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MANGANESE DEPOSITS AT PHILIPSBURG GRANITE COUNTY, MONTANA

A PRELIMINARY REPORT

BY

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ABSTRACT

The Philipsburg district, in western Montana 45 miles northwest of Butte, is primarily a silver camp, but since 1916 it has been the chief source of manganese ore in the United States. During the World War it produced about 200,000 tons of metallurgical ore, and since 1919 it has had a small but steady production of ore used in making dry-cell batteries. The total output of high-grade ore has amounted to about 477,000 tons.

The district is in a region of rather complex overthrusts, but the local structure is relatively simple. A low arch of Paleozoic limestones has been cut and deformed on the east and south sides by a small batholith of Tertiary granodiorite. The southern part of the arch has been eroded to expose early Cambrian and pre-Cambrian quartzites.

The manganese deposits are confined to an area of about 2 square miles underlain by sedimentary rocks and adjacent to the granodiorite body. They form irregular and tabular bodies in the limestones bordering east-west steeply dipping silver-zinc veins. The ore, chiefly pyrolusite, was apparently derived from rhodochrosite that was abundant in the veins and had replaced the adjacent limestones. The oxide ore is found chiefly within 600 feet of the surface, though one small body was mined at a depth of 700 feet. Below the oxidized zone rhodochrosite is locally abundant in and along some of the veins, but no commercial bodies have yet been found.

Most of the ore mined has contained between 30 and 43 percent of manganese, but recently ore containing as little as 15 percent has been taken out. The crude ore is milled at Philipsburg to concentrates containing about 70 percent of manganese dioxide (MnO_2), which is equivalent to 44 percent of metallic manganese.

Production at Philipsburg has followed development work so closely that there is little reserve ore in sight. However, the reasonably possible reserves of minable oxide ore probably amount to several hundred thousand tons. Workable bodies of rhodochrosite ore may also possibly be found at depth.

INTRODUCTION

The Philipsburg district, Montana, has been the chief source of manganese ore in the United States. The entire production has come from oxide ore bodies, though rhodochrosite, the manganese carbonate, is abundant in some of the mines. When the Strategic Minerals bill was enacted (Public 117, 76th Cong., 1st Sess.) the writer was assigned to make a detailed study of the district with a view to determining the reserves of oxide ore and the possibilities of finding minable bodies of rhodochrosite ore at depth. The field work occupied 2½ months in the late summer and fall of 1939. The writer was assisted by Glenn Reed, E. P. Kaiser, and W. T. Pecora. The work was under the direction of J. T. Pardee. The writer wishes to express his appreciation to the mining men of the district for their wholehearted help and cooperation. Chemical analyses of manganese carbonate ore were made by J. J. Fahey, of the Geological Survey, and production data were kindly furnished by R. H. Ridgway, of the Bureau of Mines.

The Philipsburg district in Granite County, western Montana, 45 miles northwest of Butte (see fig. 31) comprises an indefinitely bounded area of 7 or 8 square miles on the west slope of the Flint Creek Range; but the manganese is produced from an area of about 2 square miles just east of the town of Philipsburg. The town has a population of about 1,300, is the terminus of a branch of the Northern Pacific Railway that joins the main line at Drummond, and is readily accessible by good paved highways from Drummond, Anaconda, and Butte.

The district is in the north-central part of the Philipsburg quadrangle, the geology and ore deposits of which were described by Emmons and Calkins about 25 years ago.[1] The manganese deposits of the district were described by Pardee[2] in 1921. To these reports the present paper adds information on the ore deposits obtained from the later mine developments and geologic details whose representation has been made possible by a larger-scale topographic base map.

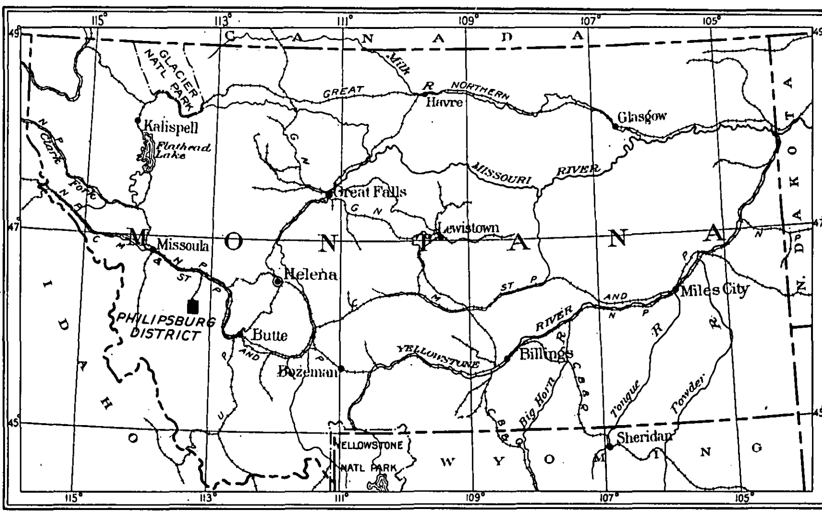

Figure 31.--Index map of Montana showing the location of the Philipsburg district.

1/ Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, 271 pp., 1913. Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Philipsburg folio (no. 196), 26 pp., 1915.

2/ Pardee, J. T., Deposits of manganese in Montana, Utah, Oregon, and Washington: U. S. Geol. Survey Bull. 725, pp. 146-174, 1921.

HISTORY AND PRODUCTION

Mining activity in the Philipsburg district began in 1864 with the discovery of rich silver ore at the Hope mine, just north of the manganese-producing area. By 1890 the district had become one of the most productive silver camps in the country. After the decline in the price of silver in 1892 mining activity was greatly curtailed and remained largely dormant until a demand for manganese was created by the World War in 1916.

The presence of abundant manganese oxide at Philipsburg was apparently unknown outside the district until a small shipment of ore was made from the Coyle mine in 1900.[3] The extensive production that began in 1916 in response to the demand for manganese in the steel industry increased rapidly to a peak in 1918, when 127,415 tons of high-grade manganese ore was shipped. After the end of the war Philipsburg, owing to its distance from the principal steel manufacturing centers, was unable to compete in the metallurgical market with other sources of manganese; however, the ore after concentration proved to be well-suited for use in dry batteries, and since 1918 between 5,000 and 28,000 tons of manganese dioxide concentrate for battery use has been shipped annually. Of four concentrating mills built at different times two remain, each of about 50-ton capacity. One of these, the Trout mill, at the Trout mine near the center of the district, uses tables and flotation; the other, the Moorlight mill, at the south edge of town, uses both a wet process and dry magnetic separation. The two mills operated near capacity in 1939.

3/ Pardee, J. T., op. cit., p. 146, 1921.

The total output of manganese ore from the Philipsburg district prior to Oct. 31, 1939, has amounted to 477,040 long tons of high-grade ore and concentrates, 116,362 long tons of tailings averaging about 20 percent of manganese, and 2,376 long tons of low-grade crude ore containing about 20 percent of manganese. The yearly output is given in the following table:

Production, in long tons, of manganese ore from the Philipsburg district, 1900-1939

[Data furnished by R. H. Ridgway, Bureau of Mines]

Year	Crude ore and concentrates containing 35% or more of manganese	Tailings containing 10-21% of manganese	Low-grade crude ore containing about 20% of manganese
1900	1/ 137	...	...
1916	3,230	...	...
1917	59,327	...	...
1918	127,415	...	...
1919	21,343	...	...
1920	20,176	...	...
1921	11,101	...	...
1922	9,706	...	...
1923	20,540	...	...
1924	23,526	...	...
1925	28,681	...	...
1926	16,641	...	...
1927	22,392	10,332	...
1928	15,124	11,156	215
1929	12,770	15,665	...
1930	11,771	11,875	...
1931	8,204	14,311	...
1932	7,012	...	...
1933	8,071	...	...
1934	9,345	10,278	969
1935	7,783	6,818	...
1936	10,551	20,307	...
1937	8,814	14,336	...
1938	5,619	319	...
1939	7,761	929	1,192
Total	477,040	116,326	2,376

1/ From Pardee, J. T., op. cit. (Bull. 725), p. 147.

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GEOLOGY

The part of the Philipsburg district described is an area of sedimentary rocks, chiefly limestones, that range in age from pre-Cambrian to Carboniferous. They are bordered on the east and south by intrusive granodiorite of probable Tertiary age and thus occupy a re-entrant in the granodiorite area. The apex of this re-entrant is near Hasmark. The sedimentary rocks have been folded into the low Philipsburg anticline, which plunges to the north. The granodiorite invades the eastern limb on this fold and on the south cuts across its axis.

Sedimentary rocks

The distribution of the sedimentary formations is shown on plate 26. Their general character, succession, and thickness are given in the table on pages 164-165.

Granodiorite

On the south and east the sedimentary rocks are intruded by the Philipsburg granodiorite batholith,[4] which occupies about 50 square miles. In the northwest corner of the area a small mass of altered granodiorite is poorly exposed, and just southeast of Philipsburg are two small areas of large granodiorite boulders that appear to be residual from granodiorite bodies. The three are probably offshoots from the main body which, as suggested by the areal extent of the contact-metamorphic rocks described below, may be present at no great depth in the south half of the manganiferous area.

In the eastern part of the district several small tongues and sills of granodiorite extend out into the sedimentary rocks, and aplite sills a few inches to a few feet wide are found as much as 500 feet from the contact. In numerous places near the contact the granodiorite contains inclusions of sedimentary rock that have been changed to lime-silicate rock, some of which shows granitic texture.

4/ Emmons, W. H., and Calkins, F. C., op. cit., pp. 97-99.

Contact metamorphism

The effects of the granodiorite intrusion are noticeable throughout a zone extending outward for distances ranging from a quarter of a mile to a mile from the contact. This zone includes practically all the areas of Hasmark and underlying formations and parts of overlying formations. The effects are most intense, of course, adjacent to the main intrusive body, but they are strongly developed also in narrow zones that border the small offshoots, including the aplite sills.

Large outcrops representing the Silver Hill formation on West Algonquin Hill and the Red Lion in the Hasmark re-entrant are composed almost entirely of garnet, green amphibole, and other silicates. Fine-grained silicate layers of the same type but less prominent are found near the base of the Maywood formation. Other parts of these formations are changed to a banded hornstone that has a distinctive appearance owing to alternating thin layers of silicates and marble. Among the silicates a pale-pink mineral--thulite--which contains an appreciable amount of manganese, occurs at three horizons--the top of the Silver Hill, near the top of the Hasmark, and near the base of the Maywood. Near the main contact much magnetite has been introduced, chiefly in the Hasmark formation, in the form of grains and aggregates which in the Redemption, Hanna, and Climax mines form bodies large anough to be workable.

Throughout most of the metamorphic zone the massive limestones have been altered to medium-grained crystalline marble, and beyond the outer limit of this change felted aggregates of fine tremolite needles are developed in places. Metamorphism has changed the generally prevailing reddish tints in the Spokane formation to green but has produced no very striking effects on the Flathead quartzite.

Sedimentary rocks in the Philipsburg district

Age	Formation	Thickness (feet)	Character
Quaternary.	Alluvium.		
Tertiary.	Terrace gravels.		
	"Lake Beds."		Gray and reddish-gray water-laid fine-grained tuff (volcanic ash) partly altered to clay.
Carboniferous.	Phosphoria formation.	180	Yellowish-brown sandstone, quartzite, and red to brown shale. Thin layers of phosphate rock near bottom.
	Quadrant quartzite.	300-325	Massive white to brown quartzite.
	Madison limestone.	1,400-1,500	Dark blue-gray limestone; chert locally abundant.
Devonian.	Jefferson limestone.	1,000-1,300	Massive blue-gray limestone; some chert near the top. Near the granodiorite contact the limestone is altered to a white medium-grained marble that shows a yellowish tint on weathered surfaces.
Silurian (?).	Maywood formation.	210-490	Fine-grained moderately thin-bedded sandy limestone, greenish to brownish-gray when fresh; weathers to tawny soil. 5-foot layer of banded white and gray shale at base. In a few places near the granodiorite the Maywood has been metamorphosed to a fine-grained silicate rock.

