MANGANESE AT BUTTE, MONTANA.

By J. T. Pardee.

INTRODUCTION.

The great increase in the value of manganese in 1916 and 1917 directed attention to the manganiferous gangue of the silver-zinc lodes at Butte, Mont., a material which, although formerly regarded merely as waste rock, is under the present high prices a possible source of considerable manganese.

A search through the published reports describing the ore deposits of Butte, supplemented by a brief field examination in August, 1917, revealed the fact, perhaps not generally appreciated heretofore, that the amount of material in the lodes that is sufficiently rich in manganese to be considered a possible source of that metal is very large. The smaller part of this material, which is found in the outcrops and upper parts of the lodes, consists of manganese oxides associated with more or less quartz. Only a very little of this meets present trade requirements, however, by far the greater portion being comparatively low in manganese and high in silica. A reserve of not more than 2,600 tons, as estimated, contains 40 per cent or more manganese, and but little more than one-third of this amount runs less than 10 per cent silica. In addition, however, fairly detailed estimates show totals of about 132,000 tons of material averaging 24 per cent manganese and 50 per cent silica and 270,000 tons averaging 11.5 per cent manganese and 73 per cent silica. Tests of the richer of these two grades so far reported by the mining companies, though not wholly satisfactory, by no means discourage the hope that it can be profitably concentrated.

By far the most of the manganiferous material below the oxidized zone at Butte consists of rhodochrosite and rhodonite, the carbonate and silicate of manganese, respectively, associated in different proportions with quartz and sulphides. The most interesting and promising feature concerning the occurrence of manganese at Butte is the fact that portions of this unoxidized material consist of fairly pure rhodochrosite and are therefore very valuable as a source of the metal. Reported analyses of material of this character in the Emma mine run from 34 to 41 per cent manganese and as low as 1 per cent silica. According to reports this material when lightly roasted gives off its carbon dioxide and as a result the percentage of manganese is increased in the product. The known workable bodies of this ore aggregate several thousand tons, and there is reason to expect that future developments will disclose large additional amounts.

Whether the general run of the unoxidized manganiferous material can be considered under any conditions as a possible source of manganese is a question for metallurgists to answer. The amount of material that contains 15 per cent or more manganese and occurs within the depths ordinarily reached in mining is indicated by the evidence available to be millions of tons. Because they lie at the surface the oxide ores can be mined as rapidly as desired, and the extensiveness of the underground workings, of which many that are temporarily abandoned could probably be made usable in a short time, will permit the carbonate and silicate ore also to be rapidly extracted. Therefore, whether Butte can be counted upon without delay for a considerable production of manganese depends on the solution of problems concerning the metallurgy rather than the mining of its manganiferous deposits.

The writer's thanks are due to several lessees and to the mining companies, in particular the Anaconda Copper Mining Co., for analyses and general assistance in field work, without which many of the details upon which the tonnage estimates are based would have been unavailable.

LITERATURE.

The reports that describe the Butte lodes most fully are those of Weed [1] and Sales.[2] Weed's report was based on field work that was virtually completed in 1907, and Sales's report was written prior to August, 1913. Several briefer reports have been published by different writers, among which, perhaps, those by Blake [3] and Peters [4] give the most information concerning manganese. As manganese was of little commercial value at the time these reports were written they do not discuss it very extensively, though they contain many facts concerning it which are of great value to the present investigation.

[1] Weed, W. H., The geology and ore deposits of the Butte district, Mont.: U. S. Geol. Survey Prof. Paper 74, 1912.

[2] Sales, R. H., Ore deposits at Butte: Am. Inst. Min. Eng. Trans., vol. 46, pp. 3–106, 1914.

[3] Blake, W. P., The Rainbow lode: Am. Inst. Min. Eng. Trans., vol. 16, pp. 65–80, 1887.

[4] Peters, E. D., jr., The mines and reduction works of Butte City, Mont.: U. S. Geol. Survey Mineral Resources, 1883–84, pp. 374–396, 1884.

HISTORY.

In the early days of silver mining manganese was considered more or less of a detriment and commonly became the despair of the silver miner, for, as is brought out by Peters,[1] a considerable increase of manganese in the ore commonly meant a reduction in its silver content. After the building of the Colorado smelter in 1879, however, manganese oxides were found useful as a flux in smelting and reduced rates were made for ores rich in that metal. For about 15 years thereafter ores rich in manganese oxides but too poor in silver to pay for working under former conditions were mined and smelted, and the production is said to have reached at times several hundred tons a month. The total amount of highly manganiferous material extracted from the lodes is therefore evidently large, possibly as much as 100,000 tons.

For many years past most of the mines in the manganiferous areas, which is equivalent to saying the mines that produced silver ores, have been idle and their workings are flooded or fallen into disrepair. Many of them were closed soon after the historic decline in the price of silver in 1892. A few were operated intermittently for a time afterward, but none, except some on the border of the copper zone, maintained anything like a steady production. Within the last few years, however, chiefly as a result of higher prices of silver and advances in the metallurgy of zinc, several mines in the manganiferous area, notably the Elm Orlu, Black Rock, Emma, and Nettie, have been extensively worked, and in 1917 preparations were under way to reopen the Moulton, Travona, Germania, and four or five others, some of which are on the Black Chief lode.

Within the copper area mining development persistently carried on since 1880 has demonstrated the great size and persistence of the lodes, a fact that has an important bearing on the persistence of those in the adjoining manganiferous areas.

