Manganese Deposits in the Drum Mountains, Juab and Millard Counties, Utah

By MAX D. CRITTENDEN, Jr., JOHN A. STRACZEK, *and* RALPH J. ROBERTS

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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CONTENTS

ILLUSTRATIONS

[Plates 20–24 are in pocket]

TABLES

CONTRIBUTIONS TO ECONOMIC GEOLOGY

MANGANESE DEPOSITS IN THE DRUM MOUNTAINS, JUAB AND MILLARD COUNTIES, UTAH

By Max D. Crittenden, Jr., John A. Straczek, and Ralph J. Roberts

ABSTRACT

The Drum Mountains are in west-central Utah 30 miles northwest of Delta, between the Sevier Desert on the east and Whirlwind Valley on the west. It is a typically barren desert range comprising a westward-tilted structural unit in which is exposed as much as 9,000 feet of quartzite (Cambrian and Precambrian?) and 3,000 feet of carbonate rocks of Cambrian age. These beds, which strike northward and dip west, are cut by myriad east- to northeast-trending faults with displacements of a few feet to a few thousand feet. Quartz monzonite dikes, pebble dikes, and vein deposits are present locally along the faults. The Cambrian rocks are overlain unconformably by volcanic rocks of probable Tertiary age.

Bodies of manganese carbonate ore were formed by replacement of two 20-foot beds of impure dolomite at the base of the sequence of carbonate rocks, along their intersection with certain preore faults. The feeding fissures locally contain veins in which rhodochrosite is associated with base metal sulfides. Downward-moving meteoric water has oxidized the ore bodies to a depth of 100 to 200 feet except where they are sealed off by structural or stratigraphic traps.

From 1925 to 1953, 72,462 long tons of manganese ore with an average grade of about 25 percent Mn were shipped.

INTRODUCTION

The Drum Mountains are in west-central Utah, about 100 miles southwest of Salt Lake City and 30 miles northwest of Delta (fig. 47). They occupy an area of 75 square miles on the west side of the Sevier Desert and form a southward continuation of the Thomas and Dugway Ranges. Whirlwind Valley to the west separates the Drum Mountains from the House Range.

The Detroit mining district with its abandoned settlement called "Joy" is near the center of the Drum Mountains, and most of the mines are in the higher part of the range a mile or two southeast. The region is barren of vegetation; and except in the bottom of washes rock exposures are almost continuous. The average rainfall

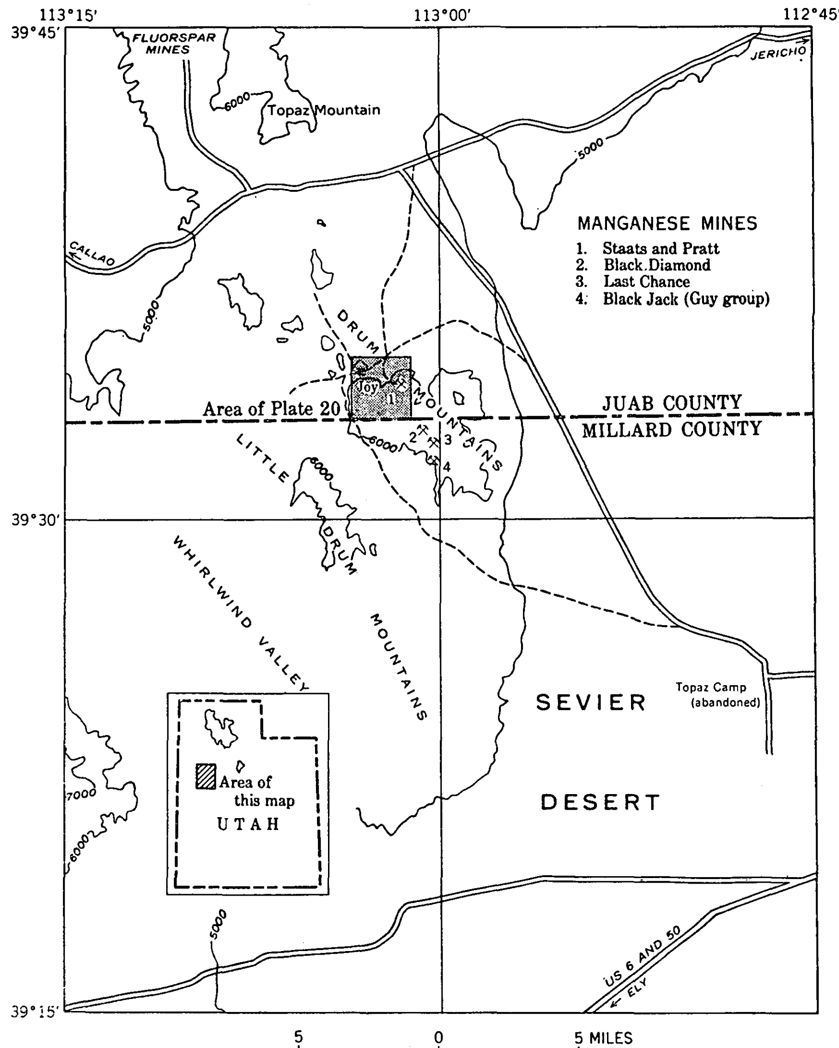


FIGURE 47.—Index map of western Utah showing location of the Drum Mountains, Utah.

is about 7 or 8 inches per year and there are no permanent streams. A small highly alkaline spring at Joy and one at Freighters Well about a mile northwest of Joy supply sufficient water for mining, but drinking water is usually hauled from Delta.

The principal manganese deposits are in the Staats and Pratt mines, in the southeast quarter of section 25, T. 14 S., R. 11 W., about a mile east-southeast of Joy (pl. 25*A*). The gold mines, around which early activity in the district centered, are mostly south of the manganese mines, and 1 to 3 miles south of Joy (pl. 20).

The nearest shipping point is the town of Delta, on the Union Pacific Railroad. Paved roads extend northwest from Delta for a distance of 17 miles, and in 1944 a Class II access road was completed from there to the Staats and Pratt mines, a distance of 25 miles. Unimproved dirt roads extend around and into the range.

Geologic study, exploration, and sampling of the Staats and Pratt manganese mines was conducted as a joint project by the U.S. Geological Survey and the U.S. Bureau of Mines as a part of the Strategic Minerals Investigation for 1941. Additional drilling was done by the Bureau of Mines between February and May, 1945 (King, 1947). This report is a summary of the geologic information revealed by the exploration, and by mining activity during this entire period. The geologic map of the Drum Mountains southeast of Joy (pl. 20) was made by R. J. Roberts, M. W. Cox, and J. A. Straczek during the summer and fall of 1941, and was extended in 1945 by M. D. Crittenden. The map of the Pratt and Staats mine area (pl. 21), the detailed maps of the Staats mine, and sections through the original drill holes were made by J. A. Straczek during 1940 and 1941, and by M. W. Cox in the summer of 1941. The recent drill holes were logged, and new workings were mapped by M. D. Crittenden in 1945. The following report, though written by Crittenden, is based in large part on the work of Straczek, Roberts, and Cox.

Metallurgical tests of the ore from these properties are described by Zimmerly, Vincent, and Schack (1942), and the results of diamond drilling are described by King (1947).

The writers take pleasure in acknowledging the hospitality and assistance of mine owners and operators in the area, particularly Mr. Fred Staats, Mr. L. W. Rassmussen, and Mr. and Mrs. Leslie Price. To W. H. King, Richard Lee, and Cyrus Greenhalgh of the U.S. Bureau of Mines, the writers extend thanks for many favors they received during the fieldwork. The original work was under the supervision of S. G. Lasky and D. F. Hewett of the U.S. Geological Survey; all of the fossils were identified by Allison R. Palmer.

GENERAL GEOLOGY

The Drum Mountains are a westward-tilted block in which are exposed as much as 9,000 feet of quartzite, probably including some beds of Precambrian age at the base, and 3,000 feet of carbonate rocks, all of Cambrian age. Quartz monzonite dikes, pebble dikes, and veins cut these rocks following east- to northeast-trending faults. Around the periphery of the range, volcanic rocks of Tertiary age rest on the older rocks.

The manganese ores are contained in hydrothermal deposits formed by replacement of dolomitic beds of manganese-bearing carbonates. The part of the ore near the surface has since been oxidized and locally enriched by the action of surface water. The ore is localized by faults and may be related in origin to dikes of quartz-monzonite porphyry.

The stratigraphy and structure of the area as a whole are described in the following paragraphs. The details of the occurrence and the control of the ore are described in the section on ore deposits. To avoid terms such as "mineralized rock" or "manganiferous material," the term "ore" is loosely used throughout this section on geology and also in the sections describing the ore deposits and the mines. This does not necessarily imply that the material can be mined profitably at any particular price.

The present work is concerned with the rocks near the top of the quartzite, and near the base of the calcareous sequence. Consequently, this part of the section was mapped and studied in detail, whereas little was done in the upper part of the section. In mapping on a scale of 100 ft. to 1 in. it was desirable to use much thinner stratigraphic units than those to which names have been applied in the nearby House Range (Deiss, 1938; Wheeler, 1948). Consequently, the units used in this report are designated by lithologic terms and by numbers and letters, rather than by formational names. The lithology and thickness of the units mapped in the Pratt and Staats mine area and the correlation with the well-known Cambrian section in the House Range are shown in figure 48.

CAMBRIAN SYSTEM

PROSPECT MOUNTAIN QUARTZITE

The lowest stratigraphic unit exposed in the Drum Mountains is the Prospect Mountain quartzite, a thick sequence of white, pink, or gray medium- to coarse-grained crossbedded quartzite, interbedded with shale, pebbly quartzite, and a little conglomerate. On the surface these beds weather buff to reddish brown, and their abundant talus imparts these characteristic hues to much of the mountain block east of the area here described. Although only a few hundred feet of this unit are exposed within the areas of plates 20 and 21, it is estimated from aerial photographs that there may be as much as 9,000 feet from the top of the quartzite to the east edge of the range. The base is not exposed. The upper limit of the Prospect Mountain quartzite is drawn at the top of a massive 50-foot bed of maroon to pinkish-coarse-grained hematitic quartzite whose weathered surfaces range in color from red to almost black,

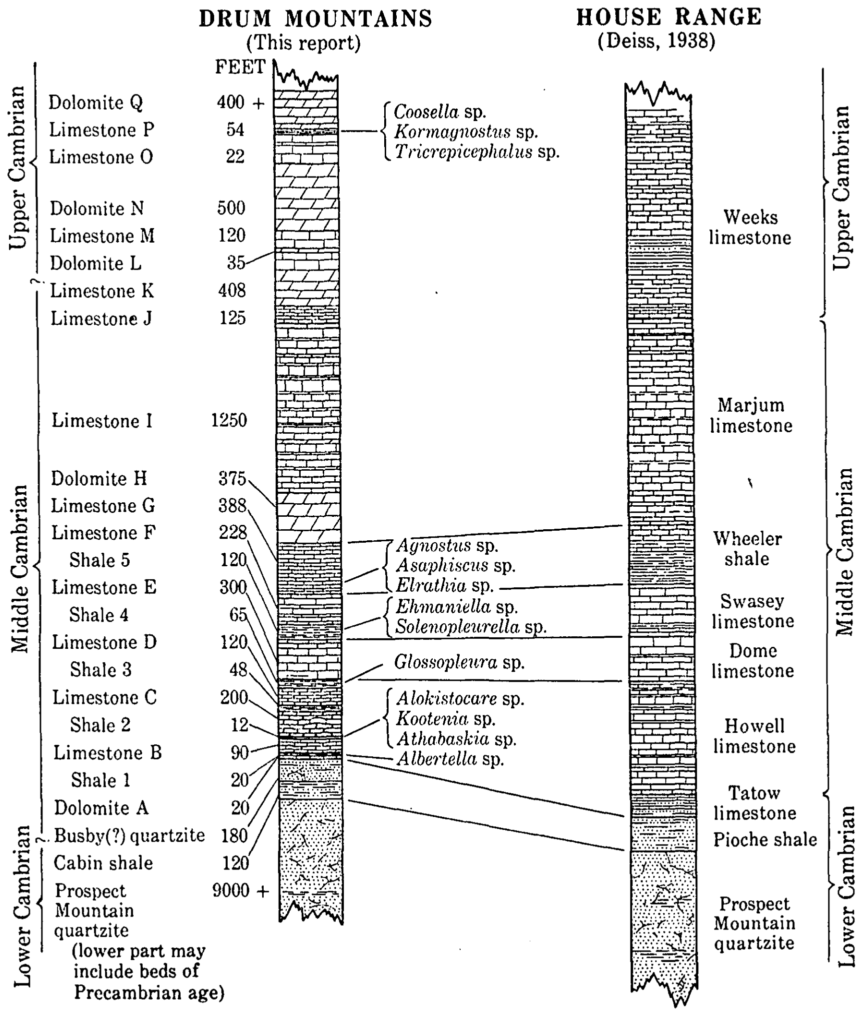


FIGURE 48.—Stratigraphic sections of rocks of the Drum Mountains and House Range, Utah. On the map of the Detroit district on a scale of 1:12,000 (pl. 20), members A to D and certain others have been grouped to form units more suitable to this scale.

and whose outcrops (pl. 25*B*) form a prominent stratigraphic marker throughout the north end of the range.

No fossils were found in the Prospect Mountain quartzite, though fucoid markings and scolithus are abundant in the uppermost beds. In the Pioche district, Nevada, this unit was presumed by Westgate and Knopf (1932, p. 6–10) to be Lower Cambrian because it grades into the overlying Pioche shale from which Lower Cambrian fossils were obtained. By analogy, the upper part of the Prospect Mountain quartzite in this area is referred to the Cambrian though the lowest fossils found here are in shale 1 and are Middle Cambrian. But the great thickness and the presence of shales near the east edge of the range suggest that the lower part contains beds of Precambrian age.

CABIN SHALE

The Prospect Mountain quartzite is overlain by 120 feet of olive-green to gray micaceous shale, sandstone, and quartzite that correspond in both lithology and position with the Cabin shale described by Nolan (1935, p. 6–7) at Gold Hill. The wavy surfaces of the thin sandy or quartzitic layers are commonly marked by worm tracks a few millimeters wide or by wormlike bodies as much as an inch thick. Ripple marks, crossbedding, and rain prints suggest accumulation in shallow water. The shales grade into quartzites both above and below.

Although rocks of this interval have been called Pioche by several workers (Walcott, 1908, p. 184, Wheeler and Steele, 1951, p. 35), the more restricted term Cabin is used here because the thickness in the Drum Mountains is only one eighth of that at Pioche, Nevada, (Westgate and Knopf, 1932, p. 9), and because both the Pioche shale and the Ophir formation include one or more beds of impure limestone that are lacking in this area.

No fossils have been found in the Cabin shale in this area, but its age is probably Early Cambrian or older, because *Albertella*, regarded by A. R. Palmer as of earliest Middle Cambrian age, occurs here in shale 1, nearly 200 feet above it. Thus, on the basis of both thickness and fauna, the Cabin shale appears to represent a much smaller time span than does the Pioche shale at the type locality, being equivalent in age to only the lower part.

BUSBY(?) QUARTZITE

The Cabin shale is overlain by 180 feet of white to gray fine- to medium-grained quartzite that corresponds in position with the Busby quartzite of the Gold Hill district (Nolan, 1935, p. 7–8) with which it is tentatively correlated. On plate 20 this unit and the Cabin shale are not distinguished from the underlying Prospect Mountain quartzite, except where the purple quartzite member has been mapped. On plate 21 the Busby(?) quartzite is divided into a lower member, 70 feet thick, consisting of medium-grained buff- to rusty-weathering white quartzite with some greenish-gray sandy shale and sandstone, and an upper member, 110 feet thick, consisting of tan fine- to medium-grained argillaceous sandstone or quartzite. Underground or in drill cores this rock is gray, but on the surface it weathers brown or olive green. Scolithus are abundant, but no other fossils were found.