Cambrian.	Red Lion formation.	225-350	Chiefly thin-bedded shaly limestone with wavy discontinuous bands of yellowish shale. Shale bands a fraction of an inch to 1 inch apart abundant in lower part but decreasing toward top. Upper part largely massive gray limestone. At top a 2- to 8-foot bed of rather pure limestone that resembles the Hasmark. Below this a 4- to 12-foot layer of dense, fine-grained gray to brown shaly limestone. In places near the granodiorite the Red Lion has been metamorphosed to a banded garnet-amphibole rock like that in the Silver Hill.
	Hasmark formation.	800-1,000	Where not metamorphosed is a massive blue-gray, medium-to fine-grained dolomitic limestone. In most of the productive area is metamorphosed to a medium-grained white marble. In a few places discontinuous shale layers 3 to 4 feet thick inter-bedded with the limestone or marble. Apparently absent in this area is a 150-foot shale member occurring in other areas near the middle of the formation.
	Silver Hill formation.	320	Thin beds of nearly pure, pale limestone alternating with thinner and slightly wavy layers of brown siliceous shale. Much of this formation in the district has been metamorphosed to a banded rock composed chiefly of marble, garnet, and green amphibole. At the base, 70 feet of dark gray shale largely changed to a nearly black thin-layered hornstone, locally showing gray spots composed of silicate minerals.
	Flathead quartzite.	135	Alternating layers of white to gray quartzite and thin-bedded dark gray shaly quartzite; 25 feet of massive, coarse-grained, white quartzite at base.
Unconformity			
Pre-Cambrian.	Spokane formation.	300+ (Total thickness in quadrangle 5,000)	Fine-grained greenish gray impure quartzite, thin-bedded and banded with dark green shaly streaks. Cross bedding prominent.

STRUCTURE

The structure of the Philipsburg quadrangle is rather complex,[5] and in much of the area the sedimentary rocks are intricately folded and faulted.

The western part of the quadrangle is occupied by a large mass of pre-Cambrian rocks that has been thrust eastward and over younger rocks. The fault plane was subsequently folded and a part of its trace on the present surface lies a short distance west of the Philipsburg district. In the vicinity of Philipsburg the sedimentary rocks are bent into a northward-plunging arch, called the Philipsburg anticline, which extends a few miles north of the district and gives place at the northwest to more complicated structure.

The Philipsburg anticline is a broad arch (pl. 26) that plunges 17°-35° N. Dips on the east limb range between 30° and 55° and on the west limb between 40° and 70°. In the northern part of the district, on the north side of Poorman Hill, a crenulation on the nose of the anticline forms two minor anticlines with a syncline between. In the northwestern corner of the area the west limb of the anticline turns into a rather sharp syncline that contains the Phosphoria formation.[6]

On the east limb of the Philipsburg anticline the Hasmark formation shows a pronounced thinning, its normal thickness of about 1,000 feet being reduced to a minimum of 350 feet; the thin-bedded shaly limestone formations also show a slight thinning. No evidence whatever can be found of a fault that would account for this condition. On the contrary all available evidence seems to indicate that the thinning has resulted from squeezing of the east limb of the arch by outward pressure exerted toward the west by the intruding granodiorite. In the

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5/ Emmons, W. H., and Calkins, F. C., op. cit. (Prof. Paper 78), pl. 1. Calkins, F. C., and Emmons, W. H., op. cit. (Philipsburg folio), pp. 18-21.

6/ Pardee, J. T., Phosphate rock near Maxville, Philipsburg, and Avon, Mont.: U. S. Geol. Survey Bull. 847, pl. 29, 1936.

thin part of the Hasmark the grains of marble are elongated in an east-west direction with a pitch of about 35°-62° E. Such flow structure, which does not appear elsewhere in the Hasmark, seems strongly indicative of a squeezing of the Hasmark during the intrusion of the granodiorite. In the Silver Hill, Red Lion, and Maywood formations the flow structure is obscure, as recrystallization did not progress far in these formations. The Jefferson limestone is largely cut out by the granodiorite, and it is difficult to tell how much squeezing has taken place, but foliation is well developed in the narrow zone bordering the granodiorite. This thinning of the Hasmark and other formations could not have been due to squeezing at the time of folding of the anticline, for such a thinning would have occurred on the steeper west limb. Apparently the Hasmark was caught between the advancing granodiorite mass and a buttress composed of the Spokane and Flathead quartzites, and material undergoing recrystallization moved from the limb up into the crest of the arch. The squeezing was greatest in the southeastern part of the district and decreased toward the north.

Pre-granodiorite faults

The earliest faults of the district are of northwest trend. The most prominent of this group, one conveniently called the Redemption fault from the earliest mine working along it, antedates the granodiorite intrusion. It extends from the granodiorite contact on the southwest side of Franklin Hill some 3,000 feet in a course about N. 40° W. to a point beyond Cliff Gulch, where it dies out in a series of sheeted zones. It dips about 78° NE. and cuts out the Silver Hill formation along the west limb of the Philipsburg anticline, but the total amount of displacement is difficult to determine. Apparently the southwest wall has moved down and to the southeast more than 1,200 feet. At places along its southeastern part the fault fissure is filled with an earlier generation of magnetite deposits, and it contains a later generation of quartz, sulphides, and manganese minerals at other places. In the southwestern corner of the area the relations of the Jefferson and Hasmark formations suggest a similar large fault of northwest trend. The Jefferson limestone is exposed on the west side of the valley of Douglas Creek, the Hasmark is exposed on the east side only 400 feet away, and the interval is occupied by alluvium. Thus there appears insufficient space for the normally intervening Red Lion, Maywood, and part of the Jefferson formations, a condition that can be the most consistently explained by the existence of a fault along which the southwest wall has moved down and to the southeast for several hundred feet.

Vein fissures

Faults later than the intrusion of granodiorite include fissures that contain the silver-bearing veins. The larger of these fissures form a group of easterly trend and steep southerly dip. Smaller less persistent fissures form a group that trends northwest and dips southwest. These fissures are abundant in the central part of the district, including the part under consideration and the granodiorite area east of it. The largest member of the east-trending group, the Granite-Bimetallic vein,[7] is wholly within the intrusive body. In the area being considered, some of the east-trending fissures break up into an en echelon series, represented by the Cliff and Pocahontas veins. The smaller discontinuous northwest-trending fissures seem to be also of an en echelon type. Both the east-trending and the northwest-trending fissures and the Redemption fault contain deposits of zinc and manganese ore.

7/ Emmons, W. H., and Calkins, F. C., op. cit. (Prof. Paper 78), pp. 202-206.

The east-trending vein fissures, called "verticals" by the miners, range in width from a few inches to 20 feet and can be traced for distances of a few hundred feet to 2,600 feet. In the northern part of the district on Hope Hill these east-trending veins are poorly exposed at the surface but seem to be more continuous at depth in some of the workings. Nearly all of these fissures dip steeply to the south, but locally their dips decrease to as little as 60° S. and in a few places they dip steeply to the north. The smaller northwest-trending vein fissures strike N. 60°-70° W. and dip steeply to the southwest. They range in width from a fraction of an inch to 2 feet. Some of them appear to break across from one east-trending fissure to another, but few junctions have been observed.

On all these vein fissures movement has been slight, rarely more than a few feet, and in both sets the north wall has moved east nearly horizontally. Along the east-trending fissures displacements commonly range from 2 to 8 feet; on the northwest-trending fissures displacements in most places amount to only a few inches but in a few places they are as much as 8 feet.

Bedding faults

Bedding faults are abundant in the thin-bedded limestones and along formation contacts but are sparingly present in the massive limestones and marbles. They range in size from mere slips to shear zones as much as 30 feet wide. In several places in the thin-bedded limestones there are zones from 30 to 200 feet wide made up of abundant small bedding slips. In the Headlight tunnel (pl. 31), which cuts most of the Maywood formation, the Headlight vein is displaced in at least 15 places by faults of various sizes in the Maywood.

Some of the bedding faults are pre-ore and contain manganese minerals and some quartz, but most of them are post-ore and displace the veins. The direction and amount of pre-ore movement could not be determined. Post-ore movement has been normal; in places the hanging wall has moved straight down the dip and in other places, on the east limb of the anticline, it has apparently moved down and toward the northeast. Displacements of veins by these post-ore faults commonly range from a few inches to as much as 30 feet, and in a few places they may range between 50 and 200 feet; however, where the apparent displacement is large, it is not clear whether the displacement is of a single fissure or of two en echelon fissures both of which have been cut off and displaced a small amount.

The strongest bedding faults are along formation contacts, chiefly the Silver Hill-Hasmark, the Red Lion-Maywood, and the Jefferson-granodiorite. How persistent these faults are cannot be definitely determined, but in nearly every place where the contacts are exposed a fault is present. Pre-ore faulting took place along all these contacts but was not as persistent as the post-ore faulting. Pre-ore and post-ore faulting also occurred along the Hasmark-Red Lion and the Maywood-Jefferson contacts but faulting was not so strong or persistent as along the others. The fault along the Red Lion-Maywood contact can be traced for at least 3,000 feet and is probably much longer.

ORE DEPOSITS

The ore deposits of the district include those valuable chiefly for silver and zinc and to a minor degree for lead and copper, as well as those yielding manganese ore. They occur in or adjacent to the east- and northwest-trending vein fissures. The silver ores include both sulphide and oxidized ore, the zinc ore has been chiefly sulphide, and all the manganese ore mined to date has been composed of oxides. Rhodochrosite ($MnCO_3$) is abundant in some of the deposits that have been explored below the oxidized zone, but no minable bodies have yet been found. The silver and zinc ores are confined to the veins that fill the east- and northwest-trending fissures, and the minable bodies range in width from a few inches to 30 feet.

The manganese ore deposits are chiefly irregular replacement bodies found in the limestones bordering or enveloping the silver veins. Some, particularly those in the Hasmark and Jefferson formations, have a tendency toward a lenticular or pod shape and are disposed along the east-trending veins like irregular beads on a string, as shown on plates 26 and 30. In places these bodies tend to be tabular in shape and to occupy the vein itself, but generally they extend out into the wall rock on one or both sides of the vein (see fig. 32). The amount of ore found in the vein itself is comparatively small.

Other deposits lie along the pre-ore bedding faults in the thin-bedded limestones and are tabular to lenticular in shape. Such deposits, conveniently referred to as bedding veins, are found in the Silver Hill, Red Lion, and Jefferson formations and along each of the formation contacts from that of Silver Hill with Hasmark to that of Jefferson limestone with granodiorite. The most productive of these horizons lies at the top of the Red Lion formation immediately under the basal shale of the Maywood formation and is called the Headlight bed (pl. 30). In the marbleized Jefferson limestone and at the contact between Jefferson limestone and granodiorite both a tabular bedding vein and irregular bodies have been formed.