GEOGRAPHY.

As the geography of the Butte district is well known, an extended description is unnecessary, though mention may be made of the fact that the district is somewhat remote from the principal markets for manganese ore at the present time. In round figures the distance by rail to Chicago is 1,500 miles, to Cleveland 1,850 miles, and to Pittsburgh 2,000 miles. With respect to possible future markets that may be developed by the growth of electric smelting Butte is more fortunately situated. It is in the Rocky Mountain region, where large amounts of hydroelectric power are generated at many points near by, and the distance by rail to Portland, Oreg., or to Seattle

[1] Peters, E. D., jr., op cit., p. 379.

and other points in the Puget Sound region is less than 800 miles. At present Butte is served by four transcontinental railroads.

The part of the district under present consideration is approximately a rectangle 4 miles from east to west and 3 miles from north to south that lies west and north of Silverbow Creek and east of the "dead wash" or Tertiary lake-bed area which begins at Rocker. Its surface in general is a rather gentle slope that faces the south and southwest, ranges from 5,400 to 6,400 feet in elevation, and has no very conspicuous features except a sharply conical hill 500 feet high known as The Butte. In detail the surface is modified by several shallow gulches and low rounded hills, of which the celebrated Anaconda Hill is an example. At close range appear several low but rather rugged and conspicuous east-west reefs that, as a matter of fact, are the outcrops of some of the manganese-bearing lodes. The Butte is a little west of the center of the area, Anaconda Hill is at the southeast, and the city lies between the two but mostly south of a straight line joining them. Less than one-fourth of the area described is occupied by the copper zone, which so far as present developments show lies wholly east of The Butte. A broad strip, known as "the rhyolite area," that extends from the western edge of the city northwestward and includes The Butte, is barren of lode outcrops, but the remainder of the area contains deposits that carry silver, zinc, and manganese. The manganiferous area is divided by the copper zone and the rhyolite area together into nearly equal parts. For convenience the northern part may be referred to as the northern section, and the southern part may be subdivided into east and west halves which virtually coincide respectively with what are locally known as the "southwestern" and "western" sections of the district.

GEOLOGY.

The geology of Butte and of the surrounding region is described in detail by the authors cited on page 112 and others, and only its general features need be recounted. For the most part the area under consideration is underlain by quartz monzonite, a granular intrusive rock commonly known as the Butte granite. Available analyses show that this rock contains about 0.10 per cent of manganese, or little more than granites in general. In what form this manganese occurs is not determined, but a suggestion is given by the fact that the dark mica in a fairly fresh specimen obtained by the writer in the southwestern section gives a strong reaction for manganese and is therefore probably to be classified as the mineral manganophyllite. The western section and a few small areas elsewhere are underlain by aplite, locally known as the Bluebird granite, a more siliceous rock than the monzonite but closely related to it. Most of these aplite masses, however, give place to monzonite at relatively shallow depths. The rhyolite area, as its name indicates, is underlain by rhyolite, which occurs as surface flows and dikes of later age than the monzonite and aplite. As a rule the surface bears a thick mantle of more or less completely decomposed rock, but in places the boulder-like forms characteristic of partly weathered granites are moderately abundant.

The monzonite and aplite are traversed by remarkably numerous and extensive fractures, most of which may be classified according to age in two main groups—an older, commonly known as the east-west system, and a younger, the fault system, whose members are of several different ages. Fractures of both systems are thickly distributed throughout the areas of monzonite and aplite. The older fractures do not penetrate the rhyolite, but whether this rock is later than the fault system is not definitely known. On the average the fractures of the older system strike about N. 75° E. and dip steeply southward; those of the fault system show wide ranges in strike and dips. In detail many of the fractures are extremely complex, throwing off branches in great number and of different degrees of magnitude.

LODES.

Mineral deposits of the type known as quartz lodes and thought to have been formed by emanations from a deep-seated igneous body are found commonly along the fractures of the east-west system and in places along the later fractures. None have been found in the rhyolite, which is clearly later than the east-west lodes at least, but they are thickly and rather uniformly distributed throughout the areas of monzonite and aplite. As shown by the geologic map accompanying Weed's report on the Butte district[1] the area under consideration contains scores of veins whose total aggregate length is more than 120 miles. Few of them are less than 3 feet wide, the most are 6 feet or more, and several range from 40 to 100 feet. As exploratory workings from a few hundred to several thousand feet deep on most of them have not discovered their lower limits, it may be seen that their aggregate volume is enormous.

Most of the veins within the copper area, particularly those composing the great Anaconda and Syndicate lodes, have been explored to a depth of 3,000 feet or more, and their features, including their massive to extremely complex branching forms, are described in detail by the authors already cited. Outside the copper area the best known lode is the Rainbow, which traverses the northern section from the edge of the rhyolite north of The Butte to Silverbow Creek, a distance of 3 miles. It is even larger than the Anaconda

[1] U. S. Geol. Survey Prof. Paper 74, pl. 10, 1912.

and comprises a group of closely spaced and alined veins on which the Alice Moulton, Elm Orlu, and Black Rock mines are situated. Development workings over a considerable part of this lode have reached a depth of nearly 2,000 feet and show that its width commonly ranges from 40 to 100 feet. In the southwestern section the Emma, Ancient, Tzarina, and other veins that fall about in line constitute another group of lodes known as the Black Chief. This group is 2 miles long and from 20 to 80 feet wide but has been explored comparatively little below the surface. The Nettie-Hibernia and the Norwich-Great Republic vein systems, in the western section, viewed in like manner as composite lodes, are smaller than those mentioned, though of nearly the same order of magnitude. Commonly the veins that compose the different lodes mentioned branch more or less, in places sufficiently to form large stockwork-like bodies, though so far as known they appear to be less complex generally than the veins of the Anaconda lode. Their outcrops are decidedly more prominent than those of the veins in the copper area, forming reefs and broken walls that are traceable for long distances.