DOLOMITE A

The gray sandstones and quartzites at the top of the Busby(?) quartzite grade upward into a zone of brown-weathering dolomite and dolomitic sandstone designated dolomite A. This unit, the lowest carbonate-bearing rock in the section, is best exposed on the surface along the side of a ravine about 700 feet east-southeast of the Staats mine, where its characteristic brown-weathering, somewhat rounded surfaces serve to distinguish it from the quartzites below, though the fresh rocks differ little, either in color or in resistance to erosion. Although the whole unit contains some dolomite, individual beds are lenticular and strongly cross-bedded, ranging in composition from shaly or sandy dolomite to almost pure quartzite. Rapid lateral variation is also evident even in the few hundred feet exposed. This, together with the similarity of the fresh rock, combine to make it difficult to recognize the unit with certainty in drill cores.

Both surface exposures and drill hole penetrations indicate that dolomite A maintains an average thickness of about 20 feet over most of the area of plate 21. In a few places, however, as at the head of the No. 6 shaft in the Pratt mine, it is entirely absent. The absence at that place is attributed to shearing out on a low-angle fault, but the possibility that the bed simply lenses out cannot be dismissed entirely.

SHALE 1

The brown-weathering impure dolomites of dolomite A grade upward into grayish-weathering shale and fine-grained shaly sandstone designated shale 1. This unit is both thinner bedded and less quartzitic than the lower Busby(?) quartzite, but near the top there is a persistent 1½ to 2-foot bed of sandstone or quartzite that is a convenient marker in underground workings and in drill holes. The thickness of shale 1 is usually very close to 20 feet.

The one collection of fossils that was obtained from this unit about 2 miles southeast of the Staats-Pratt mine area contained trilobites identified by A. R. Palmer as *Albertella* sp. The age of shale 1 is thus defined as very early Middle Cambrian. This form also occurs in the upper part of the Pioche shale at Pioche, Nevada.

LIMESTONE B

The lowest typical limestone in the Drum Mountains is the massive thick-bedded unit designated limestone B. It has at the base 10 to 12 feet of brown-weathering impure dolomite very similar in character to dolomite A. Like dolomite A, this horizon also contains important ore bodies both in the Staats and Pratt mines and farther south in the range. Underground and in drill holes the basal zone may be recognized by the presence of dolomite instead of limestone, and by increasing amounts of sandy or shaly impurities (table 3, F). Above this zone the rock is blue-gray limestone with abundant pisolites (*Girvanella* ?) or oolites, especially near the base.

Limestone B varies little in thickness from its average of 90 feet over the area of plate 21. The only trilobites obtained came from drill hole 22, which yielded trilobites assigned by A. R. Palmer to *Alokistocare* sp., *Zacanthoides* ? sp., *Athbaskia* ? sp., and an unidentified dolichometopid trilobite from depths of 118 to 126 feet (pl. 21, section *B–B′*) or 3 to 11 feet below the base of shale 2. The age of this unit is thus established as early Middle Cambrian.

SHALE 2

Above limestone B is a 10- to 14-foot unit here designated shale 2. On the surface it has the appearance of brown-weathering thin-bedded micaceous shale. In underground workings and drill holes it is black or greenish-gray, and is seen to consist of alternating beds of shale and shaly or calcareous sandstone.

LIMESTONE C

Shale 2 is overlain by 200 feet of thin-bedded bluish-gray, fine-grained limestone here referred to as limestone C. This unit is characterized by wavy argillaceous partings one-quarter to half an inch thick that weather brown and leach out on exposure forming slabby masses with irregular or wavy surfaces. In drill cores, the irregular wavy shale bands make recognition of this unit fairly easy.

Fossils are abundant in the lower few feet, and A. R. Palmer recognized *Athabaskia* sp., *Kootenia* sp., and *Alokistocare* sp.

SHALE 3

Shale 3 is a 48-foot unit consisting of greenish-gray to brown-weathering limy shale and shaly limestone. It is conformable with the units above and below. A persistent 2-foot bed of cross-bedded oolitic limestone about 27 feet above the base serves as a marker bed both on the surface and in drill holes.

LIMESTONE D

The unit designated limestone D consists of 120 feet of thick-bedded gray pisolitic and oolitic limestone with some inconspicuous shaly beds 70 to 90 feet above the base. No fossils were recognized.

SHALE 4

Limestone D is overlain by shale 4, a 65-foot unit consisting of thin-bedded shaly limestone with thin beds of purer fossiliferous limestone near the top. On the ridge 700 feet due south of the Staats mine these beds yielded a single collection reported by A. R. Palmer to contain *Glossopleura* sp.

LIMESTONE E

Above shale 4 is a 300-foot unit consisting of thick-bedded gray oolitic and pisolitic limestone with irregular white calcite mottlings. This unit, which we have named limestone E is correlated with the Dome limestone (Walcott, 1908, p. 9, 11; Deiss, 1938, p. 1145) of the House Range, both on the basis of thickness and of its position between the faunas of shales 4 and 4.

SHALE 5

A 120-foot zone of greenish-gray- to buff-weathering fossiliferous shale and shaly limestone here designated shale 5 crops out above limestone E. The uppermost beds near the Copperhead shaft (pl. 20) yielded *Ehmaniella* sp. and *Solenopleurella* sp. which suggests equivalence with part of the Swasey formation of the House Range.

LIMESTONES AND DOLOMITES F THROUGH Q

Above shale 5 nearly 4,000 feet of limestone and dolomite unbroken by mappable argillaceous units is exposed between the Staats-Pratt mine area and the volcanic rock and the alluvium at the edge of Whirlwind Valley. This sequence has been divided arbitrarily into 12 lithologic units designated F through Q. Although these units are persistent enough to be recognized easily over the area of plate 20, their usefulness as stratigraphic markers over a larger area is uncertain, and for this reason they are designated by letter rather than by formational names. The thickness as determined from the geologic map and the lithologic character of these units are briefly described in table 1.

Between shale 5 and limestone P, fossils are not abundant except for a zone of platy limestone in the lower part of limestone G, which contains a fauna believed to be equivalent to the Wheeler formation of the House Range (Walcott, 1908, p. 9–10).

Limestone P is a fossiliferous reddish-weathering platy limestone with tan or greenish shaly partings. It is well exposed near the road that borders the range southwest of Joy (pl. 20) where the forms *Coosella* sp., *Kormagnostus* sp., and *Tricrepicephalus* sp. were obtained by A. R. Palmer. On the basis of this fauna, the

TABLE 1.—*Lithology of higher stratigraphic units*

Unit	Thickness (feet)	Lithology
Dolomite Q	400+	Light- to medium-gray mottled dolomite and limestone, top not exposed.
Limestone P	54	Reddish-weathering thin-bedded limestone and platy sandstone. (*Tricrepicephalus*).
Limestone O	220	Thin- to thick-bedded dark-gray limestone, cut off by fault, thickness estimated. Locally twiggy-textured or conglomeratic beds; some dolomite.
Dolomite N	500	Thick-bedded massive gray dolomite, cut by fault; thickness estimated.
Limestone M	120	Thick-bedded massive dark-gray coarse-grained limestone, local twiggy structures.
Dolomite L	35	Brown-weathering pale-gray dolomite; 4 ft of dark-gray twiggy-textured limestone 11 ft above the base.
Dolomite K	408	Massive thick-bedded brown-weathering dolomite and dark-gray limestone; 55 feet of *Girvanella*-bearing dolomite at base, and locally higher; considerable cross-bedding throughout.
Limestone J	125	Thin-bedded white-weathering silty dolomite.
Limestone I	1,250	A strongly banded unit consisting of: (1) 10- to 60-ft layers of cliff-forming blue-gray limestone in 1- to 3-in beds with thin irregular wavy tan-weathering silty partings, and (2) 2- to 10-ft layers thinly laminated pale-gray dolomite; lower 500 ft all type (1) with abundant twiggy structures; oolitic and *Girvanella*-bearing at base.
Dolomite H	375	Massive brown-weathering, light gray coarse-grained dolomite; lenticular; average thickness estimated from map.
Limestone G	388	Thin-bedded platy- and pale-gray-weathering fine-grained black limestone with thin silty partings; very fossiliferous (*Agnostus* sp. sponge spicules, *Elrathia* sp.)
Limestone F	228	Thin-bedded to massive (2 ft) beds of dark-gray limestone with sparse, thin wavy partings; abundant twiggy structures, oolites and pisolites.

boundary between the Middle and Upper Cambrian (fig. 48) is believed to be only a short distance below limestone P.

The highest unit exposed near the north end of the range is designated dolomite Q. Aerial photographs of the area farther south suggest that beds somewhat higher in the section may be exposed there, and it is hoped that these beds may eventually be matched with those north of the Joy fault that are known to contain Ordovician fossils.

CORRELATION

The Cambrian rocks of the Drum Mountains can be correlated, at least in a general way, with those of the House Range, 15 miles to the southwest. Most of the units described there by Deiss (1938) and Wheeler (1948) can be recognized in the Drum Mountains, yet there are a few distinctive differences. Some of these differences are probably original, but others are more likely the result of extensive hydrothermal dolomitization.

The greenish micaceous worm-tracked shale beds that characterize the Pioche shale are 265 feet thick in the House Range, but only 120 feet thick in the Drum Mountains. For this reason, and because the shales are probably older than much of the Pioche of the type section, the term Cabin shale (Nolan, 1935) is applied in this area.

An upper quartzite corresponding to what is here called the Busby(?) was not distinguished in the House Range by either

Walcott or Deiss, but the term was applied by Wheeler (1948, p. 28–29) to the beds originally called the Tatow limestone by Deiss (1938, p. 1138–1139). Wheeler does not describe the unit however, and from Deiss's description it seems much more probable that the quartzites here called Busby(?) are equivalent to the upper sandy part of the Pioche of Deiss, and that his Tatow limestone of the House Range contains beds equivalent to the ore horizons dolomite A and limestone B of this report.

The Howell formation of Walcott (1908) and Deiss (1938) was subdivided by Wheeler (1948, p. 35–38) into a lower dark limestone called Millard, a medial light limestone called Burrows, and an upper dark unit called Burnt Canyon limestone. This three-fold division is not recognizable in the Drum Mountains because the medial pale limestones are entirely lacking, and the unit as a whole (dolomite A through shale 4) is proportionally thinner.

Limestone E is correlated with the Dome limestone of Deiss on the basis of thickness and lithology and because they both occupy a similar position between horizons containing *Glossopleura* and *Ehmania* faunas. A similar identity is indicated for limestone G and the Wheeler formation.

The upper part of the section in the Drum Mountains is characterized by a series of pale brownish-gray coarse-grained dolomites designated by the letters H, K, L, N and Q; which are interlayered with limestone units I, J, M, O and P. Although the dolomitic units can be recognized throughout the northern Drum Mountains, they are locally lenticular even there, and some of them are believed to be the result of hydrothermal dolomitization. It is not surprising therefore that they are not all recognized in adjoining less-altered areas. Thus dolomite H and limestone I together appear to be equivalent to the Marjum limestone. Surprisingly, however, the fine-grained thinly laminated white dolomites of limestone I are entirely absent from the Marjum, to judge from the descriptions of Deiss (1938, p. 1129–1132).

The only distinctly reddish sandy zone in the Drum Mountains, limestone P, appears here in the midst of a massive series of coarse hydrothermal dolomite, and it is therefore uncertain with which of several reddish sandy horizons in the House Range it should be correlated. Although it contains the only *Tricrepicephalus* discovered in the section, the absence of fossils in the massive dolomites below make it impossible to place the base of the Upper Cambrian closer than about 1,000 feet.

The boundary between Lower and Middle Cambrian is inferred to be a short distance below the *Albertella* bearing shale 1.

IGNEOUS ROCKS AND ASSOCIATED FEATURES

TERTIARY(?) VOLCANIC ROCKS

The Paleozoic sedimentary rocks of the Drum Mountains are overlain on the west and south by tuff, volcanic breccia, lava flows, and interbedded conglomerate that form the Little Drum Mountains. Most of the material has the composition of quartz latite or dacite, but some andesite and basalt are present both as pyroclastic rocks and flows. Rocks of this group also cover most of the area north of the Joy fault, but their relation to the topaz-bearing rhyolite of the Thomas Range was not determined. Mount Laird (pl. 20) appears to be an eroded quartz-latite plug that cuts through rhyolitic and andesitic flows and tuff.

The volcanic rocks crop out in a series of low hills along the west edge of the range (pl. 20), where they rest on a gently undulating surface which dips gently westward, and which cuts without interruption across all the faults within the bed rock. It is clear therefore that the volcanic rocks were erupted after the major period of faulting within the range. They are, however, cut and displaced by the Joy fault, and it is possible that the southwestward tilting of the volcanic rocks, and their consequent erosion from much of the range, may be a result of these fault movements. The volcanic rocks are also cut by one small pebble dike, which indicates that some explosive activity occurred later than the main period of eruption. Since the pebble dikes in the central part of the district are mineralized, it is evident that the mineralization also post dates the volcanic rocks.

TERTIARY(?) INTRUSIVE ROCKS

Dikes, sills, and small stocklike bodies of varying texture and composition are present throughout the Drum Mountains. They are most commonly intruded along faults, and have the form of steeply dipping dikes with local sills extending out along the bedding. The dikes range in size from a few feet to 1,500 feet long and from a few inches to 80 feet or more wide. Here and there small pipelike bodies have developed at fault intersections.

Where fresh, these dike rocks are typically dark gray, massive, and porphyritic with phenocrysts of feldspar, biotite, and hornblende up to half an inch in length. Moderately altered specimens are lighter in color, and with intense alteration become white and punky. Flow structure is obscure in small specimens but generally can be detected by the faint alinement of phenocrysts in a mine exposure or drill core.

Microscopic study shows that the dikes in the Staats–Pratt area are quartz monzonite porphyry. The phenocrysts, which make up about 50 percent of the rock are: andesine, in anhedral to subhedral crystals that usually show little zoning; brown biotite, usually subhedral; green hornblende; and a few deeply embayed crystals of clear quartz. The groundmass is a holocrystalline mixture of quartz and orthoclase, in grains ranging from 0.01 to 0.1 millimeter in diameter. The bulk composition of the typical rock is 30 percent andesine, 25 percent orthoclase, 30 percent quartz and 15 percent biotite and hornblende. Hydrothermal alteration is almost always evident, even in hand specimens that appear quite fresh. Sericite, calcite, chlorite, and clay minerals are the typical alteration products.

Fine-grained quartz diorite crops out over an area about 1,000 feet square southeast of the Copperhead shaft (pl. 20), and other bodies of the same rock crop out farther south in the range.

A small intrusive body of andesite(?) porphyry crops out near the Black Jack mine and extends 1,500 feet or so southeast. This dark greenish-gray rock contains phenocrysts of andesine, augite, and bastite possibly replacing enstatite. The groundmass is a patchy microcrystalline aggregate of vague feldspar laths.

CONTACT METAMORPHISM AND ALTERATION

Silicate minerals including garnet, vesuvianite, epidote, and diopside have developed locally within the limestone and dolomite at distances of as much as 100 feet from the larger intrusive bodies. Bleaching and recrystallization, however, are apparent for considerably greater distances from the contacts, particularly around the quartz diorite body southeast of the Copperhead shaft.

Other types of alteration are believed to be related to the mineralization. Along many faults there are bodies of jasperoid, in which the banding and bedding of the original limestone are faintly preserved; along others, the limestone has been leached until it is completely friable (sanded).

