to be marked by smooth walls bearing scattered crusts and slabs of dark-gray sulfides, which contain streaks of native gold and tellurides.

Workable ore bodies have been found only in and near the Pony Express Limestone. The ore shoots were spotty, but some of them were very high grade, and $68,000 worth of ore is reported to have been taken from one small stope.

The May Day vein has produced more ore than any other vein in the Idaho and May Day mines. It varies in strike from due north to N. 25° W. and in dip from 55° to 85° E., and the displacement along it ranges from 20 to 30 feet. The vein has been explored for a distance of only 600 feet north of the May Day and Idaho faults. The drifts of the May Day No. 1 and B levels extend considerably farther north, but they followed westerly splits of the true vein.

The May Day vein has been stoped continuously from the surface, where some of the ore is said to have been rich in free gold, to a depth of 455 feet. The wall rocks of its productive part thus range from the Entrada Sandstone up into the lower part of the Morrison Formation. The best ore is reported to have been taken from the vein between the two faulted segments of the Pony Express Limestone member of the Wanakah and from replacement deposits in the limestone itself.

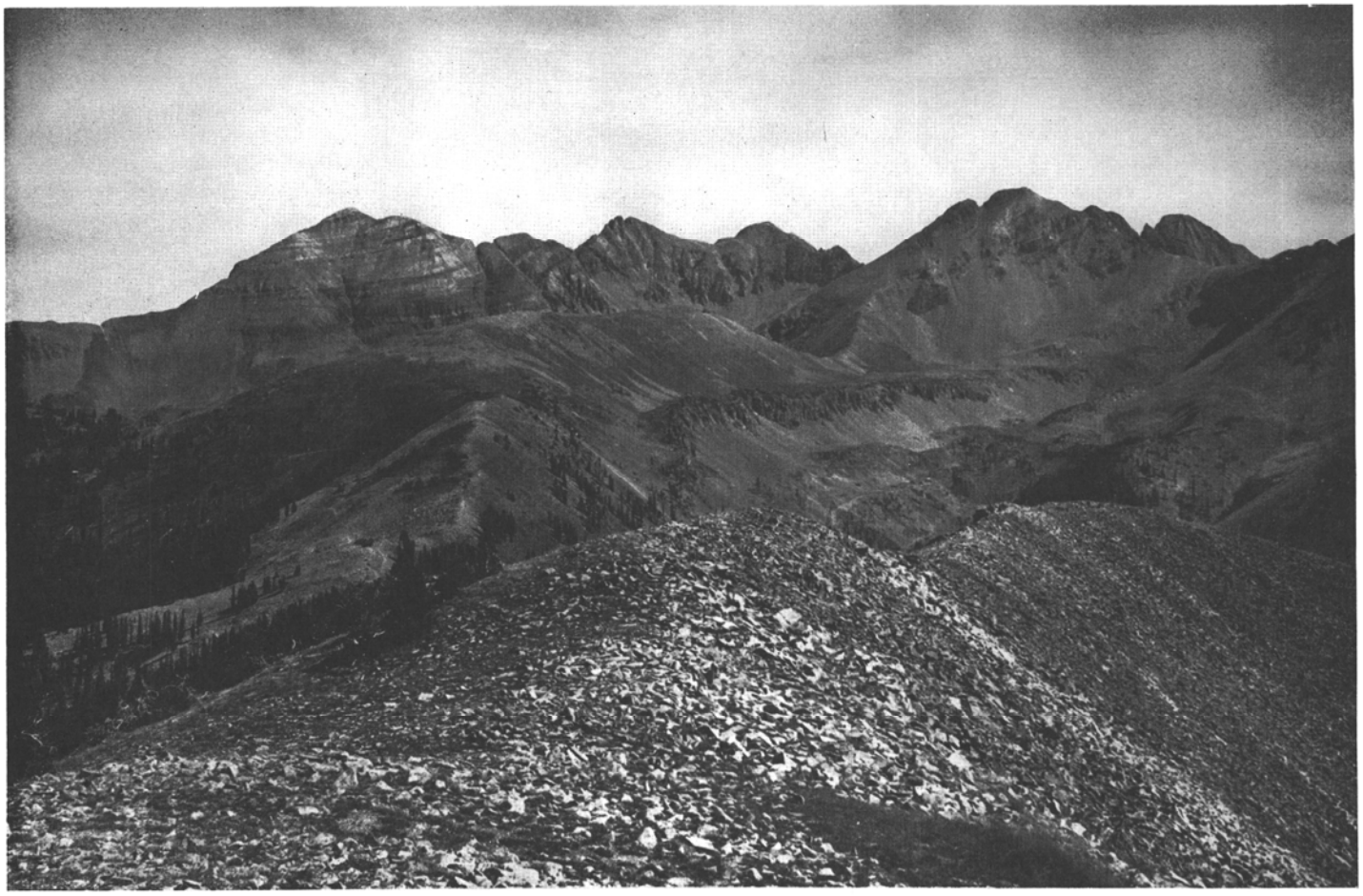
The Brooklyn vein is the eastern most of the veins developed by the Idaho and May Day mines. The discovery workings were south of the May Day fault, where the Dakota (?) Sandstone forms the wall rock. Probably all the underground development work has been done on the segment that lies between the Idaho and May Day faults.