MANGANESE.

OCCURRENCE AND DISTRIBUTION.

The country rock at Butte contains a small percentage of manganese, which is of no commercial value as a source of the metal, but manganese occurs otherwise only as an original constituent of the quartz veins, which are regarded as the product of a deep-seated intrusive magma. Rather curiously, manganese minerals are scarce in the veins that yield copper ore, and in fact they are not found in those of an area that surrounds Anaconda Hill and was called by Sales[1] the central copper zone. Outward from this zone manganese minerals appear, but they are not plentiful within the area that produces ores predominantly valuable for copper. Beyond this area on the north, west, and southwest, in a peripheral zone commonly known as the silver area, manganese minerals are plentiful in all the veins. Outward from this zone manganese is again generally less abundant, and the outer as well as the inner limit of the manganiferous zone is therefore rather indefinite. The width of the zone in which the veins are strongly manganiferous, however, ranges from 1 to 2 miles approximately, being greatest toward the west. Owing to the general lack of underground work and the mantle of wash that conceals the bedrock in the valley of Silverbow Creek, the extent of the manganiferous zone on the east and southeast is not known. Presumably its ends lie beyond its present known limits, which are near Meader-

[1] Sales, R. H., Ore deposits at Butte: Am. Inst. Min Eng. Trans., vol. 46, p. 59, 1914.

ville and the Northern Pacific Railway station, but they do not necessarily meet so as to form a closed ring. However, many of the veins of East Ridge, directly across the valley, are moderately manganiferous.

About half of the manganiferous zone lies north of the copper area and east of the rhyolite, and is referred to as the northern section; the remainder lies in what are locally known as the southwestern and western sections. Though manganese is widely distributed in all parts of the zone, it appears to be relatively most abundant in the southwestern section. It occurs abundantly as deep as the workings have gone, though according to Bard and Gidel[1] it seems to be less plentiful in the deeper parts of the veins.

MINERALOGY.

The classification commonly made by the miners, who group the different oxides together as "black manganese" or simply "manganese" and the carbonate and silicate as "pink manganese," is sufficient for many practical purposes as well as significant of the strong color contrast between the minerals of the oxidized zone and those that preponderate below. Such a classification, for example, separates the minerals commonly known and used in metallurgy from those which are comparatively new and untried. As a rule the constituent minerals of the oxidized material at Butte are difficult to distinguish separately, a fact that may in part account for differences in the conclusions the authors already mentioned have reached concerning the relative abundance of the different oxides.

Peters,[2] who apparently made more than a casual examination of the manganese oxides at Butte, gives the order of their frequency of appearance as pyrolusite, psilomelane, braunite, and wad. Braunite was not seen by the writer, but after psilomelane manganite may be added to the list. Manganiferous siderite also was observed by the writer, but it appears to be uncommon, having been found only in a dump at the old workings of the Burlington mine, in the western section. Most of the oxidized material is tentatively classified as pyrolusite because it gives little or no water in the closed tube and is of medium hardness—too soft to be classified as psilomelane and too hard to contain much wad. It is not homogeneous, however, and is doubtless a mixture of several oxides. Small crystals of steely luster are plentifully scattered through the mass and in places form solid aggregates. Their habit is prismatic or less commonly platy; in places they form crusts composed of radiated aggregates.

[1] Bard, D. C., and Gidel, M. H., Mineral associations at Butte, Mont.; Am. Inst. Min. Eng. Trans., vol. 46, p. 126, 1914.

[2] Peters, E. D., jr., op. cit., p. 380.

As a rule they are moderately soft and contain more or less water and are therefore classified as manganite, though they may in part be altered to pyrolusite.

Psilomelane forms mammillated crusts and concretionary masses and is easily identified by its compact and homogeneous appearance and hardness; it is not easily scratched by a pocket knife. Commonly it shows a somewhat satiny luster on freshly fractured surfaces. Some of the jaspery oxide ore, which consists of finely divided manganese oxides in a matrix of chalcedonic quartz, resembles the psilomelane but is distinguished from it by a very imperfect solubility in acids.

A widely distributed but not plentiful brownish-black manganese oxide soft enough to stain the hands readily is classified as wad.

As a rule there is little difficulty in determining the manganese minerals of the unoxidized zone, which are limited so far as known to rhodochrosite, rhodonite, and hübnerite. Hübnerite, the tungstate of manganese, a heavy, moderately hard reddish-brown or black mineral crystallizing in bladelike forms and showing smooth glistening cleavage faces, is found in the Gagnon, Tramway, and some other mines, but so far as known it has not been found in the strongly manganiferous area. It is valuable as an ore of tungsten.