PEBBLE DIKES

Along many of the more prominent faults in the Drum Mountains, there are lenticular masses of quartzite cobbles like those in the Tintic district (Farmin, 1934, p. 356) that have been called "pebble dikes." These are tabular, pipe-like, or, more rarely, sill-like bodies ranging from an inch or two as much as 20 feet in width and from a few feet to 100 feet or more in length. The "pebbles," which range from a half inch to a foot in diameter, are mostly quartzite derived from the Prospect Mountain quartzite, and they are usually well rounded and commonly have a concentric onionlike outer shell; but unlike stream pebbles, the surface is rough and pitted—a texture suggestive of corrosion rather than attrition. In addition to quartzite, there are generally a few less-rounded fragments of porphyry, limestone, and shale. The matrix of the dikes is a more or less silicified mixture of finely pulverized rock fragments and clay.

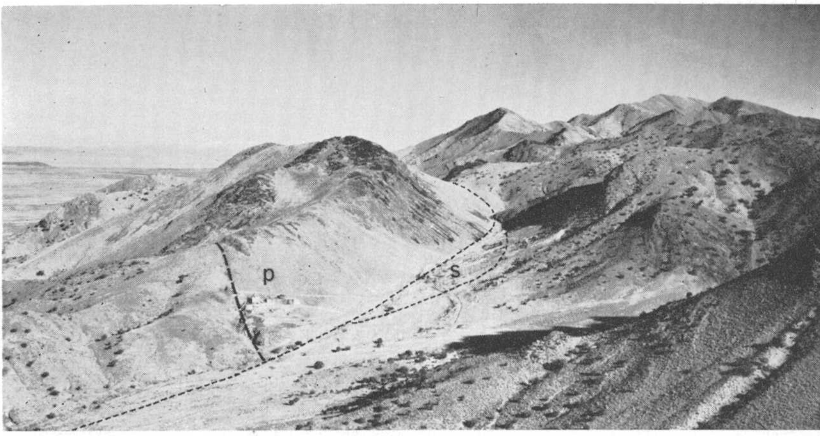
Pebble dikes are most abundant in the area between Joy and the Martha mine (pl. 20), but one small dike crops out in the volcanic rocks 1,600 feet south 56° W. of the NW. corner of sec. 35. The quartzite fragments here are at least 5,000 feet stratigraphically above the highest quartzite, but the actual distance traveled may be greater since they may not have moved normal to the dip.

At the Staats mine, the Copperhead mine, and elsewhere, pebble dikes are intimately associated with the quartz monzonite dikes. The most persistent features of these relationships are: (1) pebble dikes occur on one or both walls of the dikes, (2) fragments and masses of igneous rock are common in the pebble dikes and quartzite pebbles commonly occur as inclusions in the adjoining igneous rocks, (3) pulverized quartz monzonite forms part of the matrix, (4) pebble dikes extend both laterally and vertically beyond the limits of the igneous dikes, (5) the limestone adjoining pebble dikes and faults is always more or less altered, and is sometimes extensively "sanded." This evidence suggests that the pebble dikes here, like those that have been described by Lovering (1949, p .11–13) in the Tintic district, are closely related in time to the porphyry intrusive rocks, and that they were carried upward with and often far beyond the igneous rock itself by the explosive force of fluids or gases associated with the igneous intrusion.

STRUCTURE

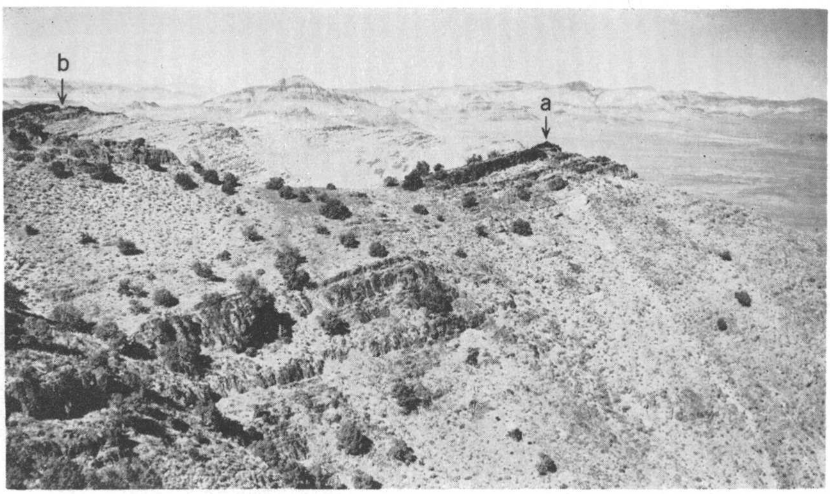
The Drum Mountains southeast of Joy form a relatively simple westward-tilted block whose straight eastern face suggests a deeply eroded fault-line scarp. Although the actual fault is not exposed, its strike must have been nearly north. Near Joy, the mountain block is interrupted by a transverse normal fault with at least 2,000 feet displacement, which drops volcanic rocks down against the bedrock. It is called the Joy fault because of excellent exposures in an old adit near the former mining camp of that name, (pl. 20) where it strikes N. 70° E. and dips 75° N.

The sedimentary rocks within the range form a faulted homocline, striking N. 20° W., and dipping 30° SW. Thus the beds are truncated at a low angle by the range front and are cut off almost at right angles to the strike by the Joy fault. Folding is absent in the north end of the block and only a few gentle flexures were observed in the south end of the block. The most significant structures within the range are transverse faults with relatively small displacement, which form a complex branching and interlocking pattern. Most of these faults dip steeply, and 80 percent or more



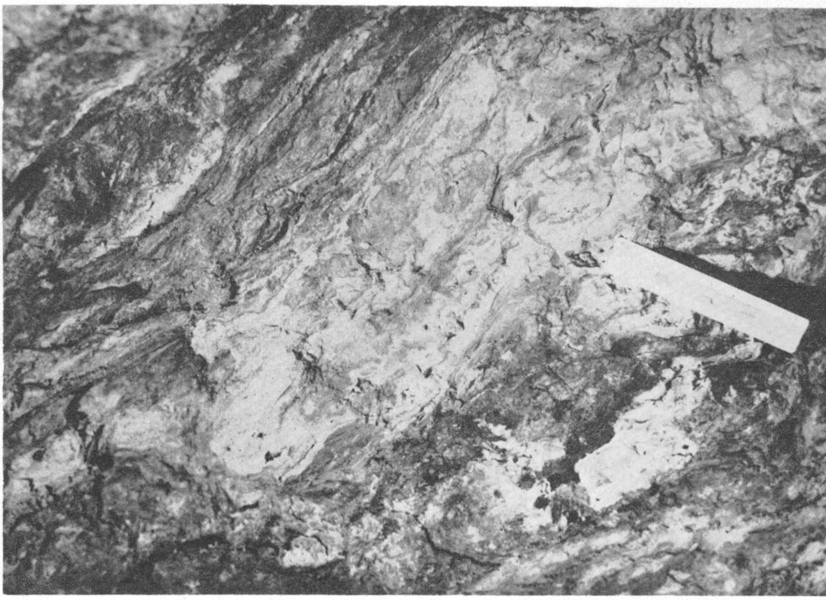
A. STAATS-PRATT MINE AREA FROM THE WEST

The Staats mine, *S*, is in a thin sliver of dolomite, *A*, between two branches of the curving Staats fault. The Pratt mine workings, *P*, are alined along the Pratt fault. The dark hill in the center is capped by the purple quartzite member at top of Prospect Mountain quartzite.



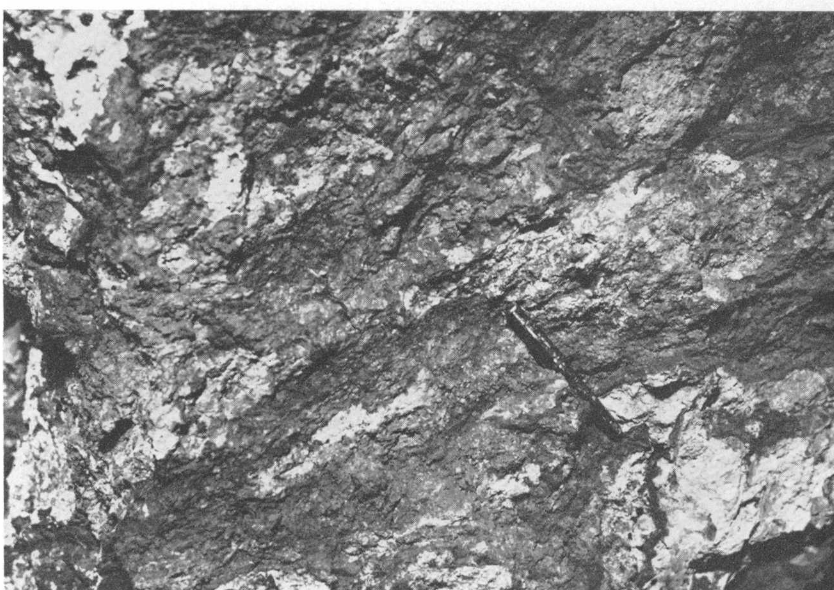
B. WESTWARD-DIPPING PURPLE QUARTZITE MEMBER AT THE TOP OF THE PURPLE MOUNTAIN QUARTZITE

View northwest, showing offset beds from *A* to *B* on the Staats-Last Chance fault system. Topaz Mountain in the Thomas Range is on the skyline just above *A*.



A. CARBONATE ORE, NO. 1 SHAFT, STAATS MINE

Light area is manganoan carbonate replacing impure dolomite and shale.



B. MANGANESE OXIDES, PRATT MINE

Light areas are unreplaced dolomite gangue.

strike N. 20° to 80° E. Both normal and reverse faults are present but the cumulative displacement is down on the south side, thus shifting the formational contacts progressively westward from south to north.

The transverse faults fall naturally into two groups; one, including the Pratt, Hawk Rock, and Ibex faults, strikes N. 30° to 40° E.; the other, including the Staats, Keystone and part of the Last Chance faults, strikes nearly east (pl. 20). Although there are exceptions (for example the Last Chance fault, which bends from east to northwest) most of the northeast-trending faults show normal displacements of less than 500 feet, they tend to shift the formation contacts to the right as one crosses the fault, and they commonly terminate against faults of the east system. The east-trending faults are generally somewhat longer, have larger displacements (as much as 1,000 feet), and the downthrown block is usually on the south which shifts the contacts to the left as one crosses the fault.

Although the northeast faults are commonly terminated by faults of the east system, they do not appear to be offset by them and the two systems were probably formed contemporaneously. Quartz monzonite and pebble dikes occupy faults of both sets, and were intruded after most of the movement on the faults had taken place. However, sheared pebbles, and slickensided walls are found in many places, indicating that some movement has also occurred since the dikes were emplaced.

ORE DEPOSITS

Two types of ore deposits are present in the Drum Mountains, manganese deposits, which are the principal concern of this paper, and gold–copper deposits, which were the basis for the early mining activity in the district. Although the two types of deposits are of the same age and are related in origin, both their mode of occurrence and their composition are distinct, inasmuch as the manganese deposits contain only traces of precious and base metals, and the gold–copper deposits contain only small amounts of manganese. The gold-copper deposits are briefly described on page 515, but were not studied in detail.

HISTORY AND PRODUCTION

Mining activity in the Drum Mountains began in 1872 (Butler and others, 1920) with the exploration of gold and copper deposits, and the Drum district was first organized in that year. It was reorganized as the Detroit district in 1879 and mining has continued intermittently since that time. Production was greatest from 1895 to 1918 and some gold–copper ore was mined as recently as 1941, but the total value is less than $50,000. The town of Joy grew up during the early period of mining activity, but has been deserted for many years.

Although deposits of manganese were probably discovered in the early days, manganese claims were not reported in this district until 1913, and the first verifiable production was in 1924, when Harry C. Joseph began shipping manganese oxides from the Guy group. Small production from the Staats and Pratt mines began in 1925 and continued intermittently through 1941 by a number of operators, most of the ore going to the Columbia Steel Co. in Provo, Utah. In 1942 the ore bodies revealed by diamond drilling were developed and the ore was purchased and stockpiled at the mines by the Metals Reserve Co. Stockpiling was continued until February 1944, when the Geneva Steel Co. purchased the oxide stockpiles and began buying ore directly from the mines. Production during World War II was nearly double that from 1924–1941 (table 2).

TABLE 2.—*Production of manganese ore in long tons, from the Staats–Pratt mines*

[Source: Crittenden (1951) and from records of U.S. Bureau of Mines; Metals Reserve Co.; and Geneva Steel Co. Published by permission of Fred Staats, owner of the Staats mines]

Year	Ore [1] (10–35 percent Mn)	Year	Oxide [2] (20–30 percent Mn)	Carbonate [2] (27–31 percent Mn)
1925	500	1942	1,189.0	246.2
1927	21	1943 [3]	14,704.0	4,437.5
1928	286	1944	10,723.0	350.0
1929	4,084	1945	4,234.0	----
1930	7,861	1946	2,263.8	----
1935	190	1947	4,578.6	----
1936	[4] 3,367		676.4	----
1937	[5] 3,115	1948	----	823.9
1939	59			1,193.9
1940	484	1949	----	212.8
1941	324	1951	----	1,416.1
		1952	----	2,121.2
		1953	----	1,605.4
		Total production	----	72,462.0

[1] Natural weight.
[2] Long tons, dry weight.
[3] Production for 1943 also included 1,397 long tons, dry weight, of mixed ore containing 31.15 percent manganese which is included in total production figure.
[4] Includes 1,635 long tons of 34 percent or more manganese.
[5] Includes 32 long tons of 34 percent or more manganese.

MANGANESE DEPOSITS

Manganese occurs in small quantities along many of the faults in the Drum Mountains, but minable deposits have been found in only three areas. The most important area, a mile east-southeast of Joy, includes the Staats and Pratt mines. A second area is east of the Copperhead mine at the southeast edge of plate 20 where rhodochrosite was discovered in 1954. The third area, 2 to 2½ miles southeast of Joy (fig. 47) includes the Black Jack, Black Diamond, and Last Chance mines.

The deposits were formed by replacement of the lowest dolomitic beds at the base of the thick sequence of carbonate rocks along their intersection with premineralization faults. The resulting ore bodies are usually tabular, and are elongated parallel to the intersection of the host bed and the controlling fault. They range in size from pockets a few inches thick and a few feet long to bodies 20 feet thick and 500 feet or more long. The grade depends largely on the completeness of replacement of the wallrocks.

MINERALOGY, GRADE, AND CHARACTER OF THE ORE

The manganese minerals identified in the Drum Mountains are the oxides pyrolusite, wad, and psilomelane, and the carbonates rhodochrosite, manganoan calcite and manganoan dolomite.

Pyrolusite is the only manganese oxide observed in the mine workings, or in recent shipments. It is variable in form, occurring as dense masses, radiating prismatic crystals, or granular aggregates. The oxide shipping ore (pl. 26*B*) is a mixture of clay, altered silicified limestone, calcite or dolomite, iron oxide and pyrolusite. Its gross composition is indicated by the following partial assay of 9,816 long tons produced from the Pratt mine in 1944:

	Average (percent)	Range of carload shipments in percent: Low	High
Mn	20.38	13. 60	28. 80
SiO_2	28.82	19. 68	38. 50
H_2O	7.30	2. 25	12. 60
Sulfur	0.14	0. 01	0. 80
Arsenic	0.31	0. 01	1. 00
Zinc	0.02 (estimated)	--------	---------

Iron was not determined in these shipments because the ore was purchased for direct use in the blast furnace. Iron was determined, however, in 505 long tons of somewhat higher grade ore from which the following summary was recorded:

	Average (percent)	Range in percent: Low	High
Mn	36. 60	35. 855	42. 01
Fe	5. 40	4. 5	6. 9
SiO_2	17. 33	14. 30	19. 4
Al_2O_3	4. 93	1. 32	6. 55
H_2O	5. 96	3. 6	10. 2
Phosphorus	0. 002	--------	---------

Twenty-two samples of oxide and carbonate ore obtained during drilling showed the following range in composition:

	Average (percent)	Range in percent: Low	High
Mn	14. 0	7. 1	28. 9
Insoluble	35. 0	9. 24	56. 66
Fe	5. 47	2. 53	9. 10
P	0. 19	0. 066	0. 348
As	0. 22	0. 02	0. 50

Traces of gold and silver are found in most of the manganese ore, and in the altered wallrocks and fault zones. Of 18 samples assayed by the U.S. Bureau of Mines, 2 were found to contain from 0.01 to 0.02 ounces of gold per ton and 0.012 to 0.1 ounces of silver per ton.