Mineralogy

Silver and zinc-lead ores

Below the oxidized zone the chief ore minerals of the silver and zinc-lead deposits are sphalerite (ZnS), galena (PbS), and tennantite ($4Cu_2S.As_2S_3$) which is locally called gray copper. Enargite ($3Cu_2S.As_2S_5$), is found in several places and in a few is moderately abundant. Pyrite, chalcopyrite, and the ruby silvers polybasite, pyrargyrite, and proustite are commonly present in small amounts.

Quartz is the chief gangue mineral, but rhodochrosite is abundant in many places; and ankerite, calcite, and barite are commonly present in small amounts. In many places the vein filling is chiefly barren quartz, and throughout the lodes quartz is the most abundant mineral. Much of the ore is an intergrowth of quartz and sphalerite that contains smaller amounts of galena and gray copper. Rhodochrosite was one of the latest of the minerals to be introduced, and it commonly fills cavities or cements a breccia of the ore described. Small amounts of ankerite, calcite, and quartz are later than the rhodochrosite (pl. 27). In the northern part of the district numerous veins of quartz formed along bedding planes, chiefly in the Jefferson limestone. Some of these veins have the form of "saddle reefs," and some contained rich silver ore, for example, the Hope mine, which has produced more than $4,000,000 in silver.[8/] Manganese is scarce in these bed veins except in the eastern part of the Hope Hill area near the granodiorite.

8/ Emmons, W. H., and Calkins, F. C., op. cit. (Prof. Paper 78), p. 213.

Rhodochrosite

Rhodochrosite is believed to be the source of the manganese-oxide ore deposits in the district, and its possible abundance at depth has been one of the chief problems of the investigation. Below the oxidized zone rhodochrosite is fairly abundant in many parts of the veins, but no bodies seen by the writer contain enough manganese to constitute minable ore. The rhodochrosite content commonly ranges from a small amount to as much as one-third of the vein. In several stopes from the lower levels of the Algonquin and Trout mines silver and zinc-lead ore bodies from 10 to 30 feet wide are reported to have contained abundant rhodochrosite. Available specimens of this ore contain as much as one-third rhodochrosite or about 13 percent of metallic manganese. On the 500-foot level of the Scratch Awl mine rhodochrosite in places makes up from 10 to 30 percent of the vein and in places is nearly absent. Picked specimens of rhodochrosite from the Algonquin dump and the Scratch Awl 500-foot level, including one supplied by the operator from the Algonquin 700-foot level, contained from 39.59 to 41.65 percent of manganese. Analyses were made by J. J. Fahey, of the Geological Survey.

On the 500-foot level of the Scratch Awl mine thin rhodochrosite seams are abundant in bedding slips in the Silver Hill and the Red Lion formations (see pl. 32). In the south workings, where the bedding of the Silver Hill formation strikes parallel to the Cliff vein, the rhodochrosite seams commonly extend more than 5 feet from the vein. In the north workings the Horton vein cuts across the bedding of the Red Lion formation, and there is a zone 200 feet wide in which rhodochrosite seams are numerous (see pl. 32). This zone apparently has considerable extent for it is exposed in the crosscut from the shaft about 700 feet south of the Horton vein; but here it is only about 20 feet wide. Individual seams a fraction of an inch to 1 inch wide contain from 11.96 to 22.61 percent of manganese, but they are commonly spaced several inches apart, and it is doubtful if any sizable part of the zone contains more than 2 or 3 percent. The total average for the zone would probably be 1 percent or less.

At the west breast of the drift on the Horton vein on the 500-foot level of the Scratch Awl mine is a body of rhodochrosite that may be more typical of the source of the oxide ore than anything previously described. At this place (pl. 32) is a zone 6 feet or more wide in which the marbleized Hasmark formation is partly replaced by fine-grained rhodochrosite which seems related to a network of minute quartz seams. This fine-grained rhodochrosite is a very pale pink and grades almost imperceptibly into the white marble or into a gray carbonate that in turn grades into the white. Examination of the pink material under the microscope shows that individual grains of the marble have been partly replaced by rhodochrosite. This material contains 22.63 percent of manganese. The fine-grained gray carbonate is apparently also a partial replacement of the marble by manganese carbonate for it contains 9.49 percent of manganese. The pink carbonate makes up but 25 percent of the zone and the gray carbonate less than 5 percent, so that the entire zone probably averages no more than 6 or 7 percent of manganese. In other places, of course, the replacement may have been complete or nearly so and may have resulted in the formation of extensive bodies of nearly pure rhodochrosite. A 3-inch layer in the middle of the zone shows incipient oxidation to pyrolusite.

Pardee [9] described a similar body of pale pink granular rhodochrosite on the lower levels of the old Speckled Trout mine. Specimens of this material contained 27.03 percent of manganese. Bodies of this type of material have not been reported from the Algonquin and new Trout mines, both of which have workings below the level of oxidation; the material already found is so pale in color, however, that it might easily be overlooked underground unless a special search was made for it. Unfortunately the lower levels of the Speckled Trout, Trout, and Algonquin mines were inaccessible in 1939.

It seems entirely possible that such fine- to medium-grained rhodochrosite resulting from grain-by-grain replacement of marble in the Hasmark formation may be the original manganese mineral in the Hasmark and may form bodies of high enough grade to be minable in the future.

Manganese-oxide ore

Pyrolusite ($MnO_2 \cdot nH_2O$) is the chief mineral of the black oxide ore, but psilomelane ($MnO_2(Mn,K,Ba)O \cdot nH_2O$) is abundant, and braunite ($3Mn_2O_3 \cdot MnO \cdot SiO_2$), manganite ($Mn_2O_3 \cdot H_2O$), and wad are found in some of the mines. Quartz, limestone, and clay are more or less abundant as residual materials resulting from the decomposition of the veins and nearby country rock. Limonite (brown iron oxide) is locally abundant at the borders of some ore bodies and is present in small amounts elsewhere. Lead, in the form of cerussite ($PbCO_3$) or galena partly oxidized to cerussite, is abundant enough in some of the ore to make it unsuitable for battery use, although it commonly amounts to only a small percentage.

9/ Pardee, J. T., Deposits of manganese ore in Montana, Utah, Oregon, and Washington: U. S. Geol. Survey Bull. 725, pp. 162-163, 1921.

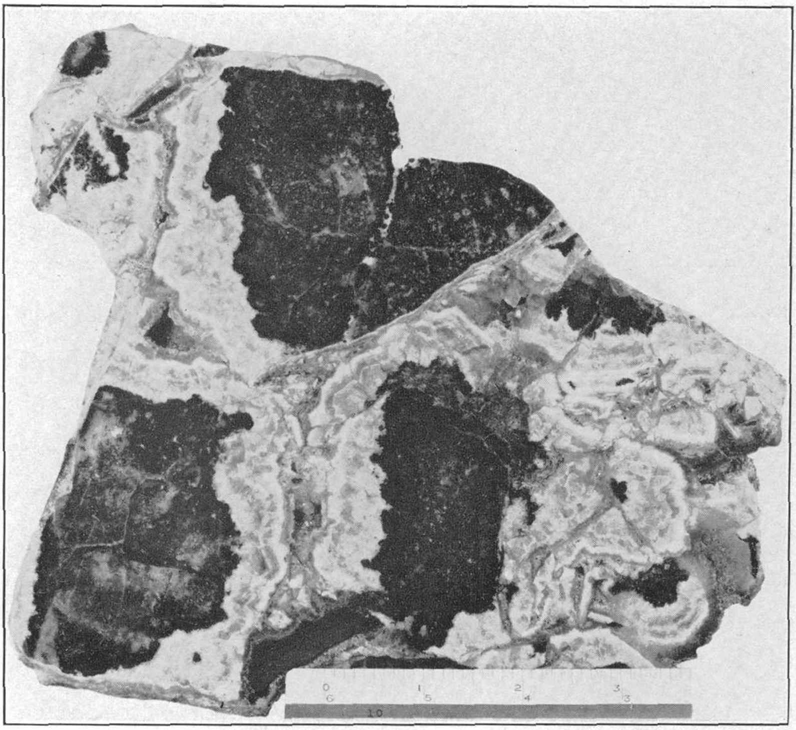
Most of the pyrolusite is fine-grained, soft, and earthy, but some shows the radiating fibrous character that suggests replacement of manganite. The texture of the ore ranges from finely porous to cavernous, as shown on plates 28 and 29, A; nodular masses of ore are also common. Psilomelane is more or less intergrown with the pyrolusite in much of the ore, and in many of the mines it has been abundant. The nodular ore shows alternating layers of pyrolusite and psilomelane.

Braunite does not appear to be common in the district, but some masses have been found on the dumps of the Sharktown and Little Dandy glory holes, and it is moderately abundant in specimens from the bottom level of the Headlight mine about 500 feet below the surface.

Wad, the soft brown earthy mixture of hydrated manganese oxides, is common in many of the mines. It is most abundant in the ore bodies in the Silver Hill formation, where it occurs around the fringes of the ore bodies. In places in the Headlight mine thin layers of wad lie on the footwall of the ore, and in other places the ore grades longitudinally into wad (pl. 31). In many mines in the district small amounts of wad are more or less intermixed with pyrolusite and psilomelane.

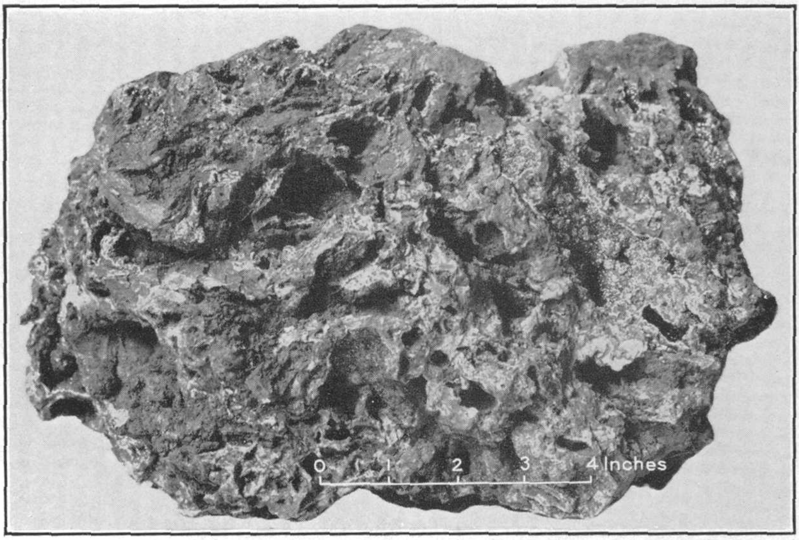
Manganite is nowhere abundant in the district, but it is found in several of the mines as small coatings of radiating needlelike crystals in cavities in the ore.

Quartz is an abundant gangue mineral in much of the ore and occurs both as white sugary vein quartz and as silicified limestone. Fragments of silicified limestone as well as of unaltered limestone and marble are common in the ore. Different kinds of clay, more or less mixed with limonite, partly fill cavities in the ore, and a white or cream-colored variety locally fills late fissures in or near the ore bodies.

