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RESURVEY OF THE GEOLOGY AND ORE DEPOSITS OF THE LA PLATA MINING DISTRICT, COLORADO.[1]

(Preliminary report)

by

EDWIN B. ECKEL[2]

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ILLUSTRATIONS

[1]Published with permission of the Director, U. S. Geological Survey, of the Colorado State Geological Survey Board, and of the Colorado Metal Mining Fund.

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Introduction

A re-study of the ore deposits of the La Plata district, Colorado, was begun in 1935 by the United States Geological Survey as a part of the cooperative program carried on with the Colorado State Geological Survey Board and the Colorado Metal Mining Fund. This paper is a progress report on the first season's field work and will be followed by a more comprehensive report when the project is completed. Results of the original geologic survey of the district, made by Whitman Cross, A. C. Spencer, and C. W. Purington in 1889, were published in Geologic Folio 60 of the United States Geological Survey in 1901.

The La Plata district, also known as the California district, lies within the La Plata Mountains in southwestern Colorado, from 8 to 18 miles northwest of Durango (fig. 1). The district includes parts of La Plata and Montezuma Counties. All the principal peaks of the La Plata Mountains lie within a circle about 9 miles in diameter which centers in the valley of the La Plata River near the mouth of Tirbircio Creek (pl. 1). The approximate extent of the whole La Plata Mountain group, as well as of the mining district, is indicated on figure 1. The altitude ranges from about 8,000 feet above sea level on the lower slopes to 13,225 feet on Hesperus Peak. Many of the peaks exceed 12,000 feet.

Existing topographic maps are old and in many respects inadequate for detailed geologic mapping. The mountainous area is shown on the maps of the La Plata and Durango 15-minute quadrangles, published by the United States Geological Survey on a scale of 1:62,500, or approximately 1 inch to 1 mile. Photographic enlargements of parts of the two maps, on a scale of 1:24,000, or 1 inch to 2,000 feet, were used for field mapping. The area mapped during the first season is shown on plate 1.

F. W. Galbraith, who was with the party during the greater part of the season, and R. S. Moehlman, who joined it late in the summer, gave exceptionally able and willing

assistance in field and underground mapping. James Williams spent about 6 weeks in the field. His stratigraphic and paleontologic studies provided a workable basis for recognition and differentiation of the sedimentary formations in the metamorphosed area. Mining men and others in the district and in Durango and Mancos were uniformly helpful and courteous and cooperated in every way possible.

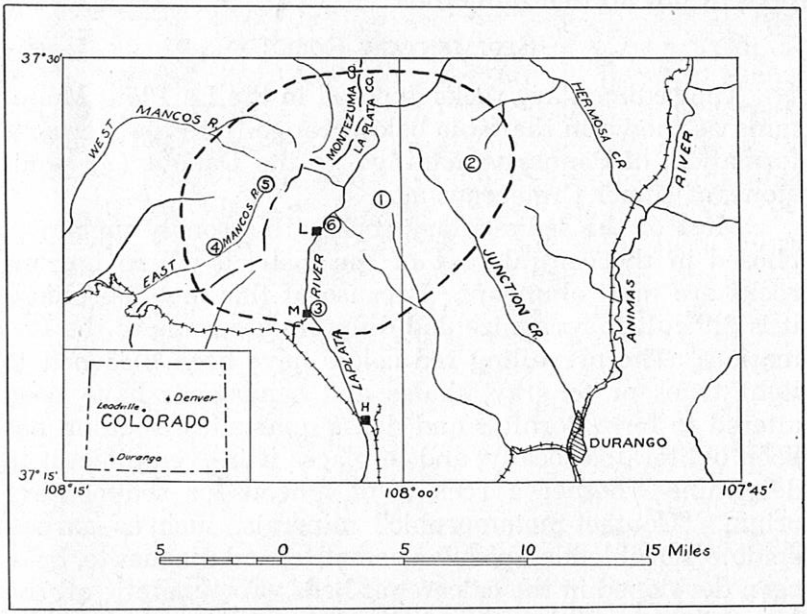

Figure 1. Index map showing location of the La Plata district, Colorado.
Towns: L.—La Plata, M—May Day (Parrott), H.—Hesperus.
Mines: 1.—Gold King, 2.—Neglected, 3.—May Day-Idaho, 4.—Red Arrow, 5.—"Doyle," 6.—Honey Dew.