The occurrence of manganese carbonate ore in the Drum Mountains, and the fact that it is the primary mineral from which the oxides were derived, was pointed out by Callaghan (1938, p. 508–521). As he observed, the primary manganese mineral is manganese-bearing carbonate of varied color and form. In a typical exposure (pl. 26*A*), the primary ore consists of irregular pods, layers, or masses of vuggy manganese carbonate surrounded by and replacing soft altered shale or partly leached impure dolomite. Individual layers of carbonate range from a few inches to several feet thick and may be continuous for 30 to 50 feet or may be highly irregular and lenticular. The intervening shale locally contains considerable pyrite, and in underground openings usually is split and broken by the development of secondary gypsum.

In most hand specimens it is apparent that more than one variety of manganese-bearing carbonate is present. The larger part of the rock consists of dense gray carbonate, but there are streaks and veinlets of a later coarsely crystalline pale-pink rhodochrosite containing numerous drusy cavities. Locally, the pink rhodochrosite has almost completely replaced the gray material.

The gray manganiferous carbonate is comparatively fine grained, 0.01 mm to 0.5 mm. The color, though typically lead gray, may be white or almost black depending upon the quantity and nature of inclusions. The most abundant are, numerous myriad minute dusty nonmetallic particles, nearly opaque in thin section, which probably are the principal cause of the gray color. In addition, pyrite is almost always present in rectangular or tabular grains 0.01 to 1 mm in size that cut across the carbonate crystals, and as minute grains that occur between the crystals of carbonate. A few irregular grains of galena and sphalerite are the only other metallic minerals observed.

The gray carbonate was originally reported as rhodochrosite, but was later determined (by Jewell J. Glass of the U.S. Geological Survey) to be a mixture of rhodochrosite (ω=1.815) and a manganoan carbonate (calcite or dolomite; ω=1.698).

The pink rhodochrosite occurs most commonly as vuggy banded veins that cut and irregularly replace the gray carbonate. It is coarsely crystalline (0.5 to 5 mm.) and forms comblike or radiating masses terminating in rhombohedral crystals. In general, the pink mineral contains more manganese than the earlier gray groundmass, and contains almost no pyrite. Nearly all the crystals are zoned, many showing rhythmic variation of indices parallel to crystal faces, and locally some show zones of minute transparent inclusions parallel to the rhombohedral crystal faces. The index of refraction (omega) of the pink mineral was determined by Glass to range from 1.810 to 1.822, with 1.815 predominant. The index calculated by Wayland (1942, p. 614–628) from the analysis given by Callaghan (1938, p. 500) is 1.818.

In most specimens the pink rhodochrosite appears to have veined and replaced the gray mineral without visible evidence of brecciation or fracturing. Locally, however, there are distinct veins filling dilation fractures, and in a few specimens, the pink mineral cements brecciated fragments of gray carbonate.

The last primary minerals to be deposited are pale-cream colored or faintly pinkish carbonates containing only 1 to 25 percent manganese. They occur throughout the ore as rhombohedral crystals lining vugs in the pink rhodochrosite, but they are most abundant at the edges of the ore bodies where the mineralization was weak. In these areas, they may form plumose or spherulitic masses replacing dolomite or limestone.

Optical and chemical data on six types of carbonate from the Staats mine area are included in table 3.

TABLE 3.—*Analyses and indices of refraction of manganese-bearing carbonates from the Drum Mountains*

	A	B	C	D	E	F
$MnCO_3$	77.65	65.65	85.38	18.11	10.80	1.06
$FeCO_3$	15.57	9.11	7.21	1.69	4.61	5.11
$MgCO_3$	2.43	5.75	1.93	6.04	14.87	38.14
$CaCO_3$	2.78	8.57	4.67	69.26	39.64	53.25
Insol	.48	9.28	.72	5.12	30.17	2.25
Total	98.91	98.36	99.91	100.22	100.09	99.81
ω Index of refraction						
Lowest	1.815	1.698	1.810	1.670	1.690	1.687
Highest	1.822	1.815	1.822	1.695	1.703	----------

A. Pink rhodochrosite reported by Callaghan (1938), analyst R. K. Bailey.
B. Gray rhodochrosite reported by Callaghan (1938), analyst R. K. Bailey. Determined by Jewell J. Glass to be a mixture of rhodochrosite (ω=1.815) and manganoan calcite, or dolomite (ω=1.698).
C. 415232 Pink rhodochrosite of varied composition. No. 1 shaft. Analyst K. J. Murata.
D. 415150 Pinkish-cream, rhythmically zoned manganoan calcite. DDH 2, 78 feet. Analyst K. J. Murata.
E. 415147A Impure gray rhythmically zoned manganoan dolomite. DDH 2, 64 feet. Analyst K.J. Murata.
F. 415133 Gray crystalline dolomite. Base of limestone B. Analyst K. J. Murata.

Throughout the area in which there has been manganese mineralization, pyrite has been introduced into most of the fault zones and into the shale and quartzite adjoining. Locally the rock may contain 20 to 30 percent pyrite, and scattered anhedral grains composing up to 5 percent of the rock may be present 20 to 30 feet from a fault. In one place marcasite occurs in radiating globular masses, 1 to 4 inches in diameter replacing altered shale along a fault zone. It is hypogene, occurring in close association with rhodochrosite.

ORE CONTROL

The manganese deposits in the Drum Mountains are bedded replacement deposits whose general location is determined by the intersection of certain host beds with premineral faults that served as channels for mineralizing solutions. The size and grade of the individual ore bodies, however, are determined by local physical controls that can only be defined by detailed study in areas of extensive exposures and workings.

All the significant manganese deposits are localized in two stratigraphic units, dolomite A and a similar brown-weathering sandy dolomite at the base of limestone B. The lowest of these, dolomite A, is a lenticular zone usually about 20 feet thick consisting of cross-bedded sandy to quartzitic dolomite that grades upward into shale and downward into quartite. The higher bed is commonly about 8 feet thick, but it too is lenticular and locally is entirely absent. Separating the two zones is shale 1, which comprises about 20 feet of interbedded sandy shale and shaly quartzite. Although these two host beds probably contain, in places, as little as 50 percent of carbonate, their selective replacement may be due in part to their being the lowest carbonate rocks in the stratigraphic sequence and consequently the first beds of this composition to be encountered by ascending solutions. It appears unlikely, however, that this factor alone is sufficient to account for the observed extent of the ore bodies. The physical properties of the stratigraphic sequence are probably of equal importance, and would affect the mineralizing process in two ways. First, because the ore beds form the transition between massive thick-bedded quartzite and interbedded limestone, dolomite and shale, any deformational stress affecting the area would inevitably be concentrated at such a marked physical discontinutiy, and the resulting shearing and brecciation would facilitate movement of mineralizing solutions; second, the imperviousness of shale 1, especially when subjected to shearing and hydrothermal alteration, would act to confine solutions to dolomite A to seal off the feeding fractures above it.

The principal ore body in the Pratt mine (the Pratt ore body, pls. 21 and 22) is a raking ore shoot formed by replacement of dolomite A. The feeding fissure was probably the Winze fault, from which mineralizing solutions moved out into dolomite A following the inverted trough formed by shale 1 and the Black Boy fault. The south edge of the ore body is sharply bounded by the Black Boy fault through much of its length; the north edge coincides for some distance with the Winze fault, but for the rest, it is irregular and fades into unmineralized altered dolomite.

The No. 5 and No. 6 ore bodies in the Pratt mine (pl. 22) were formed by replacement of limestone B and dolomite A respectively in proximity to the Pratt fault. The mineralizing solutions appear to have risen along the Pratt fault, or a branch of it and moved out into the fractured zones adjoining shale 1. Although the No. 6 ore body and Pratt ore body are both in dolomite A, they apparently are not connected, since the 50-level drift shows the ore-bearing bed to be discontinuous in the interval between them.

In the Staats mine the structural factor most important for localizing the ore bodies is a local branching of the Staats fault, along which first porphyry magma and later mineralizing solutions rose to the level now exposed. In the sliver between the two branches the beds have been sheared and brecciated facilitating their widespread penetration by mineralizing solutions. Smaller faults, such as the Stope fault (pl. 23) now occupied by narrow veins of rhodochrosite, have provided local channels for solutions.

The detailed structural control in the Staats mine is probably similar to that described in the Pratt mine, but is not known in comparable detail because of the lack of workings and the difficulty of interpreting the complexly faulted structure from diamond drill holes.

OXIDATION

The depths to which the manganese carbonate deposits in the Drum Mountains are oxidized is highly variable, because oxidation is effected by oxygen-bearing meteoric water whose movement is controlled by permeable openings. Consequently, the extent to which a particular or body is oxidized depends more upon its structural relations and its surroundings than upon depth alone. In the Pratt mine, manganese oxides extend to depths of as much as 300 feet in DDH 34 and 37 and in the Pratt ore body, while carbonate ore is preserved in the No. 6 ore body at depths of 50 feet or less. The explanation is found in the differences in permeability—the faults and the Pratt ore body being open to downward-moving water, whereas the No. 6 ore body was sealed at its lower end by the termination of dolomite A (pl. 21, section *B–B′*).

In the Staats mine, the depth of oxidation is only 30 to 40 feet, even along faults. This may be due to the fact that the ore bodies all lie within the block bounded by the Staats and South Staats faults which are sealed by porphyry and gouge, and which consequently have limited ground water movement. It is probably significant also that alteration is more intense in this area which tends to make both the faults and the shaly units less permeable than in the Pratt mine. This effect is particularly evident in shale 1 and is well shown in DDH 4, 5, and D (pl. 24) where the ore above shale 1 is oxidized to a depth of 60 feet or more but the ore below is oxidized to a depth of only 30 feet.

The oxidation of primary manganese-bearing material commonly results in appreciable local enrichment either by movement and concentration of the manganese or by leaching of the gangue. In the Staats and Pratt mines, veinlets of manganese oxide cut and replace the wallrocks to a limited extent, but the migration appears to have been local because the oxides seldom extend more than a foot or two from the position of the primary ores. Moreover, the average grade of the carbonate ore that has been mined is higher than that of the oxide ore, indicating that there has been relatively little overall enrichment during oxidation in this area.

ORIGIN

The manganese deposits of the Drum Mountains are hypogene hydrothermal replacement deposits, whose formation appears to be the result of a fairly well defined series of events. First, the otherwise underformed rocks were broken by faults with displacements of 500 to 1,500 feet. Certain of these faults provided openings which were intruded by igneous rocks, forming dikes, sills, and locally somewhat larger discordant bodies. Following this, there was additional faulting, and the openings thus formed provided channelways for mineralizing solutions, which deposited manganese-bearing carbonates and sulfides at favorable sites. Since then, minor faulting has occurred, but in most places it has not been sufficient to brecciate the ore and there is no evidence to suggest more than one major period of mineralization. Finally, upilft and erosion, or fluctuations of the ground-water table due to climatic changes, permitted oxygen-bearing meteoric water to enter the permeable fissures and the ore bodies, altering part of the manganese-bearing carbonate to manganese oxides.

The source of the manganese-bearing solutions can only be inferred; the close regional association of the deposits with dike rocks suggests that they may have a closely related origin at depth. No evidence was found to indicate the absolute age of these deposits, but by analogy with similar hydrothermal deposits in Gold Hill (Nolan, 1935, p. 53) and in the Stockton-Fairfield area (Gilluly, 1932, p. 65–66) they are presumed to be Tertiary.

FUTURE OUTLOOK

The outlook for additional large discoveries within the immediate area of the Staats and Pratt mines is not bright. Drilling in 1941 explored the larger faulted segments of the ore-bearing beds from the South Staats fault to the northwest edge of the Pratt mine near the Price shaft. Moreover, the drilling in 1946 was designed to test the best remaining prospects in this interval but most of the holes failed to cut ore.

On the other hand, the possibilities for additional discoveries at other places along the strike of the ore-bearing beds appear to be good, particularly where they are cut by dikes or fissures. Experience to date indicates that such areas are commonly softer than the adjoining rocks and form valleys containing shallow alluvial fill. Prospecting of these areas is just as important as the intervening hills where exposures are continuous.

At depth, the areas of greatest interest are loci of intense hydrothermal alteration, such as the areas of sanded dolomite near the Copperhead mine and the jasperoid bodies near the Martha mine. These resemble so closely the types of alteration associated with ore in the Tintic district, that their intersection with the ore horizons, dolomite A and limestone B (section *A–A′* plate 20), offer particularly attractive targets. Moreover the abundance of manganese near the surface suggests that the whole district may be zoned, and if this is the case deep ores may contain proportionally larger amounts of base metals. A combination of geochemical studies and diamond drilling is an appropriate means of testing these possibilities.

GOLD-COPPER DEPOSITS

From 1904 to 1917, gold-copper deposits at the Ibex, Copperhead, Keystone, and E.P.H. mines are said by V. C. Heikes (Butler, Loughlin, and Heikes, 1920, p. 464) to have produced ores with a total value of $45,809. Most of the deposits are associated with lenses of massive yellowish-brown jasperoid that have replaced the limestone at irregular intervals along faults. Gold, and the copper minerals malachite, azurite, chrysocolla, brochantite(?), chalcopyrite, and chalcocite, together with abundant pyrite are sporadically distributed along fissures and fractures within the silicified zones, the dikes, or the adjoining wallrocks. Butler, Loughlin, and Heikes (1920, p. 463) report that a carload of gold ore shipped in 1882 contained 14 percent bismuth. However, there are no subsequent records of significant amounts of this element.

MINES AND PROSPECTS

PRATT MINE

OWNERSHIP

The principal manganese deposits of the Drum Mountains (pl. 20) are on a series of numbered claims called the Black Boy group.

Workings are in two areas about a quarter of a mile apart; the northernmost, here designated the Pratt mine, includes all the workings in the area of the Pratt fault regardless of ownership. The principal shaft and most of the workings are on property owned by the Pratt heirs, and were operated from 1941 to 1945 by the Ward Leasing Co. of Salt Lake City. The No. 5 shaft and adjoining workings, and the southwestern end of the Pratt ore body, are on claims owned by Fred Staats.

DEVELOPMENT

The most extensive workings in the Pratt mine are those connected with the No. 6 shaft (pls. 21 and 22). This is a 45° incline 165 feet deep, which was begun on the Pratt fault at the portal of the No. 6 adit. Levels extend north from the shaft to the Pratt ore body at vertical depths of about 50 feet and 100 feet below the collar. The ore body was stoped between the two levels, and above the 50-level to within 75 feet of the surface. Later the lower part of the body was mined by means of an inclined winze that was started from the 100-level drift near the south edge of the ore. Two short sublevels were driven at about 150 feet and 200 feet below the collar of the No. 6 shaft, and the ore was stoped from the 200-level upward. More than 25,000 dry long tons of oxide ore were produced from the body from 1942 to 1945.

The geologic factor that was most important in mining was the incompetence of shale 1. This unit, which forms the hanging wall of the Pratt ore body, is so sheared and altered that it would not stand in the back of room and pillar stopes if the ore was broken completely away. Consequently it was necessary to devise a mining method that would leave a shell of ore intact to hold the shale until mining was complete. This was done by driving a raise 6 feet high and 15 to 20 feet wide on the footwall of the ore body, then drilling and blasting the back of the stope, slushing out only enough ore to make room for drilling the next round. The position of the shale was determined by drilling test holes into the back with long steel, and the last round was drilled so as to leave 3 to 4 feet of ore. The broken ore was moved by slushers since most of the stopes were too flat to permit the use of gravity methods.