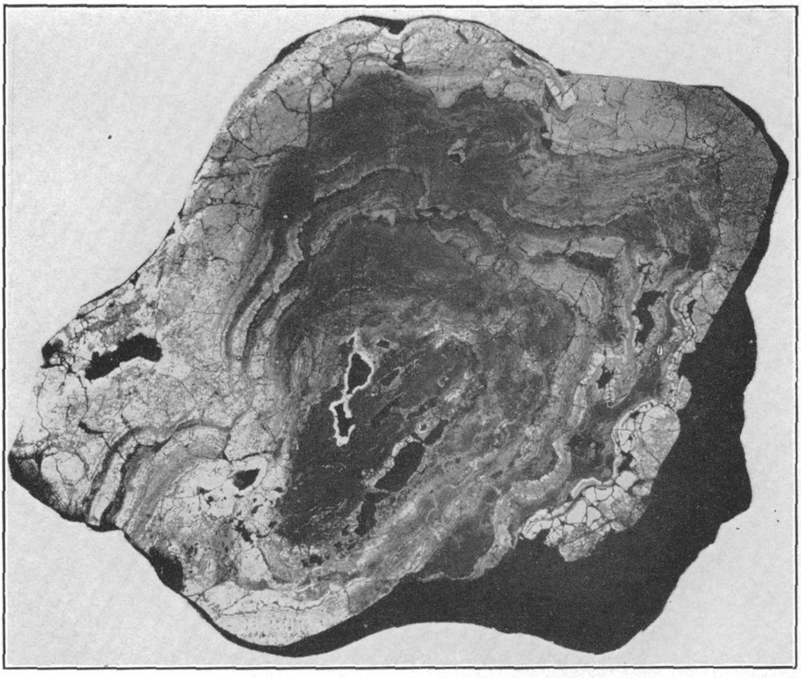


POLISHED ORE SPECIMEN FROM 900-FOOT LEVEL OF ALGONQUIN MINE.

Shows a breccia of intergrown quartz and sphalerite cemented by successive layers of coarse-grained sphalerite, rhodochrosite, ankerite (white). and quartz.



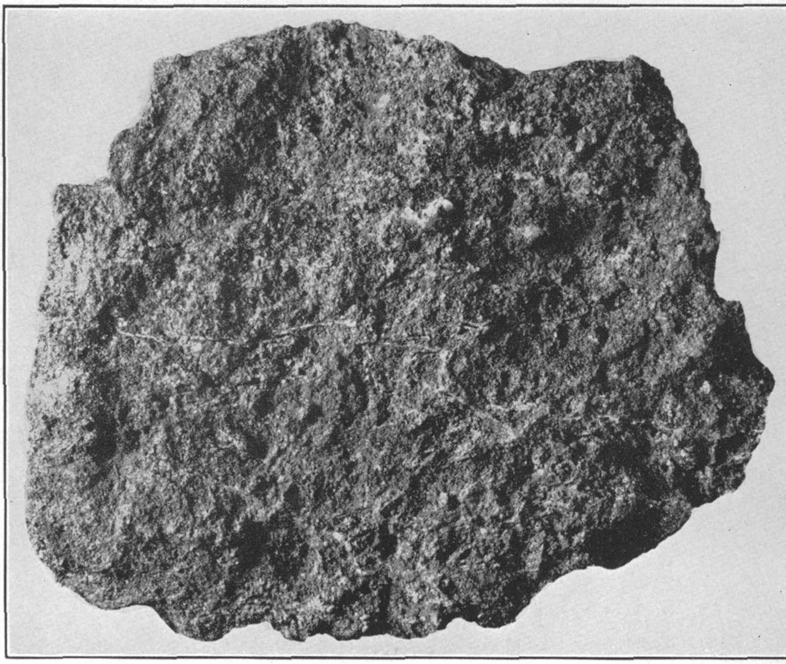
A. Cavernous oxide ore from Algonquin mine.



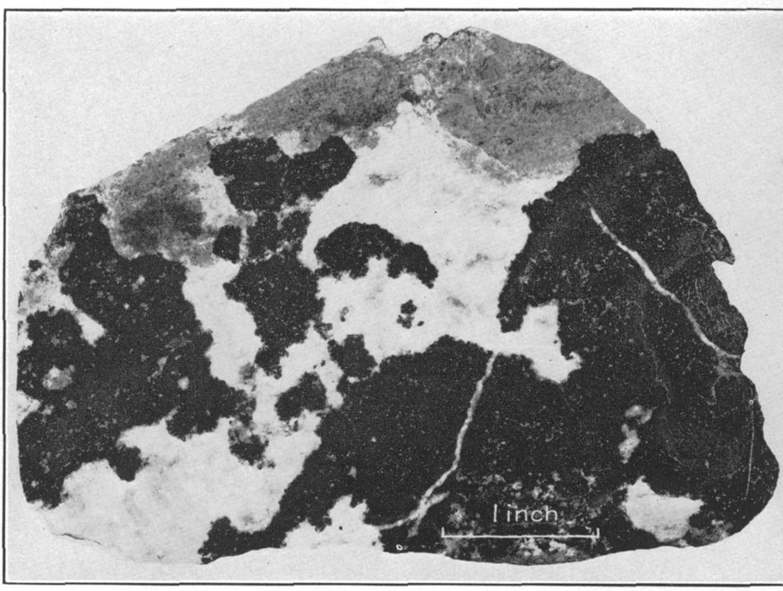
B. Section of manganese nodule from Bryant mine.

MANGANESE-OXIDE ORE.

After Pardee, U. S. Geol. Survey Bull. 725, pls. 8 and 9.



A. Finely porous oxide ore from Headlight mine.



B. Oxide ore irregularly replacing quartz (gray) and marble (white), from Sharktown glory hole.

MANGANESE-OXIDE ORE.

Origin of the ore deposits

There seems little doubt that the primary ore of the Philipsburg district was deposited from hydrothermal solutions that rose from depth along the vein fissures. The original source of the manganese was the granodiorite batholith, as indicated by the presence of the manganiferous silicates thulite (a variety of zoisite) and spessartite (manganese garnet) in the contact-metamorphic zone. The early ore-bearing solutions introduced quartz and the sulphides, which were chiefly confined to the vein fissures, except in the northern part of the district, where they commonly followed bedding planes. However, the later solutions, which carried the bulk of the manganese, deposited manganese carbonate by replacing the more permeable parts of the limestone wall rocks adjacent to the veins and along bedding fissures in the thin-bedded limestones.

All available evidence indicates that the oxide ores have been derived from oxidation of rhodochrosite, but there is little to indicate whether appreciable transportation of manganese has taken place. Pardee,[10] who had an opportunity to study many of the high-grade oxide ore bodies when they were being mined, has concluded that the porosity of these bodies is approximately that which would theoretically result from oxidation of rhodochrosite in place. In many of the mines, however, there is evidence of replacement of the quartz, marble, limestone, and even shale by the manganese oxides (pl. 29), and it is possible that in the course of weathering and oxidation some of the manganese has been dissolved by circulating ground water and redeposited at lower levels. On the 200-foot level of the Algonquin mine and the 200-foot level of the Mullen mine

10/ Pardee, J. T., op. cit. (Bull. 725), p. 156.

manganese oxides, both brown and black, are being deposited at present in open fractures in the tunnel walls and also on rock fragments in the floor of the drift.

Depth of oxidation

Most of the manganese-oxide ore has been mined within 500 or 600 feet of the surface, though one body was mined at a depth of 700 feet; on the other hand, some residual rhodochrosite has been found at a depth of only 100 feet.

The water table in the district is irregular but in general descends to the north and west. Water at present stands about 50 feet below the surface in the Algonquin shaft, in the southern part of the district, but the Headlight workings, in the northern part, are dry at a depth of 500 feet. The irregularity of the water table is due to differences in the permeability of the different rocks, as may be seen by tracing it away from the granodiorite. In the granodiorite and quartzite the water is very close to the surface, in the thin-bedded limestones of the Silver Hill it descends gradually, and where the massive marbles are reached it plunges steeply. On the 500-foot level of the Scratch Awl mine water flowing out of the Silver Hill and other thin-bedded limestone formations is pumped into a sump in the Hasmark and drains away. Likewise in the True Fissure mine, water that issues from the granodiorite sinks after it is let into the marbleized Jefferson limestone by a drift 100 feet below the surface.[11/]

In the southern part of the district, where the water table is close to the surface, ground-water circularion has permitted oxidation from 100 feet to a few hundred feet below the water table, notably in the Trout and Algonquin mines. In the ex-

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11/ Pardee, J. T., op. cit. (Bull. 725), p. 156.

treme northwestern part of the district water stands in the Shapleigh shaft of the Hope mine at an altitude of 5,200 feet, and Pardee 12/ estimates that in the limestone area oxidation is nearly complete down to this average altitude, or throughout a zone that averages 750 feet in depth. The writer's study of the district serves to substantiate Pardee's estimate, and it therefore seems likely that future prospecting may reveal oxide ore bodies to such a depth.

Localization of the ore

The localization of both the irregular replacement bodies and the bedding vein deposits seems to have been largely controlled by the junctions of vein fissures with bedding faults. The location and size of the ore bodies seem directly related to brecciation and fracturing that accompanied movement along both types of fissures. Thus the most favorable horizons are adjacent to planes of weakness in the formations--such as thin shale layers, contacts of thin-bedded and massively bedded limestone, or contacts of thin-bedded limestones and lime-silicate layers. These favorable horizons are (1) the middle of the shaly limestone of the Silver Hill formation underlying contact-metamorphosed layers, (2) the base of the marbleized Hasmark formation, (3) the top of the Hasmark marble, (4) the top of the shaly limestone in the Red Lion formation, (5) the base of the marbleized Jefferson limestone, and (6) the Jefferson marble adjacent to the granodiorite contact. The massive marble of the Hasmark and Jefferson formations apparently became brecciated much more readily than the thin-bedded limestones and thus tended to contain the larger and higher-grade

12/ Pardee, J. T., Manganese ore reserves at Philipsburg, Mont., Memorandum for the press, pp. 3-4, Oct. 16, 1929.

deposits; in fact the entire Hasmark formation might be regarded as a favorable horizon, for many good ore bodies are scattered through it, notably those at the Horton, Durango, Cliff, and Morning mines.

Along many of the bedding faults in the Hasmark are rather wide fracture zones, and where these have been cut by vein fissures there is likely to be a sizable ore body. Where faults occur along a formation boundary marked by a shale bed the un-

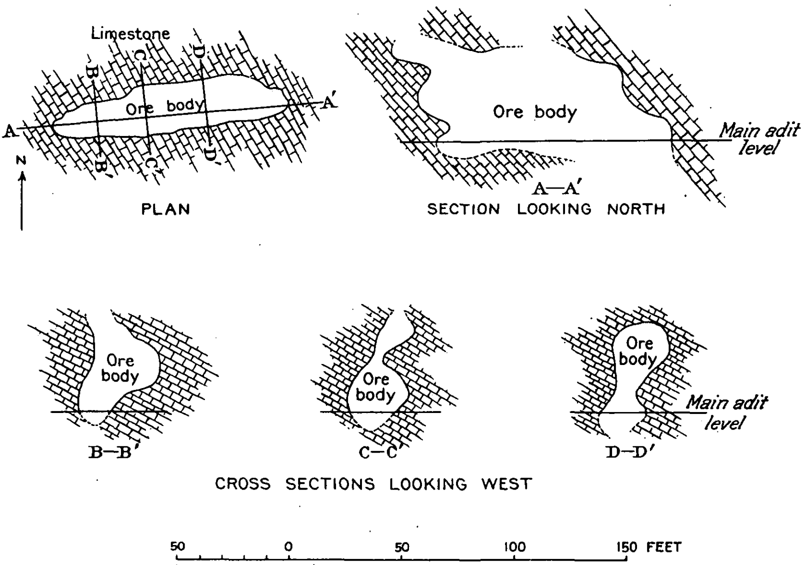

Figure 32.--Plan and sections of manganese ore body at Algonquin mine. After Pardee, J. T., U. S. Geol. Survey Bull. 725, fig. 28.

derlying or overlying limestone is commonly brecciated and, if in the vicinity of vein fissures, filled with manganese oxide.