General Geology

The La Plata Mountains have been carved from a domal uplift of sedimentary rocks that were intruded by numerous stocks, dikes, and sills of igneous rock. The sedimentary rocks are much altered in the central part of the mountains

but are essentially fresh elsewhere. Most of the sills or sheets of porphyry were forced in along bedding planes, but many cut across the bedding in places. The stocks and dikes cut across all formations and appear to have caused much of the rock alteration. Few of them displace older structural features. The strata in general dip away from the central higher areas. Faults, some of rather large displacement, are present but are not numerous.

Sedimentary Rocks

The sedimentary rocks exposed in the La Plata Mountains, as shown in the table below, range from the Hermosa formation, of Pennsylvanian age, to the Dakota (?) sandstone, of Upper Cretaceous age.

Most of the sedimentary rocks are strongly metamorphosed in the central part of the district, where igneous rocks are most abundant. Because of this metamorphism, it is difficult to recognize and differentiate some of the formations. The prevailing red colors have been bleached to light tones or to gray, shales and sandstones have been altered to form hornfels and dense quartzites, bedding has been obliterated locally, and in places it is even difficult to determine whether a rock is of igneous or sedimentary origin. "Contact-metamorphic" minerals, such as garnet, epidote, hornblende, specular hematite, and magnetite, have been developed in the calcareous beds. Fortunately, all the formations occur in normal development outside the district, notably along the Animas River (fig. 1). Studies of these unmetamorphosed rocks by Messrs. Williams and Galbraith and the writer yielded good marker beds, distinctive fossils and faunas, and other distinguishing characteristics for each formation. A sufficient number of these characteristics could be recognized or correlated with their metamorphic equivalents in the more highly metamorphosed parts of the region studied to make it possible to separate the formations even where they have been much altered.

Sedimentary Rocks of the La Plata District, Colorado

Age	Formation	Name used in older reports	Name in local use	Thickness (feet)	CHARACTER
Upper Cretaceous	Dakota(?) sandstone	Dakota sandstone	Dakota sandstone	100 — 300	Gray or brown sandstone with variable conglomerate at or near base. Carbonaceous shale partings at several horizons.
Upper Jurassic	Morrison formation	†McElmo formation	McElmo formation	400 — 500	Alternating friable fine-grained yellowish or gray sandstones and variegated shales. Largely altered to dense light-colored quartzite and hornfels in central part of district.
		†La Plata sandstone	"Upper La Plata sandstone"	200 — 500	Massive friable white sandstone, distinctly cross-bedded. Altered to hard white to brownish quartzite in central part of district.
			"Middle La Plata shale"	25 — 100	Alternating pinkish to red shales and friable white or light-colored sandstones. Same character as †McElmo formation where metamorphosed.
			"La Plata limestone"	½ — 8	Medium-gray to black massive unfossiliferous limestone. Locally replaced by pyrite; elsewhere in central part of district altered to garnet, epidote, specular hematite, and other "contact-metamorphic" minerals.
	Entrada sandstone		"Lower La Plata sandstone"	170 — 200	Massive friable white sandstone, distinctly cross-bedded. Same character as "Upper La Plata sandstone" where metamorphosed.
	Dolores formation	Dolores formation	Dolores formation, including Bay City lime of miners at or near base	250 — 650	Salmon-pink to bright-red mudstones and fine-grained sandstones. Several beds and lenses of fine limestone and shingle conglomerate at or near base. Same character as †McElmo formation where metamorphosed. Limestone conglomerate beds commonly altered to "contact-metamorphic" minerals but retain distinctive texture.
Jurassic(?) and Upper Triassic	Cutler formation	Cutler formation	Cutler formation	1500+	Alternating dull-red arkosic sandstones, conglomerates, limy shales, and mudstones. Same character as †McElmo formation where metamorphosed. Nodules of limestone unaltered in places, elsewhere represented by nodules of garnet, epidote, etc.
Permian	Rico formation	Rico formation	Rico formation	100 — 250	Dull-red shales, sandstones, and thin sandy fossiliferous limestones. Same character as †McElmo formation where metamorphosed. Where exposed on Lewis Creek and La Plata River limestone beds are essentially fresh and contain recognizable fossils.
Pennsylvanian	Hermosa formation	Hermosa formation	Hermosa formation	2800±	Alternating green to gray and occasionally dull-reddish sandstones, shales, and fossiliferous limestones. Only the upper 500 feet is exposed within the La Plata district. Locally the limestones are marbleized; otherwise alteration is of same character as that of Rico formation.

