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Arizona Bureau of Mines
G. M. BUTLER, Director

MANGANESE ORE DEPOSITS IN ARIZONA

BY ELDRED D. WILSON
and
G. M. BUTLER

Entered as second class matter November 23, 1915, at the postoffice at Tucson, Arizona, under the Act of Aug. 24, 1912. Issued semi-quarterly.

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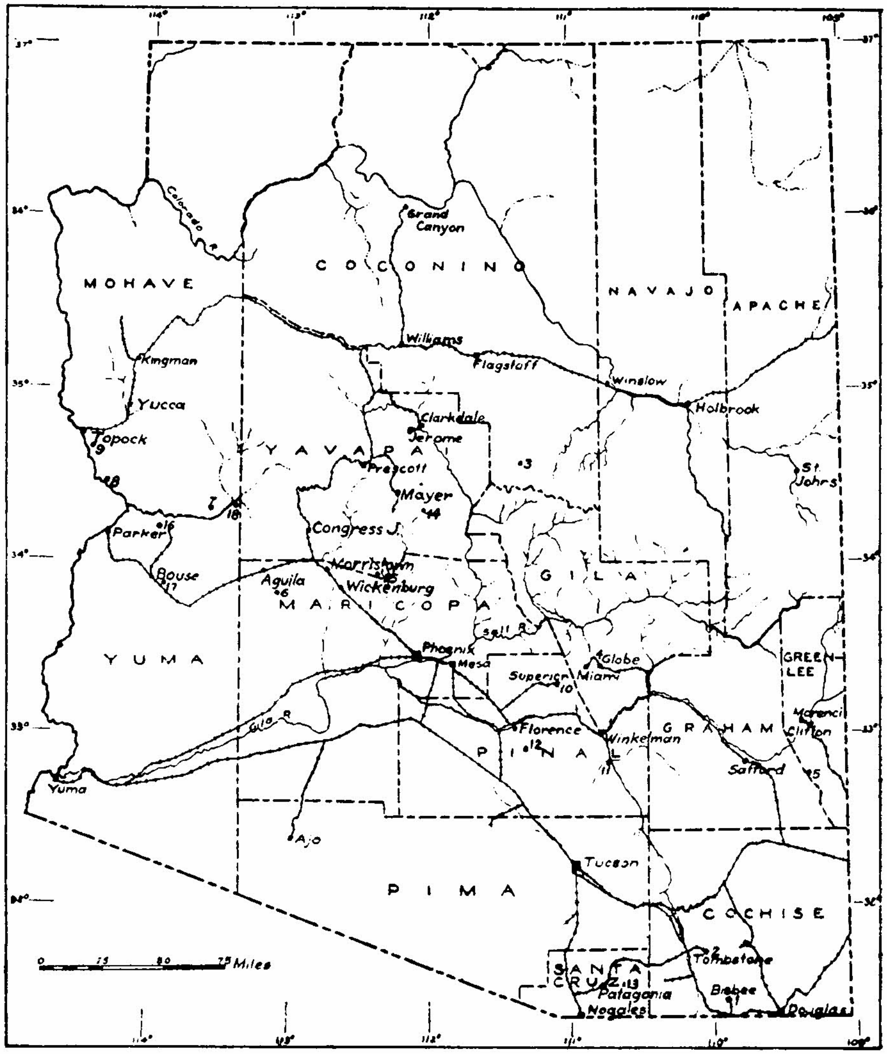

Figure 1.—Index map showing distribution of manganese-bearing regions of Arizona, as considered in this bulletin.

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3. Long Valley ....(See pages 55-58)
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5. Ash Peak ....(See pages 62-63)
6. Aguila ....(See pages 65 70)
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MANGANES ORE DEPOSITS IN ARIZONA

BY ELDRED D. WILSON

and

G. M. BUTLER

PART I.—INTRODUCTION

By G. M. Butler

MANGANESE MINERALS

Manganese does not occur as a native metal, but is found in nature in a great variety of combinations with other elements, whereby it forms a part of more than 100 minerals. Practically all of the manganese of commerce, however, is obtained from one or more of the first seven of the following minerals:

Psilomelane	Rhodochrosite
Pyrolusite	Bementite
Manganite	Rhodonite
Wad	Hausmannite
Braunite	Alabandite

PSILOMELANE

Composition: MnO_2 (manganese dioxide) with MnO (manganese monoxide), H_2O (water), K_2O (potassium oxide), BaO (barium oxide), etc. The mineral is essentially manganese dioxide, but the percentage of metallic manganese rarely reaches sixty, and in hard, compact, homogeneous material the percentage may amount to only fifty or even less. The percentage of water varies from about three to ten, and none of the other oxides mentioned, with the possible exception of oxide of barium, are usually present in proportions as high as three percent.

Luster: Dull metallic to dull; occasionally satiny on a freshly broken surface.

Color of Powder: Usually grayish black; rarely brownish black.

Hardness: Usually too hard to be scratched with a knife, which leaves a shining mark on the surface of the mineral.

Fracture: Curving fracture like flint. Fractured surfaces are very smooth.

Specific Gravity: 3.7 to 4.7.