The more nearly tabular bodies found within the veins are mostly confined to the east-west fissures and tend to occur where the veins turn abruptly to the southeast.

Size and grade of ore bodies

Few individual ore bodies have yielded more than 10,000 tons. Those of irregular form commonly range in length from 50 to 200 feet, in breadth from 30 to 150 feet, and in thickness from 10 to 60 feet. Several of these ore bodies are shown on plate 30, B, and two are shown in detail in figures 32 and 33. In the Trout and Algonquin mines irregular ore bodies in the limestone of the Hasmark formation form more or less connected

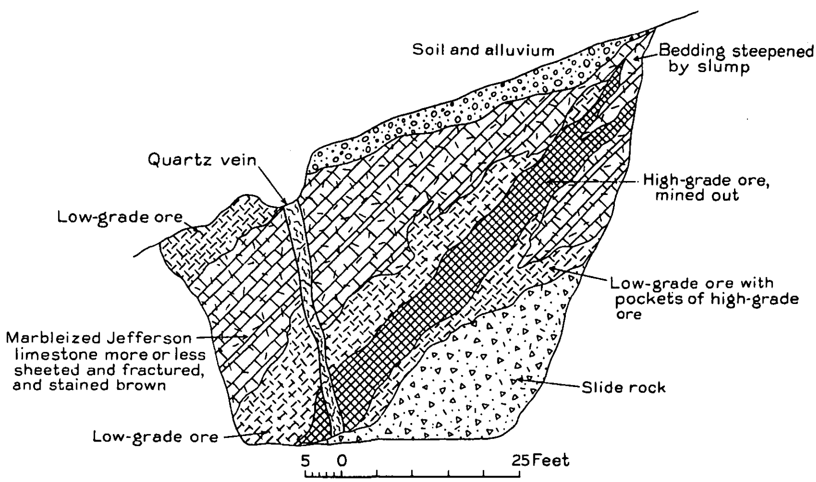

Figure 33.--Sketch of ore body in Sharktown glory hole, looking south.

groups 400 to 600 feet long (fig. 35). Tabular ore bodies or bedding veins are relatively constant in thickness; the Headlight bed ranges from 3 to 8 feet and the low-grade bodies in the Silver Hill between 15 and 30 feet. In length and breadth the range is from 50 to 300 feet. The Headlight ore bodies are largely connected for a length of 1,000 feet (pl. 30).

Much of the manganese ore is of relatively high grade. That mined for shipment in 1917 and 1918 [13] averaged 43 percent of manganese, 17.5 percent of silica, and less than 2 percent of iron. Phosphorus was low. Ore intended for milling has contained from 32 to 38 percent of manganese and 20 to 25 percent of silica. In recent years nearly all the ore has been treated in mills at Philipsburg and consequently has not been carefully mined or sorted. Most of that mined in recent years has ranged from 30 to 38 percent of manganese, 15 to 25 percent of silica, 2.50 to 3.50 percent of iron, and less than 1 percent of lead. Some bedded ores mined from the Silver Hill formation have contained as little as 15 to 20 percent of manganese. Crude ore mined from the replacement ore bodies in the Hasmark has averaged about 35 percent of manganese, that from other formations above the Hasmark has averaged about 30 percent, and that from the Silver Hill formation about 17.5 percent.

Since 1918 nearly all the manganese ore mined at Philipsburg has been milled and the concentrates have been used in dry batteries. For this use it is the available oxygen that is valuable rather than the manganese content. Thus the specifications refer to manganese dioxide content (MnO_2) rather than to metallic manganese.

Specifications for battery ore, furnished by C. A. Hyder, manager of the Trout Mining Division of American Machine & Metals, Inc., are as follows:

	Percent		Percent
MnO_2..................	70.00	Cu less than.........	0.035
Pb less than.........	.35	As less than.........	.040
Fe less than.........	2.00	CO_2 less than........	2.00

The average analyses of concentrates produced from the Trout mill in 1935 and 1939 as given in the following table are fairly representative of those produced in recent years.

13/ Pardee, J. T., op. cit. (Bull. 725), p. 154.

Average analyses, in percent, of concentrates produced from Trout mill in 1935 and 1939
[Data furnished by C. A. Hyder, manager, Trout Mining Division of American Machine & Metals, Inc.]

		1935 1/	1939 2/
	H_2O	2.5	0.40
	Mn	47.64	47.34
	SiO_2	9.63	14.51
	MnO_2	70.06	70.21
	Fe	1.41	1.74
	Cu	.028	.017
	As	.030	.096
Available	O_2	12.75	12.86
	Pb	.165	.19

1/Concentrates produced from replacement deposits in the marbleized Hasmark formation.
2/Concentrates produced from bedded deposits in the Silver Hill formation.

Future possibilities

From the foregoing it is obvious that future prospecting should be directed to the favorable horizons (see p. 179), particularly where they are intersected by the known east- or northwest-trending veins. Adjacent to the Algonquin and Pocahontas veins the favorable horizons in the Hasmark seem to have been largely explored, but on most of the veins farther north, as shown on plate 30, the horizon at the lower contact has not yet been opened. This horizon is reported to have been the most productive in the Trout and Algonquin mines, and a good-sized ore body was opened along it on the Cliff vein (see pl. 30). It might be advantageously explored by diamond drilling from the 500-foot level of the Scratch Awl mine or by sinking the Horton and Huffman shafts to greater depths, which would also explore other parts of the Hasmark above the base. The upper Hasmark contact might also be explored at depth along several of these veins such as the Myrtle, Horton, Huffman, and Bay Horse-Durango.

Considerable ore has been taken from several mines along the Redemption fault in the southwestern part of the district. All these mines were inaccessible in 1939, but according to M. H. Hunt the workings are between 200 and 247 feet deep. The Morning shaft, which is 247 feet deep, ends at least 700 feet above the base of the Hasmark. It seems likely that oxidized ground will be found to extend at least 250 to 300 feet deeper than the bottom of the shaft, and below the oxidized zone there is, of course, the possibility of finding minable bodies of rhodochrosite. In the other mines that lie along the fault southeast of the Morning mine, and are from 200 to 235 feet deep, the base of the Hasmark on the west or downthrown side of the fault is probably much deeper than under the Morning shaft. These mines, however, are fairly close to the quartzite, which is higher on the east side of the fault. Therefore the water table and the lower limit of oxide ore are likely to be found at no great depth below the present workings. Here again carbonate ore may be found below the water table.

In the eastern part of the district few of the favorable horizons above the Hasmark have been explored to any great depth except the Headlight bed. Although such horizons in the Jefferson are close to the granite mass oxidation has gone to considerable depth; and the water table, which is close to the surface in the granite, plunges down almost vertically, as previously mentioned, into the marbleized Jefferson limestone. On the 500-foot level of the Scratch Awl mine there is oxide ore in the True Fissure vein near the granite contact, about 380 feet beneath the surface. In the fall of 1939 this drift was being driven eastward on the True Fissure vein to explore the contact between the Jefferson limestone and the granodiorite. on the Saunders, Little Dandy, and Chicago claims, from 900 to 2,000 feet north of the True Fissure shaft, there are numerous

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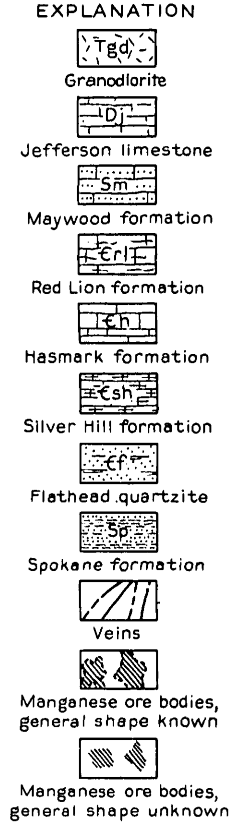
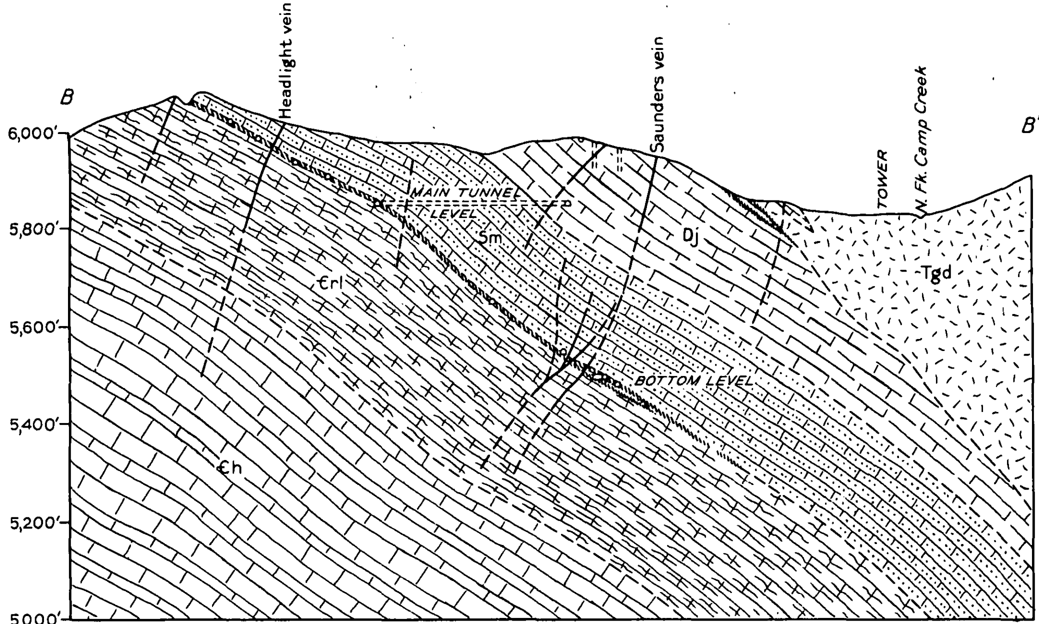
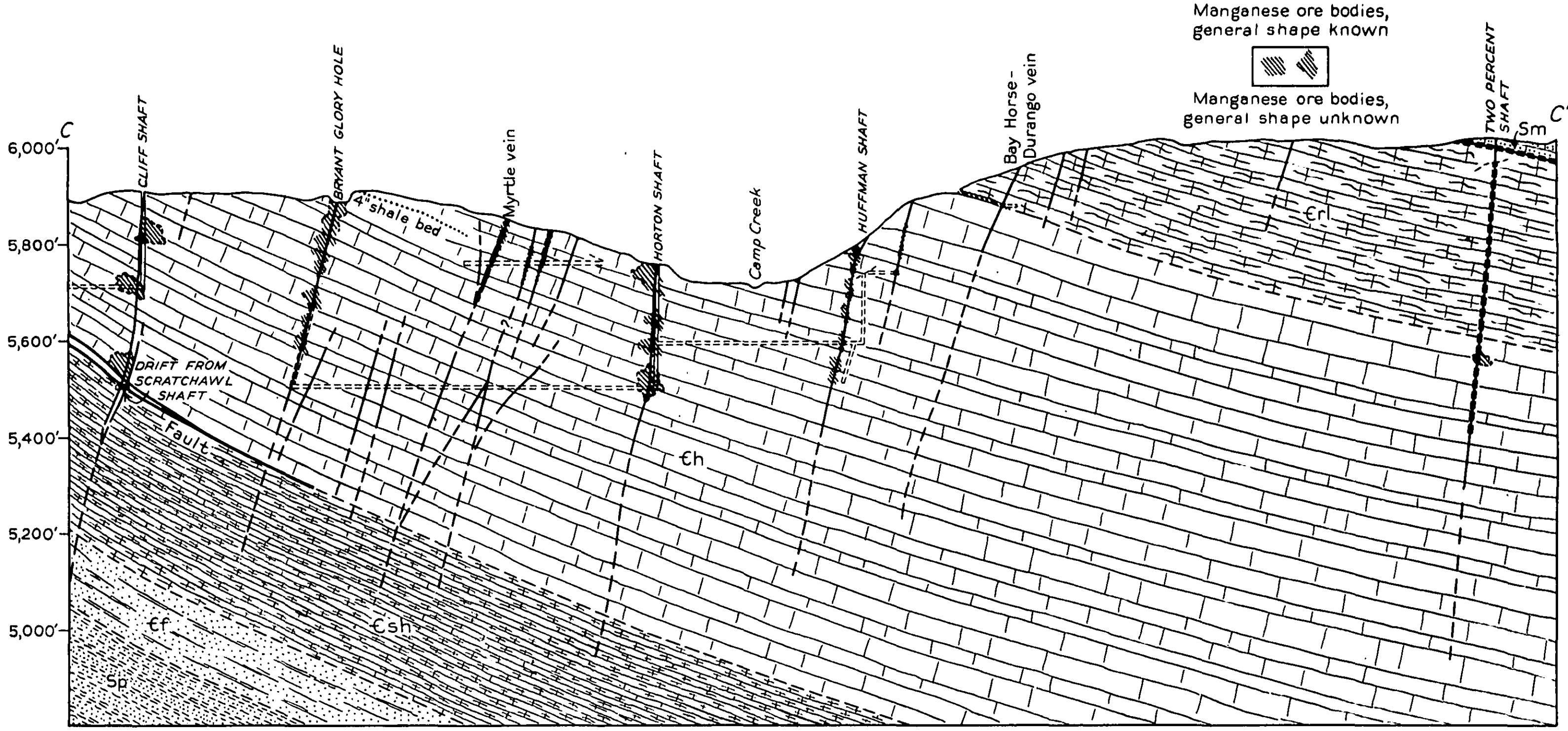