†Indicates that the name is now discarded for use in the classification of the United States Geological Survey.

Hermosa Formation

General features.—The Hermosa formation, which is typically exposed along Hermosa Creek and the Animas River (fig. 1), is a thick series of interbedded sandstones, grits, shales, limy shales, and limestones. Many of the beds of limestone and limy shale contain abundant Pennsylvanian fossils. The Hermosa is underlain by the Ouray limestone, of Devonian age, and possibly by the Leadville limestone, of upper Mississippian age. It is overlain by the Rico formation.

The Hermosa is about 2,800 feet thick on the Animas River and appears to be roughly divisible into six lithologic parts. The lowest of these is 100 to 150 feet thick and is made up of dense light- to dark-gray or blue limestone in thick beds, with which are interbedded a few thin beds of maroon mudstone and reddish sandstone. The limestones, some of which are fossiliferous, are poorly exposed in most places and weather to form somewhat steeper slopes than those formed by the rocks which immediately overlie them.

The second part of the formation is about 450 feet thick and weathers to form comparatively smooth slopes. The lower half of it, which is very poorly exposed in most places, is probably made up in large part of shale. The upper half is composed of alternating thin beds of greenish shaly sandstone, arkosic sandstone, and green, maroon, and black shales. A few beds of limestone from 1 to 2 feet thick are interbedded with the shales.

The third part of the formation, about 300 feet thick, weathers to form prominent cliffs and benches. It is characterized by thick beds of greenish and brownish sandstone and grit, some of which are conglomeratic. A few thin shaly beds occur between the sandstones, and there are several 4- to 12-foot beds of dark-blue to black fossiliferous limestone.

Black bituminous shale containing one or more thick beds of gypsum and a few thin beds of fossiliferous lime-

stone characterizes the fourth part, which is about 1,250 feet thick. The rocks weather to form smooth slopes in general. Thick green micaceous and shaly sandstones occur near the base of the black-shale series.

The fifth part of the Hermosa section is about 450 feet thick. The lower third weathers to form slopes that blend into those of the underlying part, but the upper two-thirds commonly forms prominent cliffs and steep-walled box canyons. This part is characterized by the presence of several beds of blue-gray fossiliferous limestone from a few inches to 10 feet thick and by an almost equal development of thick maroon arkosic grits and sandstones and of red and maroon shales, mudstones, and limy shales. Exclusive of the limy shales and mudstones, a total of 21 feet of limestone was measured in this part of the section. Most of the grits and sandstones are coarse-grained, and some of them are conglomeratic.

The uppermost part of the Hermosa formation, about 250 feet thick, is marked by dull-red or maroon colors in contrast to the grayish, brownish, or greenish colors of the lower beds, by the absence of thick beds of limestone, and by the predominance of shales and mudstones rather than of grits and sandstones. The top of the formation is marked in the sections examined by a 25-foot zone of interbedded shale and fossiliferous limestone, underlain by a 50-foot bed of massive medium-grained arkosic sandstone.

Hermosa formation in the La Plata district.—Within the La Plata district known exposures of the Hermosa formation are confined to a comparatively small area in the central part of the mountains. It is also possibly exposed along Junction Creek and its tributaries (fig. 1), but this area has not yet been mapped. The formation crops out along the bed and lower valley walls of the La Plata River not far from the center of the La Plata uplift and extends up Lewis Creek a little more than one mile (pl. 1). The relations are somewhat obscured by the presence of porphyry sills and by lack of good exposures. Some-

what less than 500 feet of beds of the upper part of the Hermosa are exposed in this area. These beds consist in large part of highly silicified mudstones and sandstones which are indistinguishable from many of the overlying Rico and Cutler beds, but two or three beds of light-gray limestone, which reach a maximum thickness of about 5 feet and contain characteristic Hermosa fossils are exposed in several places. The highest horizon at which Hermosa fossils were obtained was mapped as the top of the formation. Where no exposures of fossiliferous beds were found, however, the local top of the formation was taken just above the top of a thick bed of arkosic sandstone similar to that which occurs near the top of the Hermosa along the Animas River.