As a rule rhodochrosite and rhodonite can be distinguished from the other minerals of the Butte lodes by their pink color. Exceptionally the rhodochrosite may be so pale as to resemble calcite, but it betrays its true character by turning black when heated. Rhodochrosite, the carbonate, and rhodonite, the silicate, contain when pure, respectively, about 47 and 42 per cent of manganese. Owing, however, to the absence of silica and to the ease with which the carbonate can be changed to an oxide, simple roasting being sufficient to drive off the carbon dioxide, and to the comparative difficulty experienced in decomposing the silicate, the rhodochrosite is by far the more valuable as a source of the metal. Fairly pure rhodochrosite occurs in several places. Exceptionally fine specimens from the Emma mine show delicate shades of rose-pink and rhombic cleavage faces as large as 1 inch across. In part the material is compact and massive and in part made up of crustlike layers that range from coarse to fine in texture. As a rule the coarser-textured material is translucent and deeply tinted and the finer material rather pale and semiopaque. Open spaces are lined with free crystals. Specimens from old dumps at the Travona, Hibernia, and other mines near by are finer grained and paler, some being fawn-colored, with hardly a trace of pink. The rhodochrosite is easily scratched with a pocketknife and effervesces freely when warmed with acids. Upon being heated it turns black, develops shrinkage cracks, and becomes friable, and some of the specimens from the Emma mine decrepitate violently.

Under the microscope the mineral is difficult to distinguish from calcite, though its relief appears somewhat greater and is considerable even for the extraordinary ray. The opaqueness noticed in certain layers in the hand specimen is caused by a multitude of microscopic cavities oriented parallel to the cleavage and known as negative crystals.

The rhodonite found in old workings of the Valdemere mine and at other places along the Rainbow lode is fine grained and compact and can readily be distinguished from rhodochrosite by its failure to effervesce when heated with acids and its superior hardness; it can not be scratched with the blade of an ordinary pocketknife. In addition it commonly shows brighter shades of pink, and the color appears intensified by polishing. Specimens obtained from the dumps of the Alice mine are said to have been used as ornamental stones,[1] though so far as could be learned the mineral has never been mined by the operators for that purpose.

Microscopic examination shows the rhodonite as tufts and radial aggregates of slender prisms and less commonly in platy forms.

A summary of existing information shows that the rhodochrosite and rhodonite were introduced together into the veins but were mostly later than the bulk of the other vein filling. They were generally accompanied by quartz, however, and commonly by sulphides and were deposited as several successive generations.

The siderite mentioned is dark reddish brown, effervesces freely when warmed with acids, and gives a strong reaction for manganese. It was not seen in place, nor was any information concerning it gathered from the reports examined. The material seen is heavily coated with iron oxides, apparently because it had been long exposed to the weather. An increase in the abundance of iron oxides observed in the lodes near the western limit of the manganiferous area may mean that siderite occurs in them generally.

OXIDATION AND ENRICHMENT.

In the manganiferous area the depth of oxidation ranges from 10 or 20 to 200 feet or more but is generally less than the mean of the extremes given. According to available information the lower limit is sharp and the change from oxidized to unoxidized material abrupt. In the process of oxidation virtually all the vein minerals were dissolved except quartz, which remained as a cellular skeleton or "honeycomb," and the manganese was transported and redeposited as oxides, chiefly in cracks or other open spaces. The criss-crossed partitions of manganite in the cellular ore described on page 124 are evidently filled cracks in what at the time were solid mineral aggregates but

[1] U. S. Geol. Survey Mineral Resources, 1914, pt. 2, p. 324, 1915.

later became porous by the leaching away of all their other minerals except quartz. A common variety of the coarse-textured oxide ores consists of fractured vein quartz cemented with manganese oxides that evidently came from other parts of the lode. As solution doubtless advanced unequally at different places, parts of the lodes after being made open and porous became the receptacles for manganese oxides derived from the adjacent parts and were thus transformed into the very common cellular variety of ore that has a quartz skeleton.

Microscopic examination shows that to a very small extent the manganese oxides made additional room for themselves by replacing the quartz. Replacement of rhodonite is also plainly shown in specimens from the Valdemere mine, and probably both rhodonite and rhodochrosite have generally been replaced. Specimens composed of a mixture of oxides from the outcrop of the Ancient vein indistinctly show rhombohedral forms that strongly suggest a pseudomorphous replacement of rhodochrosite having a texture like that of the rhodochrosite found in the Emma mine. In the eastern part of the Rainbow lode, a part of the Nettie vein, and some other places very finely divided oxides and chalcedonic quartz were deposited together, forming a jaspery variety of ore.

The distances to which manganese was carried in solution before being redeposited show a wide range, but the amount of material transported to considerable distances was small. In places a little was carried below the general limit of oxidation, and some has gone rather far from the lode horizontally. Joints and seams in a rhyolite dike that cut the Great Republic lode on the east are filled with manganese oxides to a distance of 20 feet or more. The bulk of the material, however, appears to have been moved comparatively small distances.

In general oxidation is believed to have produced but little difference in the manganese percentage in the lodes. A considerable enrichment has doubtless been caused by the solution and removal of other materials, including the silica of rhodonite, and by the escape of carbon dioxide from the rhodochrosite. On the other hand, this enrichment is offset, at least in part, by the scattering of manganese oxides mentioned in the preceding paragraph. The small bodies of high-grade oxide ore that are confined to the superficial parts of the lodes are regarded, however, as residual deposits formed as the outcrops of the lodes were worn down by solutions that redissolved the oxides, collected them, and redeposited them, chiefly in open places. Whether any manganese was carried below and redeposited as rhodonite or rhodochrosite, thus forming enriched bodies similar in mineralogy to the primary ore, is not positively known, but the facts available are opposed to such a conclusion.