A. Section showing the Headlight bed vein.



B. Section from the Cliff shaft to the Two Percent shaft showing possible productive ground at depth.

CROSS SECTIONS (B-B' AND C-C' ON PLATE 26) OF PARTS OF THE MANGANESE-PRODUCING AREA.

100 0 500 Feet

U. S. GOVERNMENT PRINTING OFFICE : 1940—O-247284

small east- and northwest-trending veins that cut the marbleized Jefferson limestone near the granodiorite contact, and in these several relatively small ore bodies have been mined near the surface. Exploration of two--the Chicago and the Little Dandy veins--on the 200-foot level of the Chicago shaft revealed little ore, but this condition does not eliminate the possible presence of ore at greater depth. Farther north on the strong San Francisco vein a body of manganese-oxide ore was found where the 400-foot level cut the contact between Jefferson limestone and granodiorite. This was the only drift that explored this contact. Still farther north, on the east flank of Hope Hill, there are numerous small bodies of oxide ore close to the surface, but few if any have been large enough to mine. This is on the outer fringes of the manganese area where one would expect a similar small amount of manganese ore at depth. Exploration of the contact between Jefferson limestone and granodiorite on other levels of the San Francisco mine may give some clue as to the presence of minable ore at depth in this part of the area.

The scarcity of manganese in the Hope workings on the south slopes of Hope Hill imply that these workings are outside the area of productive manganese bodies.

Reserves

At the end of the World War in 1918, when the total production was 180,109 tons, Pardee estimated a minimum reserve of 130,000 tons of oxide ore containing 35 percent or more of manganese with an additional possible reserve of 350,000 tons.[14/] At the end of the decade 1919-28, when an additional 189,230 tons had been produced,[15/] Pardee made a revised esti-

14/ Pardee, J. T., op. cit. (Bull. 725), p. 147, 1921
15/ Figures furnished by U. S. Bureau of Mines.

mate,[16] which was based on the assumption that the mass of unexplored rocks within the manganiferous area might be expected to contain, volume for volume, as much ore as the part that had been mined. This assumption, however, failed to give due weight to certain conditions that have become increasingly apparent with further exploration--the relative concentration of the deposits toward the Hasmark re-entrant in the southeastern part of the area and the fact that most of the unexplored rock mass is in the leaner northwestern part. The figure thus obtained in 1928 of 1,780,000 tons, if reduced by 205,000 tons, the amount mined since then, leaves 1,575,000 tons--an amount that now appears far too high. It might be taken as the possible upper limit, but in view of present knowledge, the estimate presented in the following paragraphs seems more probable.

Little manganese ore was blocked out in 1939, and only a few high-grade ore bodies were exposed. The probable reserves of high-grade crude ore have been estimated by computing the probable sizes of high-grade ore bodies, chiefly in the Headlight, Durango, and Scratch Awl mines, and they amount to about 50,000 tons containing from 30 to 43 percent of manganese. Probable reserves of low-grade ore, estimated on the basis of ore bodies partly exposed in workings in the Silver Hill formation and low-grade ore left in some of the high-grade stopes, amount to about 50,000 tons containing from 15 to 30 percent of manganese.

Possible reserves of oxide ore have been estimated on the basis of favorable structural conditions in the area that has already been productive. On each vein the areas of the explored and unexplored favorable horizons have been computed to an average depth of 750 feet, and it is assumed that the pos-

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16/ Pardee, J. T., Manganese ore reserves at Philipsburg, Mont., Memorandum for the Press, Oct. 16, 1929.

sible reserves in unexplored ground will be equal to the production of like areas of explored ground. For a simple example, if vein A is explored in the Hasmark throughout a length of 500 feet and to a depth of 250 feet and has produced 10,000 tons of ore, the possible reserves in the same length to a depth of 750 feet are assumed to be 20,000 tons, as twice as large an area along the vein is unexplored. This method of computation applied to all the veins places the possible reserves of high-grade oxide ore at about 375,000 tons containing 30 to 43 percent of manganese and 125,000 tons of low-grade oxide ore containing 15 to 30 percent of manganese. The figure for low-grade ore is small because many of the high-grade deposits end against barren rock and most of the low-grade ore bodies appear not to be large. These figures for probable and possible reserves, totaling 600,000 tons, do not include the northern part of the area, nor other hitherto unproductive ground on the outer fringes of the district.

Another method of computing reserves gives a measure of check to the above figures. The areal extent of each of the favorable horizons listed on page 179, to an average depth of 750 feet in the productive area has been computed, and the total amounts to 22,350,000 square feet. The total explored area of these horizons is computed to be 12,475,000 square feet. By subtracting one from the other, the total areal extent of unexplored parts of favorable horizon is figured to be 9,875,000 square feet or approximately 80 percent of the explored ground which has yielded about 850,000 tons of crude ore of all grades. Therefore, the possible reserves of oxide ore are computed to be 80 percent of the past yield or about 680,000 tons. This figure is comparable to the 600,000 tons calculated by the other method.

An estimate of possible reserves of manganese carbonate ore cannot be made (see p.178); nevertheless, it seems likely that many of the veins persist considerably below the level of oxidation and contain large tonnages of carbonate material. According to present information the manganese content of this carbonate ore is likely to range from as little as 7 percent to possibly as much as 41 percent. Whether any large bodies of rhodochrosite of as high grade as those mined at Butte--35 to 41 percent of manganese--are to be found at depth is a question that can be answered only by exploration. One of the most persistent ore bodies in the district is in the Headlight mine (pl. 30), and it appears to have been formed by the oxidation of rhodochrosite in place. Exploration of the bed at depth below the ore body may indicate whether high-grade rhodochrosite lies below.

MINES

More than 40 mines in the Philipsburg district have produced manganese ore. They range in size from shallow cuts and trenches of no great length to mines with several thousand feet of underground workings, which in the Algonquin mine attain a depth of 1,100 feet. Outside the productive area the Hope and the Granite-Bimetallic silver-bearing lodes have been developed to depths of 570 feet and 2,600 feet respectively.[17] Many of the mines were inaccessible in 1939. Of the manganese mines that could be entered those described below have been selected as representative. In a later report it is proposed to give a more comprehensive and inclusive description of the deposits.

17/ Emmons, W. H., and Calkins, F. C., op. cit. (Prof. Paper 78), pp. 203-213.

Headlight mine

The Headlight mine is at Tower, on the west side of Tower Creek 6,600 feet N. 80° E. of Philipsburg. It was first opened in 1878 and produced a small amount of silver ore.[18] In 1917 it was opened for manganese ore [19] and has been worked, with some interruptions, to the present time. In 1939 from 40 to 50 tons of crude ore was being mined daily. The total production has amounted to about 40,000 tons of crude ore. The workings are shown on plate 31.

Geology.--The Headlight workings are in the Red Lion and Maywood formations on the east limb of the Philipsburg anticline, and all the manganese production has come from the Headlight bed at the top of the Red Lion. The main working adit penetrates nearly the entire thickness of the Maywood and the uppermost 120 feet of the Red Lion. Throughout the workings the bedding strikes from N. 5° E. to N. 20° W. and dips 32°-45° E.

At the top of the Red Lion formation is a bed of medium-grained white to yellow marble from 2 to 8 feet thick that somewhat resembles the Hasmark. This bed is underlain by a 4- to 12-foot bed of dense, fine-grained gray to brown shaly limestone and is overlain by the 5-foot basal shale bed of the Maywood. The manganese ore is chiefly confined to the bed of yellow marble but in places is found in or beneath the gray to brown shaly limestone.

Structure.--The manganese ore seems closely related to a system of relatively small northwest-trending veins from a few inches to 2 feet thick that are well-exposed in the workings. These include the Headlight vein, which is followed by the main adit, an unnamed vein, which is exposed at the hoist station on

18/Emmons, W. H., and Calkins, F. C., op. cit. (Prof. Paper 78), p.210.
19/Pardee, J. T., op. cit. (Bull. 725), pp. 170-171.

the same level, and the Saunders vein, which is exposed at the hoist station on the 500-foot level and also in the lower levels. These veins strike N. 55°-72° W. and dip 45°-85° S., the lesser dips appearing on the lower levels, where the Saunders vein includes a number of small roughly parallel fractures. Additional small slips and veinlets of northwest trend scattered throughout the mine seem to have influenced the distribution of ore. These are most numerous on the outcrop of the Headlight bed, where at least seven are exposed. (See pl. 26.) Sheeted zones trending N. 60°-80° W. and dipping steeply are also common throughout the mine. Post-ore bedding faults are numerous in the Maywood formation, a persistent one following the Headlight bed. Along all of them the movement has been normal and apparently straight down the dip.

Ore deposits.--The Headlight mine has produced small amounts of silver ore, mostly from the Headlight vein. In 1939 a small shipment from the Saunders vein on the 700-foot level contained 19 ounces of silver to the ton.

The manganese ore is confined to the Headlight bed. It is all fine-grained black oxide that appears to be chiefly pyrolusite. Most of the ore is rather finely porous, as shown on plate 29, but on the lowest levels it is finely cavernous. In places along the footwall of the ore bodies there is from a foot to 2 feet of soft brown wad or a dark brownish-gray claylike material. In 1918 ore shipped from the Headlight mine contained from 38 to 48 percent of manganese and from 11 to 25 percent of silica. The shipments averaged 43 percent of manganese, 18 percent of silica, and 2.5 percent of iron,[20] but most of the ore mined in recent years from the Headlight bed has contained from 52 to 56 percent of manganese dioxide (equivalent to 32 to 35 percent of metallic manganese).

20/ Pardee, J. T., op. cit. (Bull. 725), p. 171.