Many of the limestone beds are surprisingly fresh and unaltered, in view of the rather extreme silicification of all other beds in the section, and in at least one place on the road up Lewis Creek determinable fossils occur in a limestone at its contact with the top of a porphyry sill.

Ore deposits in the Hermosa formation.—With the exception of the Gold King mine, the lower levels of which must be in Hermosa rocks, no ore deposits are known in the Hermosa formation. The sandstone and shale beds of the Hermosa are so similar to those in the overlying Rico and Cutler beds that it seems reasonable to suppose that they would form equally favorable wall rocks for fissure veins, particularly in the areas where the rocks are silicified. Inasmuch as the Hermosa limestones are the chief ore-bearing beds in the neighboring camp of Rico, the possibility of finding replacement ore bodies in the limestones at depth in the La Plata district is worth consideration. The limestone beds are in large part rather pure, dense light-gray to blue-gray rocks and would appear favorable to partial or complete replacement by ore-bearing solutions. No limestones were recognized in the deeper Gold King workings, and no replacement bodies have been found. The outcropping limestones along Lewis Creek are fresh and unaltered,

but this may be due to the fact that there are but few ore-bearing veins in the immediate area rather than that the limestones are unfavorable host rocks for ore deposits. Some years ago a diamond-drill hole was sunk in the bed of the La Plata River about half a mile south of the town of La Plata (pl. 1) for the purpose of prospecting the Hermosa formation. All the few known veins in the vicinity of this drill hole have been relatively unproductive, and it is therefore not surprising that the limestone beds penetrated by the drill were not mineralized. Most of the limestone had been altered to marble, however. The absence of base-metal replacement ore bodies in the Hermosa cannot be regarded as proved until more prospecting is done in areas of known mineralization. One such area is in the vicinity of the present Honey Dew mine (pl. 1), where closely spaced eastward-trending veins cut a thick porphyry sill and the overlying basal beds of the Cutler formation. The vein matter is made up of quartz with varying amounts of galena, chalcopyrite, and pyrite. This is the only area in the district where base-metal ores are known to occur at the surface in any considerable quantity, and in view of the fact that the top of the Hermosa formation must be less than 300 feet below the surface some deep exploration with a view toward proving or disproving the presence of ore in the limestones would appear advisable.

Rico Formation

In its type locality at Rico the Rico formation consists of about 300 feet of chocolate-brown to dark-maroon sandstones and conglomerates with intercalated shales and sandy fossiliferous limestones. [3]Along the Animas River the strata here assigned to the Rico are only about 100 feet thick, but there is considerable uncertainty as to the position of the upper contact. The beds in the lower 70 feet are poorly exposed but appear to be made up largely of red or maroon shales. The upper 30 feet of beds are red mudstones inter-

[3]Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colorado: U. S. Geol. Survey 21st Ann. Rept., pt. 2, pp. 59-66, 1900.

bedded with thin reddish shaly or sandy limestones. Some of these limestones contain fossils that are probably of Rico age. The fossils are in large part preserved in white calcite, which causes them to stand out in striking contrast to the red matrix. One or more beds of greenish-gray fine-grained sandstone occur in the section, but the Rico is predominantly mudstone and sandy or shaly limestone.

Within the La Plata district the Rico formation is exposed in the valleys of Junction Creek and of the La Plata River. In the La Plata Valley (pl. 1) it is about 250 feet thick and, although poorly exposed, in general appears to have the same characteristics as it does along the Animas River. The beds are relatively fresh along Amethyst Creek and in and near the Gold King mine, but elsewhere they are silicified, and it is only rarely that fossiliferous beds can be found. In field mapping the top of the formation was taken at the highest fossiliferous bed.

There is considerable doubt as to the true character and age of the Rico formation. After a brief study of the fossil collections made from exposures in the district and on the Animas River, Mr. Williams wrote as follows:[4]

"The conclusions reached from the above study are: As the Rico and Hermosa faunas are now interpreted, (1) the zone identified in the field as Rico along Amethyst Creek, in the La Plata area is Rico; (2) the zone identified as Rico along Junction Creek is Rico; and (3) Rico is probably present along the Animas Valley but no substantial faunal evidence for this conclusion is contained in our collections of 1935.