Limestone *replacement ores.*— The Pony Express Limestone near some of the veins has been more or less completely replaced by ore minerals; elsewhere it is essentially unaltered. Workable ore rarely extends more than 50 feet from a fissure, and in general the tenor decreases uniformly with the distance from the fissure. Much of the best ore from the May Day and Valley View veins represented replaced limestone, and almost all the ore from workings on the "810-foot" vein was from the limestone.

Porphyry ore.—The altered porphyry of the Idaho dike, at and near the intersection of the May Day vein with the two major faults, appears to deserve consideration as a possible ore reserve. In the vicinity of the May Day fault it is strongly brecciated and kaolinized. Several hundred tons of this material that had caved into an open stope were milled and yielded $8 to the ton in gold and silver. Samples taken from the dike in places contained more than $10 to the ton.

Mineralogy.—Base metals are not abundant in the deposits, though small quanities of galena, sphalerite, pyrite, and arsenopyrite are widely distributed. The gold and silver occur largely as tellurides, but some free gold has been found in places, and free gold is said to have been abundant in the early near-surface workings.

One specimen of high-grade ore, from the Idaho mine, was obtained. The gangue is quartz, which contains a mixture of hessite, coloradoite, galena, pyrite, chalcopyrite, petzite, krennerite (calaverite?), and gold, named in order of abundance. Pyrite and a little residual barite are earlier than the ore minerals and are replaced by them. They are contemporaneous with or slightly later than quartz. The various tellurides, which are believed to be essentially con-



A. VIEW SHOWING A PART OF THE STEEP FOLD THAT CHARACTERIZES THE LA PLATA DOME.
At the extreme right, the beds dip steeply toward the west but on Jackson Ridge they are nearly horizontal. View looking northeast from Helmet Peak toward Spiller and Hesperus Peaks.

temporancous, filled open spaces and partly replaced all the older minerals.

Tenor.—Some shipments of ore contained several thousand dollars worth of gold and silver to the 100-pound sack. Production figures show that during the height of its activity, from 1907 to 1914, the Idaho mine produced ore averaging 2.88 ounces of gold and 22 ounces of silver to the ton. The ore shipped from the May Day during the years 1904-13 contained on the average 2.14 ounces of gold and 21 ounces of silver, but, as most of the shipments were of hand-sorted ore, these figures are doubtless higher than the average tenor of the ore mined.

Structural control of ore deposits.—It is evident that the main deposits that have been worked lie close to one or the other of the major east-west faults. The most reasonable explanation of this relation seems to be that the faults were in existence before the ores were deposited and that the gouge zones along them acted as diversion dams and guided the solutions. The fact that deposits have been found on both sides of each fault indicates clearly that the solutions rose vertically along the fissures and did not enter the host rocks along horizontal channels.

Character of wall rock was nearly as effective as the barren faults in controlling ore deposition. Nearly all the ore thus far produced has been taken from the easily replaced Pony Express Limestone member of the Wanakah and from the competent Entrada and Junction Creek Sandstones.

The vertical range of the ore deposits is not known, but at least 1,250 feet is indicated. Although the lower workings are at the lowest altitude of any in the district, there is no indication that the ore deposits do not extend to even greater depths in places where the wall rocks and other structural conditions are favorable.