The No. 5 ore body was mined by means of a level extending 50 feet east from the bottom of the No. 5 shaft at an elevation of about 5,900 feet. Lower levels were driven southwest from the incline at an elevation of 5,895 feet, and northeast from the bottom of the incline at an elevation of 5,887 feet. Diamond drill hole J was intersected on the 5,895-foot level, and was found to have been deflected several feet from its theoretical position. The corrected strike and dip are shown in plane and sections of the workings.

These workings, and older stopes to the east are all in oxide ore at the base of limestone B.

The No. 6 ore body was exposed at the surface near the head of the No. 6 shaft, and in the No. 6 adit, and connecting stopes. It was largely oxide, but carbonate ore was found in underhand stopes, and in a raise from the 50-level of the No. 6 shaft.

EXPLORATION

Fourteen diamond-drill holes totalling 3,195 feet were drilled in the Pratt mine area by the U.S. Bureau of Mines in 1940 and 1941. Three of these, holes 25, L, and 23A penetrated the Pratt ore body and one, J, cut the No. 5 ore body. In 1945 the U.S. Bureau of Mines drilled 6 more holes totalling 1,926 feet. These were numbered 101 through 106. The purpose was to determine whether there were undiscovered extensions of the Pratt ore body, and to test the ore-bearing beds in the downthrown block west of the Winze fault. This work indicates that the Pratt ore body extends south from the face of the 200-level at least as far as hole 101, but that the thickness and grade of the ore may be diminishing. Holes 102 to 106 failed to cut significant amounts of mineralized rock.

At the close of the diamond drilling in 1945, a block containing several thousand tons of oxide ore averaging 10 to 20 percent manganese was inferred to lie beneath the Winze fault between the 200-level and the Pratt fault. Drill hole 101 penetrated 8 feet of ore estimated to average 25 percent manganese, but the actual grade could not be determined more accurately because the sludge and core were destroyed by fire before being assayed. This block, togther with numerous stope pillars, constituted the only significant reserves of oxide ore in the mine, and most of this ore has since been mined out. In addition it is inferred that there are a few thousand tons of carbonate and oxide ore averaging 15 to 20 percent manganese in the lower edge of the No. 6 ore body.

The recent work in the Price shaft has largely mined out the blocks originally cut by DDH 34. Mineralization did not extend as far south as DDH 104 but the area farther north may be worthy of exploration. It is possible, also, that the beds may be mineralized south of DDH 104 against the Winze fault (pl. 21, section *A–A′*).

GEOLOGY

The Pratt mine is developed on bedding replacements at the two principal ore horizons of the district, in an area where the beds strike northeast and dip 30° to 40° NW (pl. 21). Both surface mapping and underground openings reveal the presence of a complex pattern of faults, the details of which still are not fully understood in areas where the interpretation depends entirely on information obtained from diamond-drill holes.

The workings all lie in the hanging wall of a major normal fault, the Pratt fault, that strikes northeast and dips about 70° NW, and on which the ore horizons, dolomite A and limestone B, have been dropped down against the quartzite footwall. This fault is well exposed on the surface and in the No. 5 and No. 6 shafts (pl. 21, sections *A–A′* and *B–B′*).

The No. 6 ore body was formed by replacement of dolomite *A* along its intersection with the Pratt fault. From the point of discovery, near the head of the No. 6 shaft, the ore extended east about 200 feet, and was continuous above the level to its intersection with the Pratt fault. When DDH 1 revealed manganese carbonate ore in dolomite A, this ore was naturally thought to be continuous with that in the No. 6 ore body. When the No. 6 shaft was sunk, however, it ran out of ore into barren quartzite at a depth of 20 to 30 feet below the collar (pl. 21, section *B–B′*), and on the 50-level, shale 1, which forms the hanging wall of the No. 6 ore body, was found to rest directly on the quartzite. Thus the No. 6 ore body terminates downwards, and does not connect with the Pratt ore body. Although no obvious fault was observed in the shaft or on the 50-level, a bedding fault is inferred as the simplest and most reasonable way to account for the downward lensing out of dolomite A. The sealing off of the lower part of the ore body also explains the presence of primary manganese carbonates there well above the level of the Pratt ore body (see p. 513) which consisted entirely of manganese oxides.

The Pratt ore body (pl. 22) is an elongated northeast-trending shoot formed by replacement of a narrow block of dolomite A bounded on almost every side by faults. It is about 800 feet long, 40 to 80 feet wide, 8 to 20 feet thick, and rises about 200 feet from the southwest to the northeast corner. From the 100-level to the upper end of the stopes, the block is bounded on the south by the Black Boy fault, a normal fault with a displacement of 20 feet or so (pl. 21, sections *B–B′* and *C–C′*). This fault was visible at several places on the south wall of the stopes as a series of strong parallel shears marked by slickensides and a few inches of gouge. It appeared to be equally prominent in the westernmost workings on the 100-level. Nevertheless it could not be identified in the main haulageway of the 100-level extending northwest from the shaft, nor in the workings below the 100-level, and it is inferred that it was cut off by the bedding fault already mentioned (pl. 21, section *B–B′*, and pl. 22). This explanation, though not entirely satisfactory, seems to be the best that can be devised.

On the northwest, the Pratt ore body is cut off by the Winze fault which strikes northeast and dips northwest. Drill holes 21, 22, and K (pl. 21) penetrate the fault, and by the position of shale 2, indicate a normal displacement of about 150 feet. This fault was recognized underground on the 100, 150, and 200-levels, but was not cut in the end of the 50-level, northeast of the stopes, nor between there and DDH 30.

Thus far it has proved difficult to relate these faults seen underground with those mapped on the surface. The Winze fault which generally strikes northeast and dips northwest, cannot continue on this strike from DDH L to DDH 21 because of the continuity of shale 2, and it must therefore make a 45° bend so as to pass between the end of shale 2, and a 2-foot bed in limestone B that crops out nearby (pl. 21). Thus from DDH 25 to the top of the ridge, the Winze fault strikes east and coincides with the surface projection of the Black Boy fault. But underground, the Black Boy fault dips south, and therefore is now regarded as a split that lies within the footwall of the Winze fault.

The stopes off the Price shaft (pl. 22) are in the down-faulted block of limestone B northwest of the Winze fault. Most of the stoping was done in the area between DDH 34 and 35 (pl. 21, section *B-B'*), but a small amount of ore was found in the block just west of the shaft. It is interesting that at the level of the workings, the beds are systematically downthrown on the south (the Price, and parallel faults), whereas the small faults on the surface directly above, displace the beds systematically down on the north.

The bedding fault appearing in the area of the Price fault (pl. 21, section *B-B'*) accounts logically for the abnormal thinning of limestone B in DDH 34 and 35. This bed does not appear to be thinned in DDH 104, however, and the reason for this is not clear.

STAATS MINE

OWNERSHIP AND DEVELOPMENT

The Staats mine is in the bottom of the wash 700 to 1,000 feet southeast of the Pratt mine and is on claims owned entirely by Fred Staats. The surface workings consist of several open pits, the largest of which is 150 feet long, 20 feet deep and as much as 60 feet wide. The main haulage level (pl. 23) at elevation 6,040 extends south 50 feet from its portal on the east side of the pit; it then branches, one drift continuing south to the No. 2 stope and another extending east to the No. 1 stope. The footwall drift forms a continuation of the east branch, and extends around and beneath the east end of the East stope. The No. 1 shaft was sunk near the west edge of the open pit, and two short levels were driven, one on the upper ore bed and one on the lower ore bed. It is inaccessible part of the year due to lack of ventilation. Most of these workings were developed before 1941.

From 1944 to about 1958, mining was confined largely to the No. 4 shaft, a 210-foot incline, which was sunk on the lower ore bed northwest of the main pit. The incline dips about 30° for the first 160 feet but steepens to 40° in the lower part. The ore bed was stoped on both sides of the shaft for a distance of about 100 feet below the base of the alluvium. The stopes are 50 to 75 feet wide and as much as 20 feet high. Slushers were used to move the broken ore from the stopes to the ore pockets above the shaft.

EXPLORATION

Twenty diamond-drill holes, totaling 4,065 feet were drilled in the Staats mine area by the U.S. Bureau of Mines in 1940 and 1941. Eleven of the holes cut manganese ore in one or both beds, indicating that the ore extends as much as 250 feet downdip from the present workings. One hole was drilled in this area during 1945.

At the end of exploration, the two ore beds were found to be mineralized to form two partly overlapping bedding replacement ore bodies extending approximately from DDH I and DDH 5 (pl. 24) diagonally southeasterly to the area of DDH D and DDH E. Part of the ore in dolomite A now has been mined out by means of stopes off the inclined shaft No. 4; the ore in limestone B is both less extensive and somewhat lower in grade, and because of its position over the existing stopes will be difficult and expensive to recover. A second pair of overlapping blocks extends southeast from DDH B and C to DDH A. Here, however, the ore in the upper block is both thicker and more extensive than that in the lower.

GEOLOGY

The mineralized area of the Staats mine lies within a lens-shaped block of ground bounded on both sides by faults. Because almost the entire area is concealed by alluvium, the location of the faults and the structure within the block (pl. 24) are of necessity inferred from underground workings, diamond-drill holes, and a few small surface exposures. The mineralized block is bounded on the north by the Staats fault which follows roughly the north side of Staats wash from the divide at its head to its junction with Ibex wash. On the south, the block is bounded by the South Staats fault which splits off the Staats fault about 800 feet east of the Staats mine, curves strongly southwesterly, passing just north of DDH 10 (pl. 21 and 24), then bends northwesterly again, rejoining the Staats fault near its junction with the Pratt fault. Both faults dip south at an angle of about 60°, though they appear much flatter in plate 24 because the sections are so nearly parallel to the strike; both are normal faults with displacement of 100 to 300 feet. A third fault, the Staats Spur fault, is inferred to lie within the block already described, and in most places, this rather than the Staats fault bounds the ore bodies on the north.

The beds within the block strike near north and dip west at an angle of 20° to 40° and are cut by numerous subsidiary faults with displacements up to 100 feet. A few of these faults are exposed in the workings connected with the inclined shaft and the main haulage level, but most are inferred from drill data. In these cases the evidence often permits more than one interpretation, and the structural pattern shown in plate 24 is only one of several possible alternatives. Most of the faults within the block appear to be subsidiary to the major faults, and to end against them. This pattern holds also for the faults of the Ibex system which meet the South Staats fault between drill holes 11B and G (pl. 24), without appearing to offset it.

Bodies of manganese carbonate ore have formed by replacement of dolomite A and the base of limestone B in the narrow block between the South Staats and the Staats Spur faults. In the area of the No. 1 shaft and the old workings southeasterly from it (pl. 23) the beds strike approximately north, and dip 35° to 40° W. Both ore beds are present and mineralized. The main haulage level (elevation 6,040 feet) follows the upper ore bed 40 feet south from the portal, then continues in shale 1 beneath the upper ore bed. The south drift cut the same ore, south of fault A, where it was mined in the No. 2 stope. South of the stope fault, the upper ore bed continues to be mineralized, as shown by DDH 2, but it has been displaced at least 50 feet west. The east drift cut the lower ore bed north of the Stope fault, but the mineralization was weak. South of the Stope fault, the lower ore bed was reached in the south drift and the ore was followed upward in the No. 1 stope to the base of the alluvium. East of the No. 1 stope, the ore continues through the quartz monzonite sill along the Stope fault and forms a small body at the upper contact of the quartzite. This body was mined in the east stope.

The interpretation of the structure in this area is complicated by the quartz monzonite sill that was intruded into the lower ore bed. As indicated in plate 23, section *A–A'*, the sill splits the lower bed, leaving part of dolomite A in contact with the quartzite and part of it in contact with shale 1. Thus DDH A cut 3 mineralized zones, 1 in limestone B and 2 in dolomite A, instead of the usual 2.

The ore exposed in the No. 1 and No. 2 stopes and in the workings off the No. 1 shaft extends downdip at least to DDH 2 (pl. 24), but was not present in DDH 10 which cuts the ore beds 240 feet farther down the dip. DDH 3, however, cut ore at both the A and B horizons, indicating a northwesterly rake to the ore shoots. Hole E did not cut the ore horizon because of faulting, but as suggested by the section through holes 12–G–E (pl. 24), some mineralization in this area is likely. Still farther northwest, holes 4, D, I, and F showed 12 to 20 feet of carbonate ore averaging 20 to 25 percent manganese in the lower ore bed, dolomite A and part of this ore has now been developed by the inclined shaft No. 4. Some mineralization was found at the base of limestone B, but it averages only 5 to 6 feet thick and 10 to 15 percent manganese.

The downdip extension of this ore shoot was further tested by holes 11B, 12, 107, and 7, which were designed to cut the ore beds at depths of 175 to 200 feet below the surface, and as much as 500 feet downdip from the workings. Holes 11B, 12, and 7 (pl. 24) cut the ore beds but found them barren. It is inferred from this, that the southwestern boundary of the ore body is an assay wall, and that mineralization was most intense near the Staats Spur fault and became weaker downdip.

Hole 107 was drilled to test for faulted segments of the ore beds at depth beneath the South Staats fault. Except for 30 feet of alluvium at the collar, the entire 300 foot depth was in porphyry. This is interpreted to be a feeder dike for the sill cut in drill holes 7, 12, G, and 11B.

To the northwest, holes 6 and H (pl. 24) cut the Staats fault before penetrating the ore beds. This suggests that the ore bodies are cut off by the Staats fault between section 6 and H, and section 7, I, and F.

The age relations of the faults are difficult to determine with certainty, since such evidence as chilled margins is largely obscured by more recent movements. Nevertheless it appears that faults A and B (pl. 23) were older faults along which the porphyry was intruded. The Stope fault is younger, however, and has cut and displaced the porphyry, and both this fault and the others have served as feeders for mineralization.

From diamond-drill data it was estimated that the average grade of the ore in these blocks is about 16 percent manganese. Mining to date, however, suggests that the diamond-drill sampling may be 5 to 10 percent low.

Diamond drilling in 1942 appears to have revealed the full extent of the ore in the area of the Staats mine, for mineralization was found to die out downdip to the west before the beds are cut off by the Staats fault. Further drilling in this area in 1946 failed to penetrate the ore beds. (See DDH 107, pl. 24.) Thus there seems to be little hope of finding lateral extensions of the known ore blocks, and so far there is no evidence of mineralization in the quartzite to suggest that deeper exploration might be favorable.

OTHER MANGANESE PROPERTIES IN THE DRUM MOUNTAINS

Several properties south and southeast of the Copperhead shaft, (pl. 20) have been explored for manganese and the Black Jack, Black Diamond, and Last Chance mines have made small shipments of low grade oxide ore.[1]

Although manganese oxides are the only minerals exposed in these properties, their general appearance and occurrence suggests that they were formed by the oxidation of manganiferous carbonate in the same way as in the Staats and Pratt mines. Here too the mineralization is associated with faults and extends outward along bedding so as to suggest a similar stratigraphic and structural control. In all of the prospects but one, the mineralized bed is the basal dolomite unit of limestone B; the lower bed, dolomite A, being either thin or absent south of the Copperhead shaft.

BLACK JACK MINE (GUY GROUP)

The Black Jack mine, in NE¼, sec. 7, T. 15 S., R. 10 W., is 3¼ miles southeast of Joy. It is easily reached by a road from Delta which branches south of the range. The property is owned by J. E. Dowd and has been operated by several lessees. The production is summarized in table 4.