"In evaluating the significance of the determinations, one must take into consideration the haste of the study and in addition, the lack of any well-digested information regarding the relationships of the Rico and upper Hermosa deposits. Also, one must consider the lack of any really substantial basis from invertebrate fossils for calling the Rico Permian. The Rico faunas as currently interpreted differ from upper Hermosa faunas chiefly in the greater number and variety of pelecypods, gastropods, and other mollusks and in the absence of any number and of certain species of brachiopods. These differences may well be due to facies influences rather than to an age distinction. Their true significance should be more carefully worked out, both in the field and in the laboratory, on a regional basis before we can be very confident that the faunas referred to the Rico are everywhere younger than other faunas referred to the Hermosa. Published lists of species from the Rico lack many of the Hermosa brachiopods and contain four or five pelecypod species that are more characteristic of beds referred to Permian in Kansas and Nebraska than of Pennsylvania beds, but the identification of some of the pelecypods is based on incomplete material, and some of the beds in Kansas and Nebraska are of disputed age. There is, then, among published articles on the larger invertebrate fossils, some evidence on which to base a reference of the Rico to the Permian and hence to refer some collections to an age younger than any of the Hermosa, but this evidence is very slender and is shown only in the most complete collections."

[4] Williams, J. S., letter of March 3, 1936.

The rocks mapped as Rico on plate 1 form a recognizable stratigraphic unit characterized by red colors, by an abundance of interbedded thin fossiliferous limestones and red shales or mudstones, and by a paucity of coarse sandstones or thick limestones.

The Rico beds are similar in general to those of the overlying Cutler formation, and the ore deposits they contain are of the same character as those in the Cutler. (See p. 12.) The only deposits in Rico beds that were seen are those of the Gold King mine and of the Lucky Strike prospect on the west side of the La Plata River about 1,000 feet south of Basin Creek (pl. 1).

Cutler Formation

The Cutler formation, of Permian age, consists of 1,500 feet or more of mudstones, shales, sandstones, grits and conglomerates. The formation is underlain by the fossiliferous Rico beds and is overlain by the Dolores formation. Dull-red and maroon colors prevail in the fresh rocks, though some beds are brownish or greenish. No true limestones have been observed, but most of the shaly beds are somewhat limy, and in many places the lime carbonate is segregated into nodular masses of relatively pure limestone. Grits and sandstones are more abundant in the lower half of the formation, and conglomerates are almost entirely confined to the lower half. No subdivision of the Cutler appears feasible at present.

The Cutler crops out over a large area in the central part of the La Plata district and has the broadest distribution of all of the sedimentary rocks shown on plate 1. Where the rocks are altered the prevailing red colors are bleached to dull-gray tones, and silicification is a prominent feature. Limy nodules are unaltered in many places, but elsewhere the limestone has been converted to a variety of "contact-metamorphic" minerals, of which garnet, epidote, hornblende, and specular hematite are in general most abundant.

The Cutler beds are soft and yielding where unaltered, and, as they do not hold open fractures, they are unfavorable wall rocks for ore deposits. Where metamorphosed to quartzites or hornfels, however, the sandstones and shales are very competent and break with open fractures that allow the passage of ore-bearing solutions. In the central part of the district, therefore, and in other places where the beds have been similarly altered the Cutler beds serve in general as relatively favorable wall rocks for ore deposits. The Gold King and Neglected mines are among those which have produced ore from veins in this formation.

Dolores Formation

The Dolores formation, of Jurassic (?) and Upper Triassic age, is about 650 feet thick on the Animas River and between 500 and 600 feet in the area shown on plate 1, although Cross states that the beds which are now referred to the Dolores formation are only 250 feet thick along the East Mancos River.[5]

The formation is made up in large part of mudstones and shales with a few sandstones. The color of the unaltered rocks, which is commonly distinctly brighter than that of the underlying Rico and Cutler beds, ranges from salmon pink through various shades of red and purplish red to maroon. The most distinctive difference of the Dolores formation from the Cutler is the presence of thin beds and lenses of limestone conglomerate. These members are made up of rather angular dense bluish limestone, set in a matrix of earthy, sandy limestone. Small flattened pebbles of shale are not uncommonly present, and fossil bones and teeth of dinosaurs, which have led to the term "saurian conglomerates" for the enclosing rocks, are widespread but nowhere abundant in the exposures examined. The beds of limestone conglomerate are commonly less than 1 foot and in few places more than 5 feet thick, and most of them are lenticu-

[5]Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), p. 3, 1899 [1901].

lar. Though two or three such beds occur near the top of the Dolores, they are best developed in the lower part, particularly in the lower 100 feet. The local term "Bay City lime" appears to have originally been applied to the limestone conglomerate zone at or near the base of the Dolores, but it has since been used for almost any limy beds in the district except the "La Plata limestone."