ORE BODIES.

CLASSIFICATION.

Two main types of manganiferous ore are found in the Butte lodes—the black or oxide ore of the outcrops and the oxidized zone and the pink or carbonate and silicate ore that occurs below. Although differing in origin and occurrence the high-grade oxide ore at Butte is essentially similar to that produced in foreign countries and the eastern United States, upon which the industries have heretofore chiefly depended. The low-grade ore, which composes all but a small part of the deposits, differs, however, from the low-grade deposits worked in Arkansas and other States east of the Rocky Mountains in that the matrix of the manganese minerals is hard vein quartz instead of rather soft clay or a similar residual material.

Manganese carbonate is new to the trade in the United States, though it has been mined and utilized for a considerable time in Europe, and so far as known, silicate ores have not yet been used as a source of manganese, except some mixed ores mined in the Province of Huelva, Spain. In accordance with the trade customs that were most common in the Northwestern States in 1917, the manganiferous material of the Butte lodes is somewhat arbitrarily subdivided into high and low grade, according to whether it contains more or less than 40 per cent of manganese and into high and low silica ores according to whether it contains more or less than 10 per cent of silica. The pink ore may be further classified as carbonate, silicate, or mixed carbonate and silicate.

By far the most of the material in the manganiferous lodes is highly siliceous and contains less than 40 per cent of manganese. Iron is present in small amounts only—generally less than 3 or 4 per cent. Therefore the classification of material containing as little as 5 per cent of manganese as a manganiferous ore, which is possible with some iron ores because they can be smelted directly to manganese-iron alloys, can not be applied unqualifiedly to the Butte deposits. Owing to the more complicated metallurgic treatment required for those deposits, the amount of manganese necessary to permit definition of the material as ore is presumably considerably more than 5 per cent. In August, 1917, the operators who were experimentally concentrating the oxide ores considered tentatively that the smallest amount of manganese permissible in the raw ore was about 20 per cent, and that figure was therefore adopted to define one of the grades of ore estimated in the field. Considered as having a possible future value, material containing from 10 to 20 per cent of manganese was also estimated as a separate grade.

With reference to their probable adaptability to mechanical concentration, the low-grade oxide ores may be broadly classified into two groups—coarse-textured ores, in which the manganese oxides and the quartz occur in somewhat distinct masses, rather easily separable from each other, and jaspery ores, in which the constituents are very intimately associated and form a strongly coherent mass. Fortunately the great bulk of the ore reserves as estimated come under the first of these groups.

The pink or unoxidized manganiferous material of the Butte lodes has not yet (October, 1917) been utilized in the United States, and its designation as ore is therefore somewhat uncertain. Rhodochrosite, however, which, as found in the Emma mine, forms bodies that contain about 40 per cent of manganese and very little silica and presumably offer slight metallurgic difficulties to their utilization, is without doubt a very valuable ore. The probability that large amounts of ore of this kind exist at Butte is indeed the most promising feature of the manganiferous deposits. Pure rhodonite, which may also form considerable bodies at Butte, is possibly to be classified as a high-grade silicate ore. It differs from the high-grade siliceous ore of the oxidized zone in that its silica is chemically combined instead of free. The great bulk of the deposits below the oxidized zone, however, are composed of rhodochrosite, rhodonite, and free quartz in various proportions and contain less than 40 per cent of manganese. They are arbitrarily classified as low-grade carbonate and low-grade mixed carbonate and silicate ores, the lower limit of manganese for each being assumed at 15 per cent.

It should be borne in mind that the classification of the manganiferous material at Butte as ore is based on the high prices paid for manganese in 1917, and the continuance or possible increase in those prices. Should the price drop to its former level probably all the manganiferous material, certainly that portion containing less than 40 per cent of manganese, would again be regarded as waste rock.

OXIDE ORES.

HIGH-GRADE ORES.

Occurrence and distribution.—Oxide ore containing 40 per cent or more of manganese and ranging from low to high in silica forms bodies near the surface, chiefly in low situations or portions of the lodes that do not crop out prominently. Such bodies were seen in all parts of the manganiferous area but are most numerous in the southwestern section, though nowhere can they be said to be abundant. In dimensions these bodies range from inconsiderable deposits to some a foot or two in width and 40 or 50 feet in length, and most of them pinch out within a depth of a few feet. Some are fairly well defined, but most of them grade rather indefinitely into leaner material.

Character and composition.—The most common variety of the high-grade ore is rather compact but not homogeneous, being evidently a mixture of the different manganese oxides. Small black lustrous crystals that appear to be chiefly manganite generally form a considerable part of the mass. Soft black or brown oxides that stain the hands readily and are presumably to be classified as wad are moderately abundant. Psilomelane was identified in a few of the ore bodies as thin mamillated crusts lining cavities. Concretionary psilomelane forms the bulk of an ore body worked by lessees on the North Pole claim, near the Germania mine.

Some free quartz is intimately associated with the manganese oxides, occurring generally either as visible grains or as a cellular skeleton or "honeycomb" more or less completely covered with the manganese minerals. Small masses of a yellowish-brown clay that are apparently residues from the decomposition of granite are commonly present. From several analyses reported, some of which represent ore bodies in place and others ore selected for shipment, it appears that the manganese content ranges from 40 to 49 per cent, silica from 4 to 26.5 per cent, iron from 1.3 to 3.2 per cent, phosphorus from 0.006 to 0.043 per cent, alumina from 2.4 to 7.3 per cent, and silver from 0.3 to 6.2 ounces a ton. Lime, sulphur, and gold occur in traces only. No analyses are available of the psilomelane ore from the North Pole claim, but a representative specimen appears to be very pure. It is soluble in acids without a residue and shows no reaction for barium.