TABLE 4.—*Production from Black Jack mine*[1]

Year	Shipper	Destination	Ore shipped (long tons)	Grade (percent Mn)
1924	H. S. Joseph	Columbia Steel Co	37	27
1940	S. D. Trotter	do	14.7	17.03
1941	do	do	64	12.44
1943	J. E. Dowd	Metals Reserve Co	145	16
1944	do	do	274	16.5
Total and average			535	16.8

[1] Crittenden (1951) p. 30.

The sedimentary rocks exposed near the mine (fig. 49) are quartzite, sandstone, shale, limestone, and dolomite which are correlative with the section at the Staats and Pratt mines. Dolomite A, though present, is thin and unmineralized and was therefore not mapped as a separate unit; instead, dolomite B and shale 1 were grouped with

[1] Early in 1954 L. J. Price shipped one car of carbonate ore averaging 21.7 percent Mn from the Dike claims, east of the Copperhead mine.

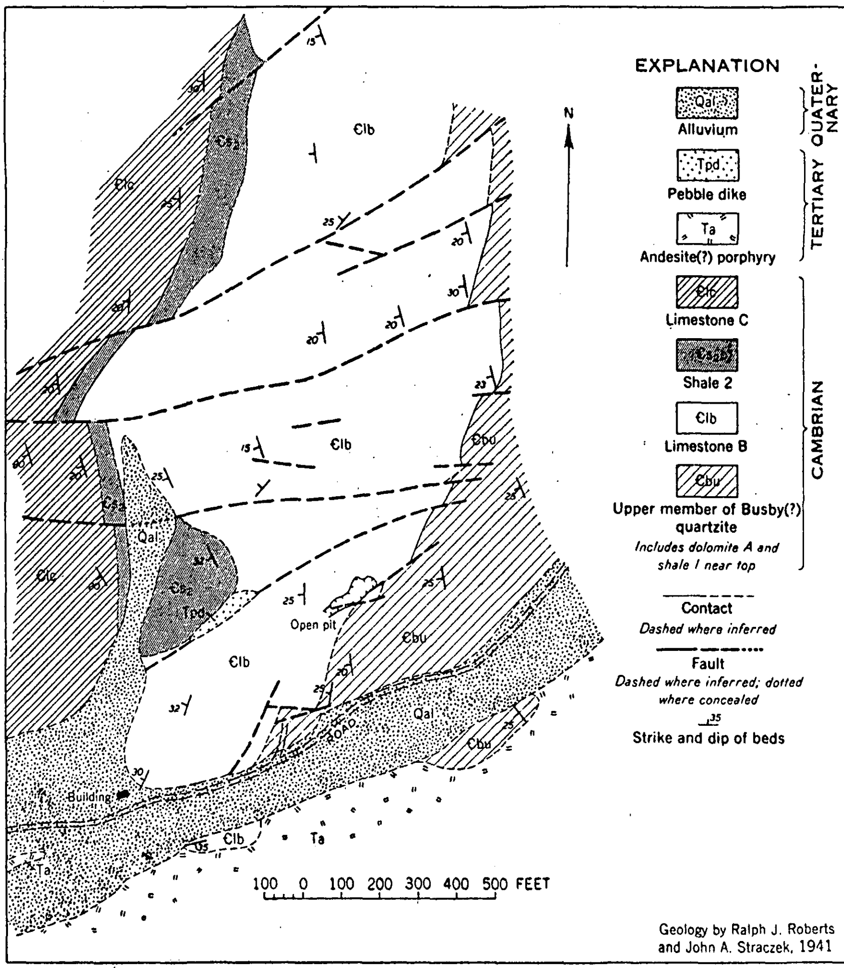


FIGURE 49.—Geologic map of the Black Jack mine.

the Busby(?) quartzite. The dolomite at the base of limestone B is thicker here than at the north end of the range, but otherwise the section up to and including limestone C appears to be lithologically identical. The rocks are cut by several small faults that strike northeast and dip steeply.

South of the mine, andesite(?) porphyry, which is in part extrusive and in part intrusive, is in contact with quartzite, shale, and limestone.

A lenticular pebble dike was intruded along one fault west of the pit. With the possible exception of the fault up the valley southeast of the workings, none of the faults have displacements exceeding 20 feet.

The workings are shallow cuts and an open pit from which short adits were driven. They explore an ore body in impure sandy dolomite overlying quartzite and shale. The ore is a mixture of manganese and iron oxides which replace the dolomite along bedding in and near faults and fault zones. No primary minerals are evident but the oxides closely resemble those in the Staats–Pratt mines known to be derived from manganiferous carbonates. Limonitic, sandy, and clayey material that is intermixed with the ores is probably the residue from the replacement of impure dolomite.

The open pit (fig. 50) is 150 feet long, as much as 50 feet wide and 20 feet deep. Most of the ore was mined from the footwall side of the pit fault but ore is also found on the hanging wall side. As exposed in the walls of the pit, the ore zone has a maximum thickness of 10 feet, but is low in grade (about 15 percent Mn) because of the amount of gangue that is mixed with the manganese oxides.

Ore reserves are small, though extensions downdip, to the west and northwest of the pit may be found.

MARTHA MINE

The Martha mine is one-half of a mile south of the Copperhead shaft on the north edge of sec. 1, T. 15 S., R. 11 W. The property was explored in the early days for gold and copper, and the present showing of manganese appears to have been made during this period; no manganese has been produced and the production of gold and copper is not known. The mine workings consist of two shafts and several opencuts that explore jasperoid masses along east-trending fault zones. The jasperoid is stained by small amounts of iron and manganese oxides but workable deposits were not found. An opencut to the east exposes limestone partly replaced by pyrolusite and wad in a zone about 5 feet thick and about 15 feet long. Although some of the material is of good grade, the deposit is small and possibilities for the development of additional ore do not appear promising.

BLACK DIAMOND MINE

The Black Diamond mine is in the center of sec. 6, T. 15 S., R. 10 W., about 1½ miles southeast of the Copperhead shaft. It consists of a single claim owned by J. J. Booth and others. A small shipment of ore is reported to have been made from the property, but the grade and size of the shipment are not known. The workings include several shallow pits and a shaft about 20 feet deep which explore showings of manganese and iron oxides in limestone and

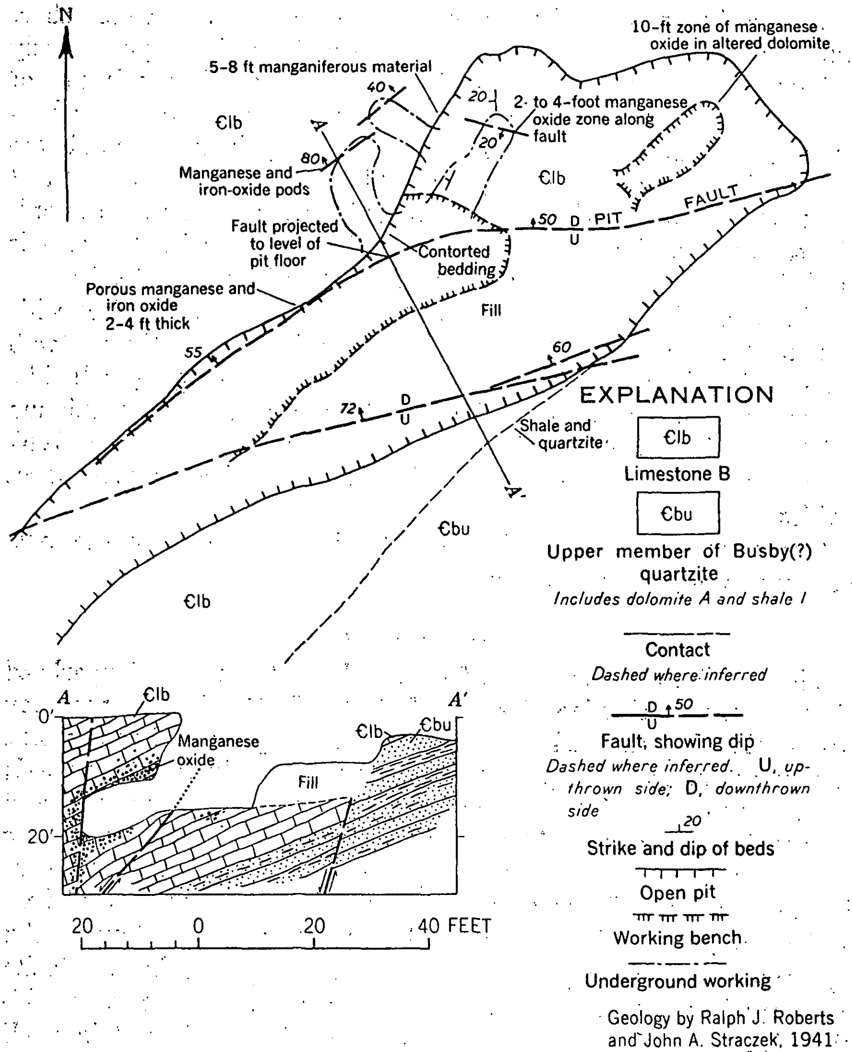


FIGURE 50.—Map and section of open pit at the Black Jack mine.

dolomite at a horizon corresponding to the upper ore zone at the north end of the range. An altered porphyritic igneous rock, presumably a dike, is exposed in the working; a pebble dike occurs along its contacts.

The manganese oxides are found in small masses along bedding and fractures. The material is low grade and the available tonnage appears to be small.

LAST CHANCE MINE

The Last Chance property comprises 9 claims owned by D. Boyd and others of Provo, Utah and located in SE½ sec. 6, T. 15 S.,

R. 10 W., 2 miles southeast of the Copperhead shaft. About 95 tons of ore, containing 25.6 percent manganese is reported to have been shipped. The property is explored by an adit 90 feet long, and four shallow pits, all in the dolomite unit of limestone B just above the quartzite. The beds in the area of the workings strike N. 20° to 30° W. and dip 20° to 30° southwest, and are cut by several small transverse faults.

The adit cuts the base of limestone B at a distance of 60 feet from the portal. The basal dolomite contains thin intercalated shale beds and is about 18 feet thick in this area. The lower 2 to 4 feet of the dolomite have been replaced by ferruginous manganese oxides along fractures striking N. 70° W. which occur as small irregular lenses that replace the dolomite along the bedding. Ore has been stoped for a length of 36 feet, a width of as much as 10 feet, and an average thickness of about 3 feet. The material now showing in the walls of the stope is low grade and reserves appear to be small.

OTHER MANGANESE PROSPECTS

The Black Wasp, three-fourths of a mile northwest of the Black Diamond property, and the Gold Ring, one-half of a mile northwest of the Black Diamond have showings of manganese oxides in limestone, but the material is low in grade and the quantity available appears to be too small to warrant exploitation.

CONDENSED DRILL LOGS

DRILL HOLE A.—*Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,117 feet; bearing: N. 17° E.; inclination: −55°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 23.4	Overburden.	
23.4- 32	Dolomite, altered, yellowish, sandy	Limestone B.
32 - 42.5	Shale and sandstone, greenish-brown; stained by manganese and iron oxides.	
42.5- 52.5	No core.	
52.5- 73.5	Sandstone and shale, brown, iron-stained; contains considerable manganese oxide.	Shale 1.
73.5- 80.5	Rhodochrosite, gray and pink; some pyrite	Dolomite A.
80.5- 83	Sandstone, hard, fine-grained calcareous.	
83 -110	Porphyry, altered	Porphyry.
110 -114	Rhodochrosite, vuggy, gray and pink; some pyrite	Dolomite A.
114 -129	Dolomite, pale-gray, crystalline; sheared talcy shale at 115, 116–117.3, and 121-123; abundant pyrite at 125.	
129 -228	Sandstone and quartzite, gray to greenish, altered micaceous; pyrite very abundant; bedding 60°–65°.	Busby(?) quartzite.

[1] Average Mn content of cores for intervals: 29–39 ft, 10.5 percent; 46.5–51.5 ft, 26.8 percent; 68–77.5 ft, 9.9 percent; 80–114 ft, 12.9 percent.

DRILL HOLE B. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,063 feet; bearing: N. 17° E.; inclination: −45°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 12	Overburden.	
12 - 73.6	Limestone, pale-gray, coarse-grained; abundant limonite staining.	Limestone B.
73.6- 74.2	Gouge, gray	Fault.
74.2- 74.6	Rhodochrosite, gray	Limestone B.
74.6- 82	Limestone, dark-gray.	
82 - 85	No core.	
85.6- 92	Rhodochrosite, gray and pink.	
92 -102	Sandstone, dolomitic, sheared and altered. Pyrite, abundant; some rhodochrosite.	Fault.
102 -178	Quartzite, altered, pale-gray micaceous with abundant pyrite	Busby(?) quartzite.

[1] Average Mn content of core for interval 82–102 ft, 11.2 percent.

DRILL HOLE C. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,079, feet; bearing: N. 17° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 10	Overburden.	
10 -118	Limestone, dark-gray mottled; much iron staining. Carbonates, manganoan, pale-pink to gray, at 90–95, 102–107, 108–109, 112–114.	Limestone B.
118 -120	Gouge, soft gray; much pyrite	Fault(?)
120 -122	Sandstone, massive white	Shale 1.
122 -127.1	Sandstone, limy, sheared and altered. Pale rhodochrosite at 126.8–127.1.	Dolomite A.
127.1-135	Dolomite, sandy, altered micaceous.	
135 -194	Quartzite, altered and sheared white micaceous; abundant disseminated pyrite.	Busby(?) quartzite.
194 -213	Porphyry, altered	Porphyry.
213 -255	Quartzite; white massive, abundant pyrite	Busby(?) quartzite.

[1] Average Mn content of core for interval 90–138 ft, 12.1 percent.

DRILL HOLE D. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,035 feet; bearing: N. 75° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 -28	Overburden.	
28 -35	Manganese oxide, possible; no core recovery	Limestone B(?)
35 -42.5	Sandstone, altered; small amounts of rhodochrosite	Shale 1.
42.5-48.7	Partly oxidized ore(?); no core	Dolomite A(?)
48.7-65	Rhodochrosite, vuggy, pink and gray.	
65 -70	Shale, altered, grayish-green	Busby(?) quartzite.
70 -86	Quartzite, pale-gray, micaceous.	

[1] Average Mn content of cores for intervals: 35–40 ft, 10.3 percent; 40–48.7 ft 5.0 percent; 48.7–65.0 ft, 29.5 percent; 65–70 ft, 13.1 percent.

DRILL HOLE E. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,047 feet; bearing: N. 75° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 15.2	Overburden.	
15.2-44.1	Limestone, light-gray, crystalline	Limestone B.
44.1-46.4	Shale, sheared, black; disseminated pyrite.	
46.4-73.7	Limestone, mottled, light- to dark-gray.	
73.7-76	Limestone, angular fragments in pyritized fault gouge	Fault.
76-88	Sandstone; abundant pyrite. Bedding 55° to core	Shale 1.
88-94	Shale and sandstone, limy, sheared and altered; abundant pyrite; traces of pink rhodochrosite.	Dolomite A.
94-95	Gouge	Fault.
95-126.5	Quartzite, gray, altered, micaceous	Busby(?) quartzite.
126.5-128	Porphyry, altered	Porphyry.
128-173.5	Quartzite, light-gray, micaceous; altered and sheared, at 131-135 feet.	Busby(?) quartzite.

[1] Average Mn content of core for interval 89-94 ft, 13.2 percent.