In field mapping the base of the Dolores was taken at the lowest horizon at which the limestone conglomerates appear, as there are no other certain distinguishing characteristics between the upper part of the Cutler and the Dolores.

In the central part of the La Plata district the Dolores beds are metamorphosed to hard, dense hornfels or to fine-grained quartzite. The limestone conglomerate beds have shared in the metamorphism and are in many places represented by beds and lenses of contact-metamorphic silicates, such as garnet and epidote. In some places, however, as in the vicinity of the Bay City mine on the La Plata River south of the area shown on plate 1, the limy beds are partly or completely replaced by auriferous pyrite. Elsewhere they are replaced by magnetite or by specular hematite. Even where the beds have undergone extreme metamorphism, however, they commonly retain a distinctive conglomeratic or nodular texture and are thus of great value as marker beds.

The shaly nature of most of the Dolores beds has prevented the formation of open fractures and even where the beds have been silicified they do not appear to be particularly favorable wall rocks for ore deposits. Locally some ore is found in veins in the Dolores, as in the upper workings of the Cumberland mine and in one of the stopes of the Idaho mine, but even there the veins tend to become narrower than they are in the overlying sandstone formations or even in the underlying Cutler strata. In many places wide strong veins in the Entrada ("Lower La Plata") sandstone pinch out to mere irregular cracks where they enter

the Dolores formation. The limestone conglomerate beds are locally replaced by ore minerals along or near ore-bearing veins and are therefore of considerable economic importance.

Entrada Sandstone

The Entrada sandstone, formerly known as and still locally called "Lower La Plata sandstone," is of Upper Jurassic age and ranges from 170 to 200 feet thick. It is one of the most distinctive and easily recognized formations in the district and is of great economic importance.

The lower 50 feet of the Entrada consists of gray to pinkish or brownish-gray sandstone, above which are massive beds of somewhat friable cross-bedded white sandstone with a few very thin shale partings in places. The sandstone weathers to form almost vertical cliffs that stand out in striking contrast to the rounded or terraced slopes assumed by the red beds below it. A distinctive feature of the Entrada is that the sandstone is largely made up of rounded relatively coarse grains of quartz, in the interstices of which are much finer sand grains.

The contact between the Entrada and the underlying Dolores is difficult to draw exactly, because in some places the uppermost bed of the Dolores is a massive fine-grained salmon-pink sandstone. Elsewhere this bed is overlain by a few feet of red shale, succeeded by typical Entrada sandstone. In field mapping the base of the formation was taken at the lowest white sandstone that is made up of sand grains of two sizes. This sandstone lies above either the reddish shale or the pink somewhat shaly sandstone of the uppermost Dolores beds. The upper limit of the Entrada is marked everywhere in the La Plata Mountains by the basal limestone of the Morrison formation locally called "La Plata limestone."

In the central part of the district, notably on Jackson Ridge and near Diorite, Spiller, and Babcock Peaks (pl. 1) the Entrada has been metamorphosed to a hard light-colored

quartzite which weathers into angular blocks and presents the appearance of weathered porphyry when viewed from a distance.

Whether fresh or metamorphosed the Entrada breaks in open fractures and so makes a very favorable host rock for ore deposits. Most of the ore produced from the Idaho mine and some of that from the May Day mine came from deposits in the Entrada. Other deposits in this formation have been found in the Jumbo, Incas, Lucky Discovery, and Century mines.

Morrison Formation

The Morrison formation, of Upper Jurassic age, includes the upper part of the La Plata sandstone and the McElmo formation as the terms were used in older reports and as they are still used locally. The whole formation ranges from about 700 to 1,000 feet in thickness and is a complex of alternating light-colored sandstones and variegated shales with some limy beds.

The basal member of the Morrison, which overlies the Entrada sandstone, is a thin, dense dark-blue or gray limestone, locally called "La Plata limestone." It is from 6 inches to about 8 feet thick within the district, with an average of 4 to 5 feet. Near the center of the district the limestone is replaced by "contact metamorphic" silicate minerals or, as in the vicinity of the "Doyle" (Hesperus) mine (pl. 1), by gold-bearing pyrite; elsewhere it is fresh or is altered in the vicinity of veins to a soft black earthy material.