The Headlight bed has been mined from the surface to a distance of 1,100 feet down the dip, and the lowest workings are about 500 feet beneath the surface (pl. 30). The workings are entirely dry except for a small water drip from the roof in the southern part of the 700-foot level and in the bottom of the south winze. The ore bodies have stope lengths ranging between 300 and 500 feet and are confined to one block, to the north and south of which drifts from 200 to 350 feet in length have failed to reveal any ore (see pl. 31). About a third of this block has contained minable ore, the remainder being low-grade or barren. The general shapes of the ore bodies are shown on plate 31. The widths or thicknesses of the ore bodies are relatively constant and commonly range from 3 to 5 feet, though in places they are 7 or 8 feet. In one place in the bottom level two separate beds of ore are exposed: one 8 feet thick beneath the shale member of the Maywood and one 4 to 5 feet thick beneath the gray shaly bed that underlies the Headlight bed (see pl. 31).

Structural control and origin of the ore.--The distribution of the original manganese minerals in the Headlight mine seems to have been largely controlled by the northwest-trending veins and by zones of brecciation and fracturing in the Headlight marble bed at the top of the Red Lion formation.

Most of the oxide ore has the finely porous appearance that results from oxidation of rhodochrosite in place, with little or no transportation of material. It therefore seems probable that there has been little enrichment of the ore during oxidation and therefore that bodies of high-grade rhodochrosite should underlie the oxide ore.

Future possibilities and reserves.--In the fall of 1939 ore containing 50 to 55 percent of manganese dioxide (31.5 to 35 percent of metallic manganese) was being mined from the bottom level of the north winze. The veins of the Saunders group, which control the ore shoot on the lower levels, seem fairly strong in the bottom level and probably will persist to a depth of several hundred feet below the present workings. As the lowest workings in 1939 were relatively dry and as oxide ore in the district extends below the level of the water table, it seems a fair prospect that oxide ore will extend for at least 200 or 300 feet farther down the dip of the beds, or 100 to 150 feet vertically below the present workings. The possibility of finding rhodochrosite ore at depth might be explored by diamond drilling either from the surface or from a crosscut drift extending 200 or 300 feet into the hanging wall.

Scratch Awl mine

The Scratch Awl mine is on the north side of the divide between Camp Creek and Cliff Gulch, about 1¼ miles east of Philipsburg. It was worked in a small way for silver many years ago.[21/] In the fall of 1917 it was reopened and supplied a moderate amount of manganese ore during that season and the next year. Since 1928 the mine has been operated almost continuously and according to C. J. Hanson, superintendent, has produced about 50,000 tons of manganese ore and about 60,000 tons of silver-zinc ore. In 1939 the mine was one of the most active in the district.

The Scratch Awl mine is opened through a vertical shaft 500 feet deep with three levels that aggregate about 8,000 feet in length. The 500-foot level, by far the longest, connects with the True Fissure shaft to the north and the Cliff shaft to the west (pl. 32). Only the 500-foot level was inaccessible in 1939.

21/ Pardee, J. T., op. cit. (Bull. 725), p. 168.

Geology.--The mine is on the east limb of the Philipsburg anticline, and throughout most of the workings the bedding dips 38°-52° NNW.; however, the western part of the drift on the Cliff vein on the 500-foot level extends across the flat nose of the anticline and there the beds dip 38°-41° N. All formations from the Silver Hill to the Jefferson are exposed on the 500-foot level.

Structure.--Numerous veins are exposed in the Scratch Awl workings, but they appear to belong to three main groups--the Cliff, the Horton, and the Scratch Awl (pl. 32). Most of the silver-zinc and manganese ore produced has come from veins of the Cliff group, which can be traced on the surface for a distance of about 3,000 feet. At the ends it is separated into short en echelon segments (pl. 26). As shown by the map of the Scratch Awl workings (pl. 32), however, the en echelon veins in the eastern part of the group apparently converge downward to form a nearly continuous east-trending vein on the 500-foot level. The cliff group as a whole ranges in strike from N. 85° E. to N. 85° W. and dips 66°-88° S. The en echelon segments strike N. 70°-86° W. and also dip steeply to the south.

Veins exposed in the northern part of the Scratch Awl workings 1,100 to 1,300 feet north of the Cliff group are of east trend and belong to the Horton-True Fissure group. This group can be traced for about 2,800 feet. The westernmost member, the Horton vein, is about 1,000 feet long; east of it and successively offset to the north are the True Fissure and Silver Chief veins. Veins of this group strike from N. 85° E. to N. 70° W. and dip 60°-88° S. The eastern part of the Horton vein and part of the True Fissure vein are exposed in the Scratch Awl 500-foot level (pl. 32). On this level the True Fissure vein is about 200 feet north of the Horton vein and is thought by Mr. Hanson to be a segment of the Horton vein displaced by one or more bedding faults along which the hanging walls moved north. This idea is supported by the fact that the True Fissure vein is cut off at the Jefferson-Maywood contact, and the only vein found on the west side of the fault is the Horton.

The Scratch Awl vein trends northwest and lies between the Cliff and the Horton-True Fissure groups. It is exposed on the surface about 400 feet northwest of the Scratch Awl shaft and has been explored on all three levels of the mine. It strikes N. 55°-75° W., dips 55°-75° SW., and on the 500-foot level consists of two branches 75 to 100 feet apart.

Bedding faults are numerous in parts of the mine and are particularly strong along formation contacts (pl. 32). They range in size from small slips to shear zones from 30 to 40 feet wide. On practically all bedding faults the hanging wall has moved down and to the north, and the displacements range from a few inches to possibly 200 feet. In both the Silver Hill and the Red Lion formations there are wide zones of small, discontinuous slips and fractures in the bedding that are filled with rhodochrosite and ankerite. One of these zones, which borders the Horton vein in the Red Lion, is nearly 200 feet wide.

Ore deposits.--All the veins contain silver and lead-zinc ore consisting of quartz with variable amounts of sphalerite, galena, gray copper, and rhodochrosite. They range in width from a few inches to as much as 18 feet, but the average width of the productive parts is between 3 and 5 feet. The veins tend to widen in the Hasmark and to pinch in the shaly limestones.

Rhodochrosite is common in vugs and fractures in the unoxidized vein material, constituting as much as one-third of the vein in places. Much of it consists of thin alternating pink and pale-pink layers. This material also fills numerous small bedding seams, fractures, and slips in the wall rock bordering the veins. On the 500-foot level along the Horton vein in the

Red Lion formation is a zone about 200 feet wide of these small rhodochrosite seams, but the entire zone probably averages only about 1 or 2 percent of manganese. At the west end of the drift that follows the Horton vein on the 500-foot level a zone 6 feet or more wide in the marbleized Hasmark formation is partly replaced by fine-grained rhodochrosite. This zone averages about 7 percent of manganese, and parts contain as much as 22.63 percent; it is discussed in detail on page 174. So far as exposed the material in the zone does not average enough rhodochrosite to be considered possible manganese ore, but it might be amenable to concentration.

Manganese oxide ore has been mined at different levels of the mine, but data of output from the 200- and 300-foot levels are not available. Nearly all the output has come from the Cliff and Scratch Awl veins. Only small amounts of oxide ore have been found on the Horton and True Fissure veins, but in the Horton and True Fissure mines large bodies of ore have been mined on these same veins.

All the ore bodies are along or adjacent to the veins. Most of them are in the marbleized Hasmark formation, but near the surface two bedding veins have been found in the Red Lion formation where it is cut by the Scratch Awl vein. Ore mined from one of these bodies in 1929 contained 50 to 55 percent of manganese dioxide (equivalent to 32 to 35 percent of metallic manganese).

On the 500-foot level at least two oxide ore bodies have been mined along the Scratch Awl vein (pl. 32). One of these was at the junction of the south branch vein with a bedding fault 140 feet south of the shaft. It measured about 70 feet long, 20 to 30 feet in breadth, and 5 to 15 feet in thickness.

Another, 150 feet to the east, lay immediately under the Red Lion contact and measured about 100 feet long, 60 feet in breadth, and 10 to 15 feet in thickness. Both were somewhat elongate parallel to the vein.

Along the Cliff vein, on the 500-foot level about 1,000 feet southwest of the shaft, a body of oxide ore lies at the junction of the Cliff vein with the Silver Hill-Hasmark contact. It contains 55 percent of manganese dioxide (equivalent to 35 percent of metallic manganese), but enough lead is present to make it unsuitable for battery use.

In the fall of 1939 exploratory work along the True Fissure vein was extended toward the contact of Jefferson limestone with granodiorite and along the Cliff vein toward the favorable horizon at the base of the Hasmark on the west side of the anticline. Another promising block to explore is the Horton vein in the upper part of the Hasmark formation on the west side of the fault that cuts the vein off near the west breast of the 500-foot level.

Trout mine

The Trout mine, at the head of Cliff Gulch about 1¼ miles S. 76° E. of Philipsburg, has been the largest source of manganese ore in the district. The mine as now operated includes the formerly separate Pocahontas and Gem mines.

The Trout workings consist of ten levels aggregating about 15,000 feet. The upper five levels connect with the Trout shaft, which is 585 feet deep, but the lower levels were opened from the Algonquin shaft 900 feet to the southeast through two crosscuts, several raises, and a winze. The lowest level is

1,040 feet below the collar of the Trout shaft. The position of the different levels and their relations to the Pocahontas, Gem, and Speckled Trout workings are shown in figures 34 and 35. In 1939 only parts of the 400- and 500-foot levels were accessible.

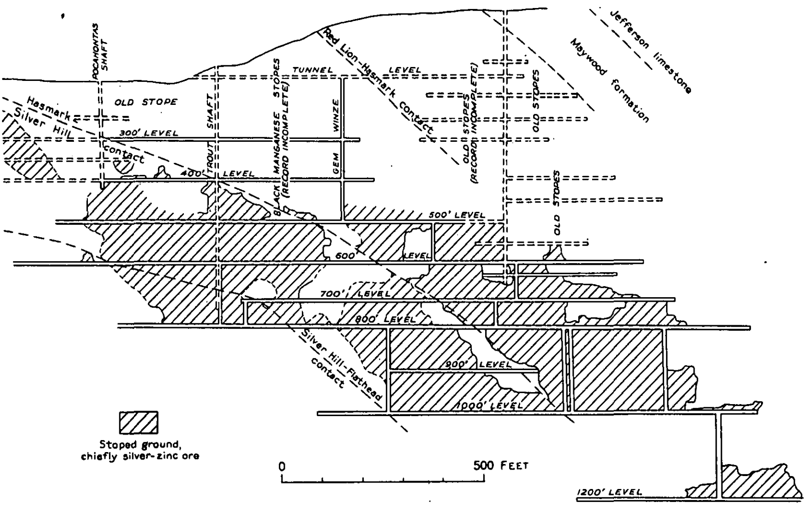

Figure 34.--Longitudinal section of the Pocahontas vein, Trout mine. From map furnished by the Trout Mining Division, American Machine & Metals, Inc.

<ins>History and production</ins>.--The Gem claim was one of the first to be located in the district, but until 1908 it was a relatively small producer of silver ore.[22] It was opened for manganese ore in September 1917, and between then and November 1918 had supplied about 30,000 tons. The Pocahontas mine also supplied

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22/ Emmons, W. H., and Calkins, F. C., op. cit. (Prof. Paper 78), p. 210.