Reserves.—Only 10 bodies of high-grade ore sufficiently large to be worthy of consideration were seen during the examination of the district. These bodies, seven of which are in the southwestern section, are estimated to contain a total of 2,600 tons. Individually they contain from 100 to 800 tons; the largest ones are in the Ancient, Minnie Jane, and Star West lodes. Though their silica content averages high it varies from place to place so that it is possible by careful assorting to obtain from most of them a little ore that runs less than 10 per cent silica. It is believed that 1,000 tons is a liberal estimate of the available amount of this ore.

Other bodies of high-grade oxide ore may be found, particularly in low places where the outcrops are not now exposed, but no large additions to the estimated ore reserves are expected.

LOW-GRADE ORES.

Occurrence.—Oxide ore containing from 20 to nearly 40 per cent of manganese forms bodies that range from 1 to 35 feet in width and from 50 to 400 feet in length. In the narrower lodes these bodies commonly occupy the full width, but in the wider lodes they generally occur as one or more streaks separated by leaner material. Their boundaries, except where formed by the walls of the vein itself, are rather indefinite, as is to be expected from the arbitrary limits placed on their manganese content.

Parts of the lodes containing less than 20 per cent and more than 10 per cent of manganese are somewhat larger than the richer parts mentioned in the preceding paragraph but otherwise are similar. Bodies of both grades extend from the surface down through the oxidized zone, which is generally from 20 to 100 feet deep.

As a rule the outcrops of the richer parts of the lodes are less prominent than those of the leaner parts, the more conspicuous reefs such as those of the Ancient and Tzarina being relatively barren quartz, though they contain enough manganese to color them noticeably. In these particular lodes the best ore occurs in streaks on either side of the main reef.

Veinlets of manganese oxides are common in the wall rocks, and in places they are so numerous as to form stockworks or stringer lodes. Open cuts expose bodies of this description 20 or 30 feet wide adjoining the Ancient and Nettie lodes. These are estimated to average betwen 10 and 20 per cent of manganese.

Character.—A very common variety of the oxide ores classed as coarse-textured consists of fractured vein quartz cemented with a mixture of manganese oxides considered to be largely pyrolusite. For the most part this variety is of coarse texture, and the manganiferous portions appear sharply distinct from the quartz. The microscope shows that some of the manganese oxides, however, have worked around the individual grains in the quartz aggregate and have replaced them to some extent. This variety, together with a cellular ore composed of a porous skeleton or honeycomb of quartz, more or less heavily coated with manganese oxides, forms most of the ore. A rather interesting variety of the cellular ore occurring in several of the veins in the southwestern section is criss-crossed by partitions about one-sixteenth of an inch thick made up of several layers of finely crystalline manganite. The angular cells or compartments between the partitions are filled with quartz "honeycomb" lightly coated with iron oxides and wad. Evidently the manganese partitions were formed in cracks, all the original substance of the ore except quartz being dissolved out afterward.

A variety of the jaspery ore rather characteristic of the eastern half of the Rainbow lode but not commonly observed elsewhere is very fine grained, hard, and compact. But little free quartz is visible in it, though analyses show it to contain a large amount of silica. The microscope reveals considerable secondary chalcedony, some of which is clouded with extremely fine black oxides. Kernels of rhodonite, the mineral from which this ore is evidently derived, remain in some of the larger unbroken fragments of the vein that occur within a few feet of the surface. Another hard jaspery variety, the texture of which is due to secondary chalcedony, is locally abundant in the Nettie lode. It contains a fair percentage of manganese, chiefly as small lustrous crystals of manganite, many of which, as shown by the microscope, are enveloped by the chalcedony. Part of the chalcedony is clouded brown with a material that is probably very finely divided iron oxides.

Composition.—Analyses are available for most of the bodies estimated and range from 10.0 to 37.0 per cent of manganese and from 28.8 to 79.1 per cent of silica (determined as insoluble residue). In round figures the general average of the higher of the two grades of ore considered is 24 per cent of manganese and 50 per cent of silica, and that of the lower is 11.5 per cent of manganese and 73 per cent of silica. In both grades iron varies but little from an average of 3.5 per cent. Generally the ores contain 1 or 2 ounces of silver to a ton, and exceptionally 10 or 15 ounces or more. More than a trace of gold is uncommon. No analyses for phosphorus are available, but the ore under consideration presumably contains no more phosphorus than the high-grade oxide ore.

Distribution.—Although manganese oxides stain all the lode outcrops in the area described as manganiferous, the distribution of material rich enough to be considered ore is by no means uniform. Of the amount of ore averaging 24 per cent of manganese as estimated in the following pages, less than 5 per cent occurs within the northern section, the remainder being about equally divided between the other subdivisions. If in addition the lowest-grade material (containing 11 per cent of manganese) is considered, the relative distribution remains almost the same, only 13 per cent of the whole being found in the northern section. It is possible, owing to the concealment of much of the outcrop of the Rainbow lode by waste dumps and mill wreckage, that considerable ore was overlooked, though even if allowance is made for that contingency the fact remains that the western and southwestern sections contain by far the greater part of the oxide ores.