Above the limestone is the so-called "Middle La Plata shale," which ranges from 25 to nearly 100 feet in thickness and consists of light-colored pinkish or greenish shales and sandstones in lenticular beds. Flakes of bright-green shale and small grains of carnelian are distinctive features of this zone, though it can be distinguished only with difficulty from the "McElmo" shales that lie above the "Upper La Plata sandstone."

Above the shale zone is the "Upper La Plata sandstone," which ranges from about 300 to nearly 500 feet in thickness and is made up in large part of massive white cross-bedded sandstone that closely resembles the Entrada sandstone. Except for stratigraphic position, no certain means of differentiation between the Morrison and Entrada sandstones have been found, but the Morrison contains in places a few minute grains of red or orange carnelian, and owing to the fact that it is somewhat more friable, it tends to weather more readily and hence does not commonly form the abrupt cliffs that characterize exposures of the Entrada sandstone. Blocks of "Upper La Plata sandstone" cover the slopes in many places and obscure or cover outcrops of the "Middle La Plata shale." Numerous partings of shale occur in places in the "Upper La Plata sandstone," and locally, notably on the southwestern part of Jackson Ridge southwest of the "Doyle" (Hesperus) mine (pl. 1), shale makes up nearly half of the member. In such places the slopes blend into those of the underlying and overlying shaly zones, and differentiation of the members is difficult. Like the Entrada sandstone the "Upper La Plata sandstone" is quartzitic in the central part of the district and weathers into angular blocks that resemble porphyry from a distance.

Above the "Upper La Plata sandstone" occur the shales and sandstones of the so-called "McElmo formation," now included as the upper part of the Morrison. This group of beds is 400 to 500 feet thick and is made up of greenish and brownish thin-bedded shales and sandstones. Flakes and lenses of brilliant green shale are widespread and locally abundant and serve to distinguish the member from all others except the "Middle La Plata shale."

The Morrison formation is one of the most productive in the La Plata district, and many ore deposits have been found in it. In addition to being an unmistakable key bed, the "La Plata limestone" is very favorable for ore deposits. Some of the richest telluride ores in the district have been found as replacement bodies in the limestone. Almost all

such ore bodies are closely associated with crosscutting ore-bearing veins. Near the central part of the district the limestone has been locally replaced by gold-bearing pyrite. The largest known deposit of this type is that of the "Doyle" (Hesperus) mine. The shaly nature of the "Middle La Plata shale" renders it unfavorable to ore deposits, and but little ore has been found at this horizon, even where the member is traversed by fissures that contain rich deposits in the sandstones both above and below. As would be expected from its similarity to the Entrada sandstone, the "Upper La Plata sandstone" is a very favorable ore bearer. A large part of the ore produced by the May Day, Lucky Discovery, Red Arrow, and other mines has come from veins in this rock. In general the "McElmo" shales are not particularly favorable to ore deposition, and the base of the member commonly marks the upward extent of ore shoots. This is particularly noticeable in the Red Arrow mine. Some telluride ore is reported to have been produced from "McElmo" beds in the May Day mine, however, and gold-bearing pyrite occurs in the Timberline and other veins on Jackson Ridge in highly silicified "McElmo" shales.

Dakota (?) Sandstone

The Dakota (?) sandstone, of Upper Cretaceous age, is the youngest sedimentary formation within the area shown on plate 1. It is 100 to 300 feet thick and consists largely of gray or brownish sandstone with a local conglomerate that varies in thickness and contains small chert pebbles at or near the base. Carbonaceous shale partings and thin beds of impure coal occur at several horizons. The formation is exposed over a broad area on the outskirts of the La Plata district, but in the area shown on plate 1 only a few small remnants occur. These are all on or near Jackson Ridge. No ore deposits are known to occur in the Dakota (?) sandstone. Rich "float" ore is reported to have been found, however, in fragments of sandstone and carbonaceous shale of definite Dakota (?) aspect.

Igneous Rocks

The igneous rocks of the La Plata Mountains are all of Tertiary age and all intrusive. They vary widely in composition and occur as irregular stocks, dikes, and sills or sheets.