DRILL HOLE F. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,011 feet; bearing: N. 75° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 15	Overburden.	
15 - 30	Limestone, altered sandy; abundant iron and manganese oxides.	Limestone B.
30 - 39	Limestone, earthy, partly weathered, sandy.	
39 - 57.0	Limestone, light-gray, crystalline, sandy; manganoan dolomite visible at 52-54 and 55.5-57.	
57 - 61	Breccia, gouge and fault; much pyrite	Fault.
61 - 62.7	Dolomite, red, hematitic, manganoan.	
62.7- 63.7	Clay; with manganese oxides.	
63.7- 80.5	Limestone, pale- to dark-gray, mottled.	
80.5- 87.6	Sandstone, altered, sheared; much pyrite; some pink rhodochrosite 86-87.6.	Shale 1.
87.6- 96.8	Gouge; with gray rhodochrosite and manganoan dolomite	Dolomite A.
96.8- 98	Sandstone or quartzite altered; with abundant pyrite.	
98 - 120	Quartzite, altered, sheared and brecciated; with clay-filled partings; very abundant pyrite.	Busby(?) quartzite.

[1] Average Mn content of core for interval 25-97 ft, 12.5 percent.

DRILL HOLE G. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,027 feet; bearing: N. 75° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 7.2	Overburden.	
7.2- 24.5	Limestone, pale-gray, medium-grained, crystalline	Limestone C.
24.5- 28.5	Limestone, iron-stained; low core recovery	Fault(?).
28.5- 116	Limestone, light- to dark-gray, fine-grained; with irregular darker mottling.	Limestone B.
116 -118.5	Shale, dark-gray, limy.	
118.5- 134	Dolomite, pale-gray, sandy.	
134 -161.3	Sandstone, light-gray, quartzitic; bedding cuts core 60°.	
161.3-181	Porphyry, altered	Porphyry.
181 -182.8	Limestone, dolomitic, pale greenish-gray	Dolomite A.
182.8-184.3	Porphyry, altered.	
184.3-185.7	Limestone, dark-gray, fine-grained	Dolomite A.
185.7-188.6	Porphyry, altered.	
188.6 197	Dolomite, dark-gray, sandy; sandstone, and shale; abundant pyrite.	Dolomite A.
197 -265	Sandstone, gray; sparse argillaceous layers cut core at 65°	Busby(?) quartzite.

Drill hole H. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,989 feet; bearing: N. 75° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 -33	Overburden.	
33 -51	Clay, yellow and brown (altered and weathered shale)	Shale 2.
51 -61	Shale, limy, brecciated and sheared	Limestone B(?).
61 -64	Pyrite, almost solid	Fault zone.
64 -77.4	Shale and quartzite, brecciated, limy.	

Drill hole I. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,999 feet; bearing: N. 75° E., inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 15	Overburden.	
15 - 57.5	Limestone, pale-gray, crystalline, altered; some garnet. No core 18.1–22.3.	Limestone D and C.
57.5- 60	Calcite, coarse; manganese oxides	Fault(?).
60 - 62.5	Limestone, pale-gray, crystalline	Limestone B.
62.5- 64.5	Manganese oxides	Fault.
64.5- 86	Limestone, dark-gray, fine-grained; coarsens and bleaches downward; increasing pyrite.	Limestone B.
86 - 88.8	Gouge; sheared limestone and shale; much pyrite.	
88.8-128	Limestone, dark-gray; with some shaly streaks. Showings of gray and pink rhodochrosite from 106–108, 109–109.7, 111–115, 119.5–123, 124–128.	
128 -137.5	Limestone, oolitic, gray and white mottled.	
137.5-140	Shale, altered; some pink and gray rhodochrosite.	
140 -147	Rhodochrosite, pink and gray, vuggy.	
147 -161	Shale and sandstone, sheared and altered; abundant pyrite. Bedding angle 80° to core.	Shale 1.
161 -168.7	Rhodochrosite, gray and pink.	
168.7-174.7	No core.	
174.7-217.2	Quartzite, altered, shaly. Bedding angle 80° to core. Porphyry 194–198.	

[1] Average Mn content of core for interval 136–169 ft, 14.4 percent.

Drill hole J. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,981, feet; bearing: S. 40° E.; inclination: −50°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0- 5	Overburden.	
5- 40	Limestone, dark blue-gray, fine-grained; thin wavy beds of shale.	Limestone C.
40- 83	Limestone, massive, dark-gray	Limestone B.
83- 89	Limestone, altered, shaly; with stringers of manganoan carbonate.	
89–102	Manganese oxides; in altered shaly limestone.	
102–120	Shale, black; gray shaly sandstone with abundant pyrite	Shale 1.
120–130	Quartzite and shale, breccia, bleached; abundant pyrite	Fault.
130–205	Quartzite and sandstone, pale-gray to white	Busby(?) quartzite.

[1] Average Mn content for interval 88–105 ft, 14.3 percent.

DRILL HOLE K. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,977 feet; bearing: S. 40° E.; inclination −50°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 4	Overburden.	
4 -139	Limestone, dark-gray, fine-grained; with thin wavy argillaceous layers. Gray manganoan dolomite from 87.5 to 89, 102.8 to 104.8, 108 to 112, 119 to 119.5, 120 to 121.6, 123 to 124, and 134 to 138.	Limestone C.
139-150	Shale, black, sandy; shaly limestone	Shale 2.
150-170.5	Limestone, dark-gray, fine-grained	Limestone B.
170.5-195.5	Sandstone, shaly, dark-gray to black; very abundant pyrite	Shale 1.
195.5-200.5	Gouge and quartzite, brecciated; 20 percent core recovery	Dolomite A and fault.
200.5-212.1	Quartzite, gray, brecciated; impregnated with pyrite	Busby(?) quartzite.

[1] Average Mn content for interval 170–180 ft, 10.6 percent.

DRILL HOLE L. *Logged by J. A. Straczek, 1951*

[Elevation of collar: 5,619 feet; bearing: S. 40° E.; inclination: −50°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0- 3	Overburden.	
3- 82	Limestone, dark-gray, fine-grained; with thin wavy pinkish argillaceous bands. Some manganese oxides 54–56, 67.5–67.8, and 69.5–71.2.	Limestone C.
82- 98	Limestone, brown, sandy; with some mica flakes and manganese oxides.	Limestone B.
98-127	Sandstone, pale-gray; shaly	Shale 1.
127-153	Manganese oxides; very poor core recovery	Dolomite A.
153-164	Sandstone, pale-gray, altered; much pyrite	Busby(?) quartzite.

[1] Average Mn. content of core for interval 126–153 ft, 15.8 percent.

DRILL HOLE M. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,935 feet; bearing: S. 40° E.; inclination: −70°]

Interval (feet)	Description	Stratigraphic units and faults
0 - 2.3	Overburden.	
2.3 -101.2	Limestone, blue-gray; with thin wavy argillaceous layers	Limestone C.
101.2-104	Cavity	Fault.
104 -107	Aragonite veins, in breccia	

DRILL HOLE 1. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,141 feet; bearing: N. 75° E.; inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0 - 6.5	Overburden.	
6.5- 29	Limestone, pale-gray or white crystalline; iron stained	Limestone C.
29 - 36	No core. Sludge suggests porphyry	Porphyry.
36 -124	Porphyry, altered.	
124 -163.8	Limestone, dark-gray, mottled; locally bleached	Limestone 13.
163.8-166	Porphyry, pyritized.	
166 -170	Limestone, gray and white mottled, crystalline.	
170 -173	Porphyry.	
173 -180	Limestone, dark-gray, fine-grained.	
180 -187.1	Sandstone, quartzitic	Shale 1.

DRILL HOLE 2. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,102 feet; bearing: N. 75° E.; inclination: −60°]

Interval [1] (feet)	Description	Stratigraphic units and faults
0 - 3	Overburden.	
3 - 12	Limestone; bleached and altered; some garnet	Limestone B.
12 - 81.3	Limestone, pale-gray bleached and altered traces of manganese oxide from 40.5–54, and of manganoan carbonates from 59–81.3.	
81.3–101	Sandstone, pale-gray or greenish; traces of manganese oxide	Shale 1.
101 –105.9	Rhodochrosite, pink and gray; 17-percent core recovery	Dolomite A.
105.9–110.7	Dolomite, manganoan, white to gray; 40-percent core recovery.	
110.7–121.1	Limestone, gray, coarsely crystalline; increasingly bleached and altered toward base.	
121.1–127	Porphyry, altered	Porphyry.

[1] Average Mn. content of core for interval of 65–81 ft, 15.8 percent.

DRILL HOLE 3. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,069 feet; inclination: —Vertical]

Interval (feet)	Description	Stratigraphic units and faults
0– 6	Overburden.	
6– 46	Limestone, shaly, blue-gray; bedding 40°–60°	Limestone E.
46– 82	Shale, gray to yellow-brown; brecciation 57–58 and 81–82	Shale 4.
82–100	Limestone, gray to white, crystalline; brecciation at 86, 87, 89, and 93.	Limestone D.
100–116	Limestone, dark-gray; bedding 40°. Gouge zone 105–106.	
116–125	Limestone, intensely altered; porphyry with strong calcitic alteration, 118.5-120.	
125–170	Porphyry, altered; inclusions of limestone in upper half	Porphyry.
170–194	Limestone and dolomite, altered, hematite-stained; gray shale 175–177; bedding 45°.	Limestone C (?).
194–201	Calcite and limonite in breccia zone	Fault.
201–237	Limestone and dolomite, mottled dark- and light-gray, crystalline; reddish at base.	Limestone B.
237–253	Sandstone, gray; bedding 30°–40°	Shale 1.
253–259	Dolomite, sandy; dolomitic limestone	Dolomite A.
259–282	Porphyry, altered.	
282–296	Dolomite, sandy; dolomitic limestone	Dolomite A.
296–326.5	Sandstone, dark- to light-gray; dip 50°–55°	Busby(?) quartzite.

DRILL HOLE 4. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,997 feet; bearing: N. 75° E.; inclination: −60°]

Interval (feet)	Description	Stratigraphic units a d faults
0 - 13	Overburden..	
13 - 64	Limestone, pale-gray white or greenish, altered; with considerable garnet.	Limestone D to 40 ft.
64 –115	Limestone, pale-gray to dark-gray mottled	Linestone B.
115 –121	Rhodochrosite, pink and gray; (5.9 feet avg. 12.0 percent Mn).	
121 –133	Sandstone and shale, pale-gray; some pyrite and epidote	Shale 1.
133 –145.4	Rhodochrosite, gray and pink; some pale-green shale and gouge (12 feet average 23.1 percent Mn).	Dolomite A.
145.4–152.5	Sandstone, shaly; traces of manganoan dolomite	Dolomite A.
152.5–173	Shale and sandstone, greenish-gray; much pyrite	Busby (?) quartzite.

DRILL HOLE 5. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,001 feet; bearing: N. 75° E.; inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0 - 14.5	Overburden.	
14.5- 58.9	Limestone, dark-gray, pisolitic; with reddish argillaceous layers and seams.	Limestone D.
58.9- 66	No core.	Faults.
66 - 81	Shale, greenish-brown, well-bedded.	Shale 3.
81 -100	Limestone, pinkish-gray, altered; 25 percent core recovery.	Limestone C.
100 -110	Cavity.	Fault.
110 -156	Limestone, pale-gray, fine-grained, altered; Traces of manganoan carbonate 136–140, 144–145.7, 146–8–147.8, 150–151, partly oxidized manganoan dolomite, 151–056.	Limestone B.
156 -162	Sandstone, white, pyritized; and sandy shale.	Shale 1.
162 -167	Clay gouge.	
167 -172.5	Manganese oxides, glack; with clay and pyrite.	Dolomite A.
172.5-179.8	Gouge or clay, gray; traces of manganoan carbonate. (7.3 feet average 11.9 percent Mn.).	Dolomite A.
179.8-187.5	Rhodochrosite, pink and gray.	
187.5-204	Quartzite, gray; with shaly partings.	Busby (?) quartzite.
204 -209	Porphyry, pale-gray, altered.	

DRILL HOLE 6. *Logged by J. A. Straczek, 1941*

[Elevation of collar; 5,977 feet; bearing: N. 75° E., inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0 - 19.5	Overburden.	
19.5- 34	Shale, greenish-brown, well-bedded; with some oolitic limestone.	Shale 4.
34 -103.5	Limestone, pale-gray, bleached and altered, oolitic; some garnet, and pyrite.	Limestone D.
103.5-107	Limestone, gray, altered, oolitic; and manganoan dolomite.	
107 -116	Dolomite, gray, crystalline, .8 feet; .8 feet gray rhodochrosite, and .3–.4 feet hard quartzite fragments (pebble dike). Two feet of core recovered.	Faults.
116 -123	Shale, gray, altered, pyritized; with a trace of manganoan carbonate. (30 percent core recovery.)	Limestone B.(?).
123 -131	Shale, altered, sandy; dense gray quartzite fragments. (Pebble dike?) (15 percent core recovery.)	
131 -140	Shale, gray to black, sulfide-bearing; fragments of white quartzite and traces of rhodochrosite; 18 percent core recovery.	
140 -153	Limestone, gray, dolomitic: traces of manganoan dolomite; 50 percent core recovery.	
153 -174	Dolomite, gray, mottled; some greenish tactite (20 percent core recovery).	(?)
174 -182	Mostly altered porphyry, (30 percent core recovery).	
182 -195	Breccia and gouge of pyritized shale and quartzite, Some rhodochrosite (6 feet average 13 percent Mn.) (30 percent core recovery.)	(?)
195 -224	Quartzite, gray; much pyrite to 211, decreasing to end of hole.	Busby(?) quartzite.

DRILL HOLE 7. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,982 feet; bearing: N. 75° E., inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0 - 17	Overburden.	
17 - 77	Limestone, gray to greenish-gray, mottled, oolitic	Limestone D.
77 - 99	Limestone, shaly, pale-gray to greenish, altered	
99 -123	Porphyry, altered.	
123 -131	Jasperoid; 20 percent core recovery.	Fault.
131 -142	Porphyry, altered; limestone inclusion, 139.5-140.5.	
142 -185.5	Limestone, gray to white, altered and bleached,	Limestone B.
185.5-187.5	Porphyry.	
187.5-204	Limestone, altered, crystalline.	
204 -212	Limestone sheared, shaly; 30 percent core recovery.	
212 -225	Dolomite, mottled, light-gray, manganoan; 11.5 percent core recovery.	
225 -231	No core; sludge indicates some manganese oxide.	
231 -247.5	Limestone and dolomite, gray to white, crystalline; traces of manganese oxide. Much limonite and hematite.	
247.5-263	Shale, brown; and shaly sandstone.	Shale 1.
263 -268	Sandstone, dolomitic.	Dolomite A.
268 -285	Sandstone, shaly to massive	Busby(?) quartzite.

DRILL HOLE 9. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,135 feet; bearing: N. 75° E., inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0 - 4	Overburden.	
4 - 35	Limestone, dark-gray; traces of garnet	Limestone C.
35 - 75	Limestone, dark-gray; with thin wavy argillaceous partings, becoming bleached downward.	
75 -205	Porphyry, altered and kaolinized near contacts	Porphyry. In fault.
205 -246	Limestone and dolomite, white to gray, altered; porphyry sills from 210-214, 219-220, 229-231, and 234.5-235	Limestone B.
246 -268	Sandstone and shaly sandstone; bedding cuts core at 90°	Shale 1.
268 -284	Dolomite, sandy; and dolomitic sandstone	Dolomite A.
284 -290	Sandstone and quartzite pale-gray	Busby(?) quartzite.