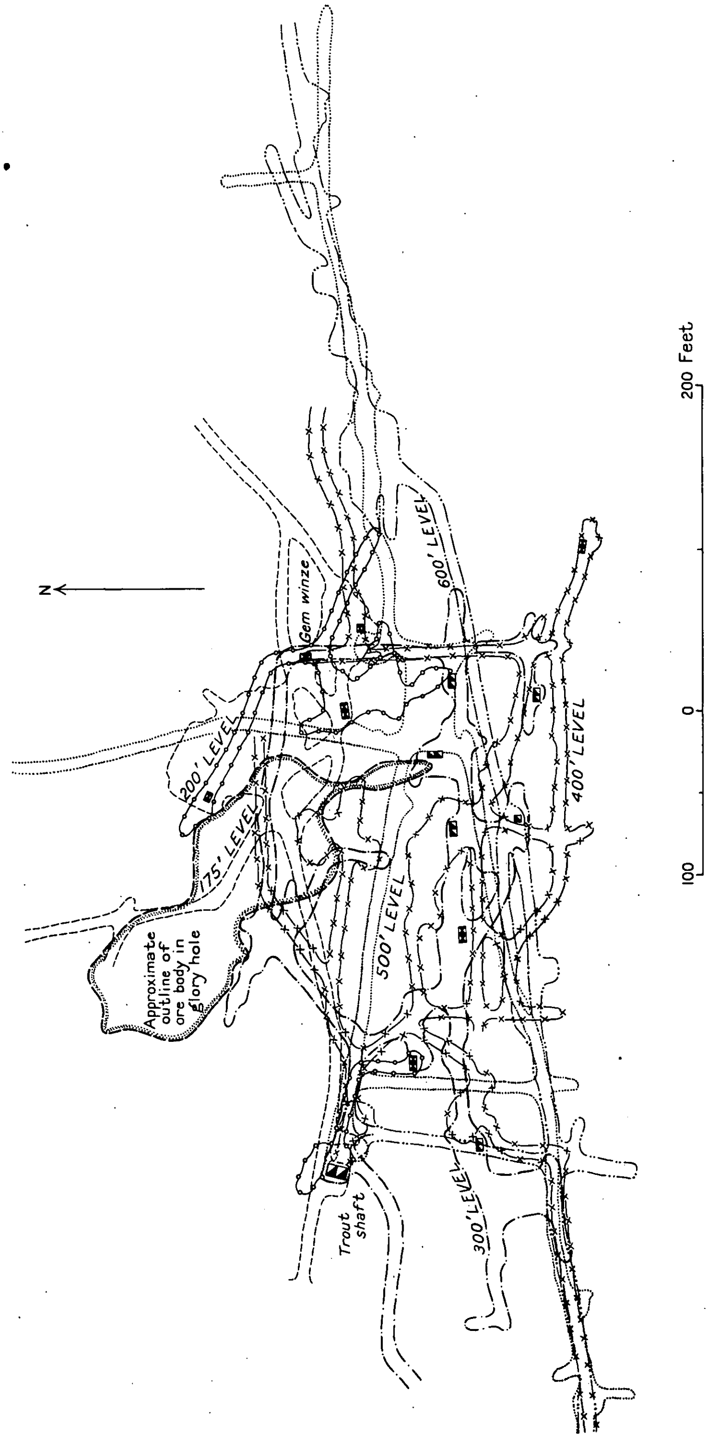

Figure 35.--Plan of the upper six levels of the Trout mine showing the general distribution of the manganese ore bodies. From maps furnished by the Trout Mining Division, American Machine & Metals, Inc.

several thousand tons of manganese ore in 1917 and 1918.[23/] In 1924 the mine was taken over by the Trout Mining Division, American Machine & Metals, Inc., and from 1924 to 1937 the combined production of the Trout groups was 166,034 tons of crude manganese ore and 240,000 tons of silver-zinc ore.

Geology.--The Trout mine is on the east limb of the Philipsburg anticline where the bedding strikes N. 25°-75° W. and dips 24°-52° NE. In general the dip seems to steepen on the lower levels, and the Hasmark formation shows a pronounced thinning downward. The workings penetrate almost the entire thickness of the Hasmark and Silver Hill formations and, in the western part of the mine, extend into the Flathead quartzite (fig. 34).

The chief vein in the Trout mine is the Pocahontas, one of the most persistent in the district. It can be traced on the surface for about 2,500 feet and is still well-defined at the bottom level, more than 1,000 feet below the surface. It has a general trend of N. 80° E. across the nose of the anticline but swings to a more easterly course in the Trout workings on the east limb, where it dips 75°-90° S. At the east end, near the Hasmark-Silver Hill contact, a group of short discontinuous veins lie on the north side of the Pocahontas vein (see pl. 33). Most of these dip steeply south, but locally some dip as little as 35°. In places they are bordered by sheeted zones or grade into them, and they appear to converge downward and to merge into the Pocahontas vein. The Trout workings explore at least six of these small veins, some of which have controlled the localization of manganese ore bodies.

The Pocahontas vein generally ranges in thickness from a few inches to 6 feet and locally thickens to as much as 20 feet. The small subsidiary veins range from a fraction of an inch to 8 inches but locally widen into irregular bodies of

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23/ Pardee, J. T., op. cit. (Bull. 725), p. 163.

manganese oxide mixed with quartz and silver-zinc ore minerals. They appear to be confined to the Hasmark and overlying formations, for none have been exposed in the Silver Hill. In numerous places these veins have been displaced from a few inches to a few feet by normal bedding faults, and they have been cut by a few steeply dipping faults of north trend.

Ore deposits.--In the Trout mine manganese ore is confined almost entirely to the marble of the Hasmark formation as explored on the upper five levels of the mine. Silver-zinc ore has been mined from all the formations, though the ore bodies tend to be much wider in the Hasmark than in the Silver Hill and Flathead formations.

The silver-zinc ore is confined largely to the Pocahontas vein, in which the ore bodies range in width from 1 foot to 30 feet. Rhodochrosite is abundant in much of the ore from lower levels, but judging from available specimens it rarely makes up more than one-third of the vein or ore. According to C. A. Hyder, manager of the company, residual masses of rhodochrosite were found in manganese-oxide ore bodies on some of the upper levels, and these are probably the ones mentioned by Pardee.[24]

The manganese-oxide ore seems to have been confined to a block of the Hasmark just east of the shaft, which is about 400 feet wide, 250 feet thick, and extends from the surface to the 600 level (fig. 35). It seems to have a general eastward pitch and has a pitch length of about 600 feet. In this block several large irregular bodies of manganese-oxide ore border or envelope the Pocahontas vein and the small subsidiary veins to the north of it. Individual bodies range from 50 to 250 feet in pitch length, from 50 to 150 feet in breadth, and from 10 to 75 feet

24/ Pardee, J. T., op. cit. (Bull. 725), pp. 162-163.

in thickness. Most of them apparently have a general elongation parallel to the veins that they border, but many of the irregularities seem to be related to the bedding of the Hasmark formation.

The ore is the typical porous to cavernous fine-grained black oxide, mostly pyrolusite, but with considerable psilomelane in places and small amounts of wad and manganite. In places abundant quartz and small amounts of zinc and lead carbonate are mixed with the ore. Most of the ore, however, is of high grade. That mined in 1917-18 from the Gem mine contained about 40 percent of manganese, 18 percent of silica, and very little iron and phosphorus, and that from the Pocahontas averaged about 42 percent of manganese and 18 percent of silica.[25] In recent years the ore has averaged 56 percent of manganese dioxide (equivalent to 35 percent of metallic manganese), 2.50 percent of iron, and 0.25 percent of lead.

The distribution of the irregular replacement bodies in the Hasmark has been controlled largely by the short discontinuous veins on the north side of the Pocahontas vein. Apparently the breaking up of the Pocahontas vein into a group of veins just east of the shaft was accompanied by widespread brecciation of the Hasmark in this vicinity, which prepared a large block for easy access of the mineralizing solutions. This block has been almost entirely mined out and the workings are mostly caved, hence it seems doubtful if any large production of manganese oxide ore will come from it in the future. In the lower levels of the mine there has apparently been no exploration for the subsidiary veins north of the Pocahontas. It is possible that they converge and merge into the Pocahontas main vein at depth,

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25/ Pardee, J. T., op. cit. (Bull. 725), pp. 163-164.

but if they continue separately they may be accompanied by bodies of finely granular pale-pink rhodochrosite large enough and rich enough to constitute ore minable in the future.

Ore bodies of other mines in the Hasmark are of the same type as those in the Trout mine. They include the Algonquin, Coyle, Climax, Cliff, Horton, Huffman, and Durango mines, as well as the Morning, Cliff Millsite, and Redemption mines along the Redemption fault. The Durango mine showed special promise in 1939. Ore bodies in the marbleized Jefferson limestone mined from the Sharktown, True Fissure, and Little Dandy and other mines north of Tower are also of the same general type as those in the Trout, though the bodies in the Sharktown glory hole (fig. 33) and in the Little Dandy mine, seem to be intermediate between the irregular replacement bodies and bedding veins.

West Algonquin and Bernard mines

The West Algonquin and Bernard mines, on the north and east slopes respectively of West Algonquin Hill, in the south-central part of the district, were opened prior to 1918, but the ore was of too low grade for metallurgical use. From 1937 to 1939 the Trout Co. operated the mines intermittently and milled the ore to a concentrate suitable for battery use. The total crude ore production from these mines has probably amounted to at least 10,000 tons.

The workings, shown on plate 34, are all in the Silver Hill formation on the nose and east limb of the anticline. There the bedding strikes from N. 55° E. to N. 60° W. and dips 27°-37° N. Different beds of the Silver Hill show slight to strong contact-metamorphic effects, as described on page 163, and the more strongly metamorphosed layers commonly overlie the ore bodies.

The manganese ore bodies are related to two east-trending veins: the Algonquin, which cuts across the nose of the anticline and dips steeply to the south, and the Bernard, a small discontinuous vein that cuts the east limb about 450 feet south of the Algonquin and dips steeply north. As exposed in the mines the Algonquin vein is from half an inch to 18 inches wide and the Bernard from half an inch to 8 inches wide.

The manganiferous ore bodies are lenticular to pod-shaped and border or envelop the veins (pl. 34). They seem to lie nearly horizontal and range in length from 40 to 200 feet, in breadth from 30 to 60 feet, and in width from 3 to 25 feet. They are bounded along both hanging wall and footwall by a few inches or a few feet of soft claylike material resulting from shearing and alteration of the shaly limestone. In this material are numerous gouge slips and in places bedding veins of quartz or seams of white clay a few inches thick. These bodies consist of a finely banded, rather porous material in which the manganese has chiefly replaced the calcareous bands of the Silver Hill and only partly replaced the shale bands. Veinlets or networks of oxide ore cut across the shale bands in many places. Around the margins of the deposits the ore grades out into soft brown wad mixed with more or less altered shaly limestone and limonite or pinches out between converging bedding faults. The ore contains from 25 to 30 percent of manganese dioxide (equivalent to 16 to 19 percent of metallic manganese). That treated in the Trout mill averaged 28 percent of manganese dioxide, 3.50 percent of iron, and 0.25 percent of lead.

It seems likely that other ore bodies of this type may be found in the Silver Hill formation along east-trending veins, but their downward extent is definitely limited by the base of the Silver Hill, which is only about 125 feet below the Bernard workings and only 200 feet below the West Algonquin workings.

Similar bedded deposits of low-grade manganese ore are found in the Mullen mine along the Pocahontas vein 500 feet northeast of No. 5 tunnel and in the Coyle mine 800 feet southeast of No. 6 tunnel. On east-trending veins farther north than the Pocahontas the Silver Hill formation is probably below the level of oxidation and therefore likely to contain low-grade manganese carbonate ore.

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