Diorite and Monzonite Porphyry

A large number of closely related rocks have been grouped as diorite and monzonite porphyry for purposes of mapping. Most of the rocks included in this group are intermediate between the two extremes of diorite porphyry and monzonite porphyry and resemble each other so closely that field distinctions are difficult or impossible. All the rocks of the group are porphyritic and exhibit many phenocrysts of white feldspar and of hornblende set in a gray to brown dense groundmass. Both texture and grain size differ markedly in different masses and locally even within a single mass, but the mineral composition of the group is relatively constant.

The porphyry occurs as stocks, sills, and dikes and is exposed over a wider area in the central part of the district than any other igneous rock type. Parts of two irregular crosscutting, stocklike bodies of porphyry are shown on plate 1 in the vicinities of Gibbs Peak and Silver Mountain, and several similar but even more irregular masses are shown by Cross in the area south of Deadwood Mountain and Silver Mountain.[6]

Sills or sheets of porphyry are very abundant throughout the greater part of the La Plata district. They range in thickness from a few inches to 300 feet or more. Some have a nearly uniform thickness throughout their horizontal extent; others pinch and swell and locally assume laccolithic form and proportions. The sills become fewer and individual sills commonly thinner away from the center of the uplift. Most of the sills have been squeezed in between the strata of sedimentary rock, but some of them cut across the

[6]Cross, Whitman, op. cit. (La Plata folio), geologic map.

beds. As a result, a thickening of the sills has in places resulted in the development of local domelike folds in the sedimentary rocks; elsewhere thick sills—for example, the one in the bed of the La Plata River near the Gold King mill—have exerted little or no influence on the regional structure.

Dikes of porphyry of varying thickness and extent occur throughout the district. Most of them are very similar to the sill rocks in general make-up and connect different sills. They probably represent the channels through which the magma flowed. The stocks, dikes, and sills appear to be closely related, and there is little doubt that all are nearly contemporaneous and that the porphyry stocks represent the original conduits through which the magmas that formed the sills and dikes moved.

The porphyries appear to be somewhat older than the syenite, monzonite, and diorite stock rocks and to be cut by them. As is noted below, however, the stocklike masses grade into porphyry sills in places and are apparently rather closely related to them.

The intrusion of the porphyritic rocks was not accompanied by any considerable metamorphism of the country rocks, as is shown by the presence of sills between unaltered beds of sedimentary rock. This feature is noticeable in Cumberland Basin, but is even more striking in the eastern part of the district. The porphyry sills do not appear to bear any genetic relation to the ore deposits, and their chief economic importance is believed to lie in the fact that they are brittle rocks and break with open fractures. As wall rocks they appear to be no more favorable to ore deposits than well-silicified sedimentary rocks. Porphyry dikes, on the other hand, are of considerable importance. The enclosing rocks along dikes are commonly rather highly silicified for a short distance away from the dikes, and fissures that intersect dikes or trend parallel to them are likely to be well mineralized on this account. A further relationship lies in the fact that ore-bearing solutions very com-

monly follow the same channels as those previously followed by the dike magmas. The Neglected vein is an outstanding example of an ore deposit associated with a porphyry dike.

Syenite and Syenite Porphyry

Two comparatively large stocklike bodies of augite syenite occur in the southern part of the area shown on plate 1. The rock is nearly everywhere altered, and its relations with other igneous rocks are obscure. The syenite is gray or pinkish and crystalline, though in most places the alteration of the feldspars obscures individual grains. According to Cross,[7] "the feldspars of these rocks are very largely alkali feldspars, and orthoclase, anorthoclase and microperthite are variably developed in the different specimens examined."

In many places the augite of the original rock is represented by ocherous to dark-brown spots of limonitic material, but where preserved, it occurs as dark-green irregular prisms that are greatly subordinate in amount to the feldspars. Quartz is present in small amounts throughout the rock.

A few sills and dikes of coarse syenite porphyry or of somewhat closely related rock crop out in the vicinity of Jackson Ridge, and others are known to occur in parts of the district that have not yet been mapped.[8] In the rocks seen near Jackson Ridge the presence of very large phenocrysts of plagioclase feldspar is a conspicuous feature.

As shown on plate 1, the syenite appears to be younger than the diorite-monzonite porphyry sills and stocks, but its relationship to the stocks of diorite and monzonite and its genetic significance with regard to the ore deposits are as yet unknown.

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[7]Cross, Whitman, op. cit. (La Plata folio), p. 6.

[8]Cross, Whitman, op. cit., p. 7, geologic map.