The preponderant coarse variety of ore is widespread, but the jaspery variety is essentially confined to the eastern half of the Rainbow lode and a section of the Nettie about 200 feet long. It is interesting to observe that 40 per cent of the total manganese oxide ore estimated for the district occurs along the significantly named Black Chief, the principal lode of the southwestern section.

Reserves.—In round figures 132,000 tons of oxide ore that averages 24 per cent of manganese and 50 per cent of silica is estimated to be present in the outcrops and upper portions of the Butte lodes. Considerable additional ore is probably to be found, because at only a few places was the full depth of the oxidized zone used in the calculations. Part of the amount given above was estimated by Messrs. Paul Billingsley, A. C. Grimes, and M. H. Gidel in collaboration with the writer, but the writer is responsible for the total.

The ore included in this estimate can be more quickly and cheaply mined and is therefore of greater present value than the low-grade ore occurring in the deeper levels, though its utilization at all under present conditions seemingly depends on a successful method of concentration. Experiments with ordinary jigs and tables so far reported by the mining companies show a concentration of 3 or 4 into 1; the product contains from 43 to 52 per cent of manganese and 7 to 15 per cent of silica, and the amount of manganese recovered ranges from 40 to 75 per cent. If, for example, an average recovery of 65 per cent could be attained, at a concentration of 3 into 1 the reserve estimated would yield 44,000 tons of concentrate containing about 46 per cent of manganese.

In addition to the ore reserve estimated the lodes contain at least 270,000 tons of oxidized material that averages 11.5 per cent of manganese and 73 per cent of silica. Whether this material should be called ore and considered valuable for manganese depends on market conditions as well as successful concentration. It has the advantage of being readily available to mining, and conceivably it might be made to yield 45,000 tons of a 46 per cent manganese concentrate.

UNOXIDIZED ORE.

CARBONATE ORES.

Occurrence.—Rhodochrosite almost free from impurities other than quartz occurs in the lower levels of the Emma mine, where it forms bodies of high-grade ore large enough to be workable. In August, 1917, their form and limits had not been determined, but according to the latest reports received (December, 1917) a little exploratory work has shown that they are to be measured by thousands of tons, at least.

Character and composition.—Specimens said to be from a body on the 800-foot level 10 feet wide range in color from pinkish gray to deep rose-pink and are coarsely crystalline, some of the rhombohedral cleavage faces being an inch across. Galena and zinc blende, together with subordinate amounts of pyrite and quartz, form mineral aggregates of an older generation sparingly scattered through the rhodochrosite. Cavities are lined with rhombohedrons on the free faces of which minute crystals of clear quartz and small grains of chalcocite and pyrite are deposited. Analyses of samples from a certain level show about 41 per cent of manganese, 1 per cent of silica, 0.6 per cent of iron, and 0.28 ounce of silver to a ton. The bulk of the ore, however, averages from 34 to 38 per cent of manganese and 6 per cent or less of silica. According to tests by the Anaconda Co. this ore is converted into oxides by gentle roasting, and the manganese percentage is thereby increased nearly one-third. The product, being light and friable, probably needs briquetting before it can be smelted—a small matter, however, considering the value of the material.

Reserves.—The probability that bodies of carbonate ore other than those in the Emma mine exist at Butte is so strong as to be almost a certainty. In the southwestern section the lode outcrops are generally richer in manganese than elsewhere. They contain the coarse-textured variety of oxide ore to the exclusion of the jaspery variety observed to be derived from rhodonite, and the only unoxidized manganese mineral found in the dumps of the old workings is rhodochrosite. Although these facts should not be pressed beyond a certain limit in support of a contention as to the tenor of the veins in depth, they nevertheless shed valuable light on the character of the veins. Finally, the rhodochrosite bodies of the Emma are in the eastern part of the largest lode of the southwestern section, the Black Chief, whose outcrop nowhere shows any indication of a change in the vein mineralogy. Therefore it is concluded that a large amount of carbonate ore is to be found below the oxidized zone, of which a considerable part will prove to be as rich as that in the Emma.

In the western section the evidence is less complete. Both rhodochrosite and rhodonite occur in the lower levels of the Nettie, whose outcrop contains both the jaspery and coarse varieties of oxide ore. Elsewhere the outcrops contain chiefly the coarse variety, but there is no positive evidence to indicate the exclusive occurrence of rhodochrosite.

In the northern section the great Rainbow lode, whose character to considerable depths is fairly well known, contains mixed carbonate and silicate ore, little of which apparently is of high grade. The authors familiar with this lode, however, mention rhodochrosite as occurring alone in places, and the possibility of finding workable bodies of it can not be absolutely denied.

MIXED CARBONATE AND SILICATE ORES.