DRILL HOLE 10. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,100 feet; inclination: Vertical]

Interval (feet)	Description	Stratigraphic units and faults
0- 7	Limestone, blue-gray	Limestone D.
7- 41	Shale, brown-weathering; with oolitic limestone bed at 19-21 feet; probable fault at 30 feet.	Shale 3.
41-113	Limestone, massive, gray, crystalline; breccia zone 76-77 feet	Limestone C.
113-128	Limestone and shale breccia; traces of manganoan carbonate	Fault.
128-190	Limestone, white, altered; much garnet	Limestone B.
190-210	Sandstone, pale-gray, altered; some shaly sandstone	Shale 1.
210-228	Limestone and dolomite, mottled, gray, crystalline	Dolomite A.
228-238	Shale, altered; and clay gouge	

DRILL HOLE 11B. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,010 feet; inclination: Vertical]

Interval (feet)	Description	Stratigraphic units and faults
0– 46	Limestone, blue-gray—dips 40°-60°	Limestone E.
46– 81	Shale, gray to yellow-brown	Shale 4.
81– 82	Breccia	Fault.
82–118	Limestone and dolomite, dark-gray to white (bleached); breccia zones at 86, 87, 89, 105–106, and 116–118.	Limestone D.
118–120	Porphyry, altered; strong calcitic alteration	Porphyry.
120–125	Limestone, bleached and altered	
125–170	Porphyry, altered	Porphyry.
170–191	Limestone, altered and iron-stained	Limestone C.
191–201	Breccia of limestone and calcite, iron-stained	Fault.
201–237	Dolomite and limestone, mottled dark- and light-gray	Limestone B.
237–253	Sandstone, gray and sandy shale; dip 30°–40°	Shale 1.
253–259	Dolomite, sandy; and dolomitic limestone	Dolomite A.
259–283	Porphyry, altered	Porphyry.
283–296	Dolomite, sandy; and dolomitic sandstone	Dolomite A.
296–326	Sandstone, dark- to light-gray	Busby(?) quartzite.

DRILL HOLE 12. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,012 feet; inclination: Vertical]

Interval (feet)	Description	Stratigraphic units and faults
0 - 12	Overburden	
12 - 20	Limestone, white to light-brown, massive	Limestone D.
20 - 46	Shale, gray to brown; breccia zone 30–31 feet	Shale 3.
46 - 91	Limestone, with gray, crystalline, oolitic; with thin wavy argillaceous beds.	Limestone C(?).
91 - 97.5	No core	Fault(?).
97.5–155	Limestone, reddish to white, crystalline	Limestone C.
155 –162	Clay gouge	Fault(?)
162 –173	Limestone, reddish, crystalline, stained by hematite	Limestone B.
173 –190	Sandstone, brown; shaly sandstone	Shale 1.
190 –201	Limestone, pale-gray, dolomitic; shaly sandstone	Dolomite A.
201 –202	Porphyry, altered	

DRILL HOLE 21. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 6,012 feet; bearing: S. 65° E.; inclination: −60°]

Interval (feet)	Description [1]	Stratigraphic units and faults
0– 77	Limestone, dark-gray; with thin wavy partings	Limestone C.
77– 89	Shale, yellow-brown	Shale 2.
89–110	Limestone, dark-gray, crystalline	Limestone B.
110–115	Cavity	
115–163	Limestone, dary-gray, crystalline; no core or sludge, 139–145	Limestone B.
163–174	Sandstone and shaly sandstone	Shale 1.
174–189	Sandstone, dolomitic, and sandy dolomite	Dolomite A(?).
189–199	Quartzite and sandstone	Busby(?) quartzite.

[1] Log reconstructed from drill hole sections.

DRILL HOLE 22. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 5,975 feet; bearing: S. 65° E.; inclination: −60°]

Interval (feet)	Description [1]	Stratigraphic units and faults
0–103	Limestone, dark-gray, fine-grained	Limestone C.
103–114	Sandstone, dark-gray, limy and black shale	Shale 2.
114–194	Limestone, dark-gray, crystalline, small amounts of manganese oxide 184–190.	Limestone B.
194–197	Breccia zone	
197–253	Sandstone, dark-gray; and shaly quartzite; much pyrite	Busby(?) quartzite.

[1] Log reconstructed from cross section.

DRILL HOLE 23A. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 5,975 feet; bearing: S. 60° E.; inclination: −60°]

Interval [1] (feet)	Description [2]	Stratigraphic units and faults
0– 76	Limestone, dark-gray, fine-grained; thin wavy layers	Limestone C.
76– 96	Limestone, dark-gray, strongly brecciated	Fault.
96–150	Limestone, dark-gray, crystalline; breccia zone 138–140	Limestone B.
150–157	Shale and sandstone, altered	Shale 1.
157–166	No core; sludge indicates manganese oxides	
166–188	Manganese oxides	Dolomite A.
188–220	Sandstone and quartzite, gray	Busby(?) quartzite.

[1] Average Mn content of core for interval 161–188.6 feet., 16.1 percent.
[2] Log reconstructed from cross sections.

DRILL HOLE 25. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 6,012 feet; bearing: S. 40° E.; inclination: −50°]

Interval (feet)	Description [1]	Stratigraphic units and faults
0– 46	Limestone, dark-gray, fine-grained	Limestone C.
46– 54	Limestone, dark-gray, shaly.	
54– 64	Limestone, dark-gray.	
64– 70	Breccia zone in limestone	Fault.
70– 74	Gouge and breccia.	
74– 88	Sandstone and shaly sandstone, dark-gray	Shale 1.
88–103	Manganese oxides; avg. 13.4 percent Mn	Dolomite A.
103–121	Sandstone and quartzite, dark-gray	Busby(?) quartzite.

[1] Log reconstructed from cross sections.

DRILL HOLE 26. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,931 feet; bearing: S. 40° E.; inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0–187	Limestone, blue-gray, fine-grained; with thin wavy argillaceous partings.	Limestone C.
187–198	Sandstone and shale, brown, limonite-stained	Shale 2.
198–204	Limestone, pinkish, dolomitic	Limestone B.
204–209	Cavity	Faults.
209–215	Calcite veins.	
215–224	Cavity.	

DRILL HOLE 27. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 5,957 feet; bearing: S. 65° E.; inclination: −60°]

Interval (feet)	Description	Stratigraphic units and faults
0– 44	Limestone, dark-gray to black, oolitic	Limestone C.
44–164	Limestone, dark-gray; with wavy argillaceous layers.	
164–176	Shale and sandstone, greenish; bedding cuts core at 60°	Shale 2.
176–214	Limestone, gray, locally sandy; breccia zones 200–204	Limestone B.
214–230	Dolomite and dolomitic limestone, reddish; much iron oxide.	
230–246	Sandstone and shaly sandstone, iron-stained	Shale 1.
246–254	No core—sludge heavy with pyrite	Fault.
254–274	Sandstone, massive, pyritized; 20 percent core recovery	Busby(?) quartzite.

DRILL HOLE 30. *Logged by J. A. Straczek, 1941*

[Elevation of collar: 6,022 feet; bearing: S. 65° E.; inclination: −60°]

Interval (feet)	Description [1]	Stratigraphic units and faults
0– 17	Limestone, fine-grained, dark-gray	Limestone C.
17– 29	Shale, brown; and shaly sandstone	Shale 2.
29–117	Limestone, dark-gray, crystalline; traces of manganese and iron oxide from 110–117.	Limestone B.
117–136	Sandstone, dark-gray; and shaly sandstone	Shale 1.
136–158	Sandstone, dolomitic	Dolomite A.
158–174	Quartzite and sandstone, shaly	Busby(?) quartzite.

[1] Log reconstructed from cross section.

DRILL HOLE 34. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 5,984 feet; bearing: S. 65° E.; inclination: −60°]

Interval (feet)	Description [1]	Stratigraphic units and faults
0– 37	Shale and shaly limestone, brown-weathering; 2 feet of oolitic limestone from 5–7 feet.	Shale 3.
37–239	Limestone, dark-gray, fine-grained; with thin wavy argillaceous partings.	Limestone C.
239–251	Sandstone, dark-gray to brown, shaly and dolomitic	Shale 2.
251–289	Limestone, dark-gray, crystalline; and dolomite	Limestone B.
289–301	No core, sludge 12.0 feet avg. 32 percent Mn.	
301–306	Dolomite, altered, sandy	Dolomite A.
306–322	Quartzite and sandstone, altered, dark-gray; much pyrite	Busby(?) quartzite.

[1] Log reconstructed from cross section.

DRILL HOLE 35. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 5,980 feet; bearing: S. 65° E.; inclination:−60°]

Interval [1] (feet)	Description [2]	Stratigraphic units and faults
0– 34	Limestone, dark-gray, oolitic	Limestone D.
34– 78	Shale, yellow-brown; 2 feet of oolitic limestone, 47 feet to 49 feet.	Shale 3.
78–276	Limestone, dark-gray, fine-grained	Limestone C.
276–289	Shale and sandy shale, dark-gray; with 10 percent pyrite	Shale 2.
289–297	Sandstone, dolomitic	?
297–306	Sandstone, brown	Limestone B(?)
306–307	Gouge.	
307–315	Dolomite, sandy.	
315–321	Limestone, altered.	
321–327	Shale, calcareous.	
327–343	Sandstone, dolomitic; and sandstone	Shale 1(?)
343–365	Quartzite, altered	Busby(?) quartzite.

[1] Average Mn content of core interval 319–323, 12.5 percent.
[2] Log reconstructed from cross section.

DRILL HOLE 37. *Originally logged by J. A. Straczek, 1941*

[Elevation of collar: 6,002 feet; bearing: S. 65° E.; inclination: −60°]

Interval (feet)	Description [1]	Stratigraphic units and faults
0– 10	Limestone, dark-gray, oolitic	Limestone D.
10– 61	Shale, limy, yellow-brown; oolitic limestone 24–26	Shale 3.
61–247	Limestone, dark-gray; with wavy argillaceous partings; brecciation 210–220.	Limestone C.
247–262	Shale	Shale 2.
262–317	Limestone, dark-gray crystalline; breccia zones at 264 and 268–270.	Limestone B.
317–323	Manganese oxides; 5.7 feet avg. 12.9 percent Mn	Faults.
323–328	Sandstone, dolomitic	Dolomite A.
328–356	Sandstone, quartzitic	Busby(?) quartzite.

[1] Log reconstructed from drill hole section.

DRILL HOLE 101. *Logged by M. D. Crittenden and W. H. King, 1945*

[Elevation of collar: 5,965 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description	Stratigraphic units and faults
0 – 9	0	Overburden.	
9 – 82	51	Limestone, blue-gray, crystalline; with wavy argillaceous bands ¼–½ inch thick; dip 30°; brecciation and faulting at 20–21, 24, and 50.5 to 55 ft.	Limestone C.
82 – 84	30	Gouge, soft; stained by manganese and iron oxides	Fault.
84 –107	37	Dolomite, brecciated, coarsely crystalline (hydrothermal); traces of rhodochrosite and pyrite; some iron and manganese oxide.	Limestone B.
107 –123.5	18	Limestone, dark-gray; with sparse argillaceous bands.	
123.5–124.5	50	Manganese oxide; estimated 15–20 percent Mn.	
124.5–125.5	100	Quartzite, white	Shale 1.
125.5–149	28	Shale and quartzite, altered, sandy.	
149 –157	0	No core	Dolomite A.
157 –165	0	Pyrolusite, fragments, hard spongy; estimated 20–25 percent Mn.	
165 –169	11	Quartzite sheared; and gouge, abundant pyrite.	
169 –207	79	Quartzite, white or greenish, micaceous; abundant pyrite, locally oxidized; dip 30°–40°.	Busby(?) quartzite.

DRILL HOLE 102. *Logged by M. D. Crittenden, 1945*

[Elevation of collar: 5,950 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description	Stratigraphic units and fault
0– 24	Lost		
24–145	99	Limestone, blue-gray fine-grained; with ¼–½ inch dark-gray wavy bands of silty limestone. More massive 136–145, 35°.	Limestone C.
145–156	68	Shale, light-gray to tan; trace of pyrite; some shearing.	Shale 2.
156–196	100	Marble, light-gray, coarse-grained; and fine-grained limestone.	Limestone B.
196–215	94	Limestone, iron-stained, medium- to coarse-grained; some brecciation.	Fault.
215–221	41	Sandstone or quartzite, altered; with stringers of manganese and iron oxide.	Busby(?) quartzite.
221–240	31	Quartzite, altered shaly and micaceous; some pyrite.	

DRILL HOLE 103. *Logged by M. D. Crittenden, 1945*

[Elevation of collar: 5,998 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description	Stratigraphic units and faults
0- 12		No core.	
12-137	100	Limestone, dark blue-gray, fine-grained; with wavy bands of dark silty limestone at 4-inch to 10-inch intervals.	Limestone C.
137-147	92	Shale, thin-bedded, black; with ¼-½ inch beds of limestone.	Shale 2.
147-244	98	Limestone, dark-gray, medium-grained; with irregular stylolitic partings; breccia zones at 177-179, 207.5, and 220-222.5. Unit becomes increasingly coarse grained, dolomitic, and sandy near base.	Limestone B.
244-266	85	Shale and shaly quartzite, altered, greenish-gray, micaceous.	Shale 1 and Dolomite A.
266-320	64	Quartzite, coarse-grained, micaceous; with some greenish micaceous shale.	Busby(?) quartzite.

DRILL HOLE 104. *Logged by M. D. Crittenden, 1945*

[Elevation of collar: 5,952 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description	Stratigraphic units and faults
0- 12	0	Overburden.	
12-163	98	Limestone, dark-gray, fine-grained; with thin wavy argillaceous layers. Few stringers of manganese oxide 162-163 feet.	Limestone C.
163-175	87	Shale, thin-bedded, greenish-gray; with abundant pyrite.	Shale 2.
175-292	76	Limestone, dark-gray, medium-grained; locally stained yellowish gray. Open cavities 221-223, 228-240. Pale tan travertine 240-246.	Limestone B. Faults.
292-308	97	Quartzite, gray; and greenish-gray micaceous shale	Shale 1.
308-339	86	Dolomite, reddish or gray, micaceous, sandy; and sandy shale.	Dolomite A.
339-372	85	Quartzite and shale, white or micaceous	Busby(?) quartzite.

DRILL HOLE 105. *Logged by M. D. Crittenden, 1945*

[Elevation of collar: 5,945 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description	Stratigraphic units and faults
0- 11	0	Overburden.	
11-170	86	Limestone, dark blue-gray; with wavy argillaceous layers.	Limestone C.
170-182	18.7	Shale, buff, thin-bedded; and shaly limestone	Shale 2.
182-206	15	Calcite, vuggy, white to tan, limonite-stained	Limestone B.
206-292	91	Limestone, white to gray; irregularly spotted or mottled with dark gray.	
292-296	95	Quartzite, white, vitreous	Shale 1 and dolomite A.
296-338	96	Shale, greenish or gray; and coarse-grained dolomite becoming quartzitic downward.	
338-391	90	Quartzite, gray or purplish; and greenish micaceous shale.	Busby(?) quartzite.

DRILL HOLE 106. *Logged by M. D. Crittenden, 1945*

[Elevation of collar: 5,927 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description	Stratigraphic units and faults
0- 14	0	Overburden.	
14-233	94	Limestone, blue-gray, fine-grained; with thin wavy argillaceous bands at 2-inch to 6-inch intervals.	Limestone C.
233-243	100	Shale, yellowish, thin-bedded, sandy	Shale 2.
243-331.5	98	Limestone, massive, gray; with irregular dark mottling. Gouge zone 274-277.	Limestone B.
331.5-348	58	Quartzite and micaceous shale, white and gray	Shale 1.
348 -375	84	Limestone, gray, dolomitic; and greenish micaceous dolomitic sandstone; considerable pyrite.	Dolomite A.
375 -396	100	Quartzite, reddish, faintly dolomitic; and greenish-gray micaceous shale; abundant pyrite.	Busby(?) quartzite.

DRILL HOLE 107. *Logged by M. D. Crittenden, 1945*

[Elevation of collar: 5,987 feet; inclination: Vertical]

Interval (feet)	Percent core recovery	Description
0- 27	0	Overburden.
27- 57	0	Clay, brown; derived from porphyry.
57-286	85	Porphyry, massive; phenocrysts one-fourth to half an inch across, in greenish-gray dense groundmass. Zone of shearing and pyrite at 205. Strong calcitic alteration at 242-248.
286-300	0	Lost core.

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INDEX

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