Occurrence and character.—By far the most of the manganiferous material of the Rainbow and presumably many others of the Butte lodes consists of a mixture of quartz, rhodochrosite, and rhodonite associated in diverse proportions. Whether this material can be made to yield manganese profitably is problematic, but a summary of the knowledge concerning it is given for the sake of completeness. All persons who have had the opportunity to inspect the silver-zinc lodes below the oxidized zone agree in recording the widespread and general occurrence of manganese minerals, and, although manganese is given secondary consideration in the reports of Blake,[1] Weed,[2] and Sales,[3] these reports plainly show that the carbonate and silicate are found to the farthest parts of the lodes explored and furthermore that they occur largely as bodies or shoots somewhat distinct from the bodies rich in silver and zinc. It appears to be true also that in the gangue of the principal zinc and silver ore bodies quartz is apt to be relatively more and manganese less abundant in the parts of the vein that are most valuable for silver and zinc. A similar condition was observed in the oxidized zone by Peters,[4] who found that the parts of the lodes richest in silver were generally high in silica and low in manganese and vice versa. Although some migration of the metals has doubtless occurred during oxidation, the movement of the manganese at least is thought, for reasons given on page 120, to have been slight, and the condition described by Peters is believed therefore to be an inherited one. From the data available it appears that the rhodochrosite and rhodonite were not strictly contemporaneous with the sulphide minerals but are largely of a later generation—a fact that doubtless accounts for the partial segregation of the two kinds of ore bodies.

Manganese minerals occur also in veinlets in the wall rocks, as noted by the observers cited and reported by the operators of the Emma mine, where they occur abundantly for a width of 100 feet, as shown by a crosscut. Similar veinlets of oxide ore occur at the surface, where they form stockworks or stringer lodes, as in the Nettie and Ancient claims. (See p. 124.) These were doubtless at first stockworks of pink ore like that of the Emma. The published reports so far as they discuss the manganiferous area show that the proportions of rhodochrosite, rhodonite, and quartz vary from place to place and also with respect to one another. To leave quartz out of consideration, rhodochrosite predominates in one place and rhodonite in another, and in a few places one is present to the exclusion of the other. Concerning their relative proportion in general, Weed[5] is of the opinion that rhodonite predominates, but Bard and Gidel,[6] although noting that these minerals seem to be less plentiful in the

[1] Blake, W. P., The Rainbow lode: Am. Inst. Min. Eng. Trans., vol. 16, pp. 65–80, 1887.

[2] Weed, W. H., The geology and ore deposits of the Butte district, Mont.: U. S. Geol. Survey Prof. Paper 74, 1912.

[3] Sales, R. H., Ore deposits at Butte: Am. Inst. Min. Eng. Trans., vol. 46, pp. 3–106, 1914.

[4] Peters, E. D., jr., op. cit., p. 379.

[5] Weed, W. H., op. cit., p. 84.

[6] Bard, D. C., and Gidel, M. H., Mineral associations at Butte, Mont.: Am. Inst. Min. Eng. Trans., vol. 46, p. 126, 1914.

deeper parts of the lodes, conclude that there is no evidence that rhodonite becomes more plentiful than rhodochrosite in depth. All three minerals may be very intimately intergrown, but commonly each is more or less distinct from the others. There are bodies of broken quartz with seams and nodular masses of manganese spar, hard quartz with veins of manganese spar, and rhodochrosite in the massive form intermingled with quartz and penetrated by thin ramifying quartz veinlets.[1] Rhodochrosite and rhodonite occur as bands cementing the vein materials and are also distributed through the vein zone, binding brecciated material.[2] Quartz with much rhodonite and some rhodochrosite occurs locally in large masses or in bands or layers, rhodochrosite forms considerable bodies in the granite horses, and pink ore forms solid bodies free of quartz.[3]

Composition.—None of the reports mentioned give analyses representing any bodies of the manganiferous material under consideration, but from the descriptions given the inference that moderately high percentages of manganese are common may be safely drawn. Such an inference is further supported by analyses recently (November, 1917) reported by the operator of the Black Rock mine, which show from 13 to 29 per cent of manganese in bodies occurring on different levels down to the 1,700-foot level. The deposits in the southwestern section, which are more richly manganiferous in the oxidized zone than those in the northern section, are probably also more richly manganiferous below that zone.

Reserves.—Though no good basis exists for computing exact tonnages of the bodies of manganiferous material under consideration, the descriptions given by those who have had opportunity to observe them leave no room for doubt that the aggregate amount of such bodies is very large. Such terms as "abundant," "large quantity," "great quantities," and "one of the chief constituents of the gangue," are commonly used by the authors of the reports cited when mentioning this material.

A few more precise descriptions are given also. Blake[4] mentions widths of 12 to 30 feet of manganiferous material in the Alice mine, and Brown[5] observes that in one place the Rainbow lode is more than 100 feet wide and composed almost entirely of rhodochrosite and quartz, though it is apparent from the context that he uses the term rhodochrosite to include both the carbonate and the silicate of manganese. Weed[6] records the occurrence of 6 to 10 feet of solid

[1] Blake, W. P., The Rainbow lode; Am. Inst. Min. Eng. Trans., vol. 16, pp. 69–73, 1887.
[2] U. S. Geol. Survey Geol. Atlas, Butte special folio (No. 38), 1897.
[3] Weed, W. H., op. cit., pp. 244, 245, 254.
[4] Blake, W. P., op. cit., p. 71.
[5] Brown, R. G., The ore deposits of Butte City: Am. Inst. Min. Eng. Trans., vol. 24, p. 550, 1894.
[6] Weed, W. H., op. cit., p. 254.

pink ore without quartz on the 600-foot level of the Ella mine (east of the Leonard), a statement which also implies a manganese content of at least 30 or 40 per cent. The bodies reported in the Black Rock mine range from 4 to 6 feet in width, and 6 feet is one dimension of a body that contains 19 per cent of manganese.

From the foregoing discussion together with a consideration of the great total volume of the lodes in the manganiferous area, as described under the heading "Lodes," (pp. 115–116), the amount of low-grade manganiferous material available below the oxidized zones seems practically unlimited.