Occurrence: In veinlets or seams, nodules, and as massive, structureless material. The massive variety often contains cavities or vugs, the surfaces of which are usually coated with globular or kidney-like protuberances. Often associated with limonite (hydrous oxide of iron) and pyrolusite (see below), sometimes occuring as alternating layers with the latter mineral. Can be associated with any of the other oxides of manganese. Often found as a black stain in rock joint planes, and this stain sometimes takes the form of fern-like markings (dendrites). Crystals are unknown excepting when formed by the alteration to psilomelane of crystalline manganese minerals.

Psilomelane may be formed by direct precipitation, or by alteration of any of the other oxides of manganese. It may be replaced by pyrolusite and braunite.

Blowpipe and Chemical Tests: When heated in a closed glass tube, psilomelane gives off oxygen gas and always yields much water. When powdered and dissolved in hydrochloric acid (HCl), it gives off greenish-yellow chlorine gas which has a very unpleasant, stifling odor; and, if sulphuric acid (H_2SO_4) is added to this solution, a white precipitate of barium sulphate ($BaSO_4$) is formed. The finely-powdered mineral imparts distinctive colors to borax and soda beads as described on page 17 of this bulletin.

Miscellaneous: The hardness, lack of structure, and smooth, curving fracture suffice to distinguish psilomelane from other manganese minerals with which it may be confused.

This mineral is the commonest ore of manganese, but is not as pure as some of the minerals mentioned later.

PYROLUSITE

Composition: MnO_2 (manganese dioxide). When pure it contains 63.2 percent of manganese, and 36.8 percent of oyxgen, but most specimens contain about two percent of water, and fractions of a percent of CaO (lime), SiO_2 (silica), and oxides of copper, iron, nickel, cobalt, potassium, sodium, etc.

Luster: Metallic or dull, some forms showing the former and others the latter.

Color: Usually black; sometimes very dark steel-gray.

Color of Powder: Black, often sooty.

Hardness: Soft enough to be scratched with a finger nail. Often soils the fingers when handled.

Fracture: The massive material has an uneven fracture, but the prismatic variety shows a splintery fracture, and the faces of individual prisms are smooth and flat, and reflect light brilliantly.

Specific Gravity: 4.8.

Occurrence: Usually occurs as dull, rather earthy masses, or granular. The earthy variety sometimes contains numerous tiny, steely-lustered, prismatic or platy crystals of pyrolusite or manganite (see below). Often found in crusts with more or less sharply crystallized surfaces, and appearing to be made up of myriads of slender parallel or divergent prisms of crystals. The massive material often contains bands or patches of these parallel or divergent prisms or fibers, and is sometimes entirely prismatic or fibrous in texture. Intergrowths of pyrolusite and psilomelane are common, and these sometimes take the form of alternate bands of prismatic or fibrous pyrolusite and hard, structureless psilomelane.

According to Thiel, [1] pyrolusite replaces manganosite, psilomelane, hausmannite, braunite, rhodonite, and rhodochrosite; is replaced by braunite and psilomelane; and, in some deposits, occurs as an original constituent of sedimentary beds.

Blowpipe and Chemical Tests: Pyrolusite is infusible in a blowpipe flame, but turns brown. When heated in a closed glass tube, pyrolusite gives off oxygen gas, and most varieties yield some water. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The softness and jet-black powder suffice to distinguish pyrolusite from other manganese minerals with which it may be confused.

This mineral is a very important ore of manganese, and may occur in deposits of sufficient purity to be used for the manufacture of chemicals and dry batteries.

MANGANITE

Composition: MnO_2, H_2O (hyrdous manganese dioxide). When pure it contains 62.4 percent of manganese, 27.3 percent of oxygen, and 10.3 percent of water, but the impurities mentioned under pyrolusite are often present in small amounts.

Luster: Usually bright metallic, sometimes dull metallic.

[1] Thiel, Geo. A., The manganese minerals: Their identification and paragenesis: Economic Geol., vol. 19, p. 122. March, 1924.

Color: Dark steel-gray to black.

Color of Powder: Usually brown, sometimes brownish black.

Hardness: Too hard to be scratched with a finger nail, but easily scratched with a knife. Does not soil the fingers.

Fracture: Individual grains or crystals break or cleave easily and smoothly in one direction, yielding flat surfaces which reflect light brilliantly. Masses made up of an aggregate of such grains or crystals have an uneven fracture.

Specific Gravity: 4.2 to 4.4.

Occurrence: Occurs in slender, prismatic orthorhombic crystals which usually have a roughly diamond- or lozenge-shaped cross-section; also as aggregates of prismatic or columnar crystals or grains; rarely granular. Alters readily to pyrolusite or psilomelane. Manganite ore is usually rather porous, the cavities being lined with the prismatic crystals already described.

Blowpipe and Chemical Tests: Infusible in a blowpipe flame. When heated in a closed glass tube, manganite yields water. When powdered and dissolved in hydrochloric acid (HCl), it gives off greenish-yellow chlorine gas which has a very unpleasant, stifling odor. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscelleaneous: The hardness and the brown color of the powder suffice to distinguish manganite from other manganese minerals with which it may be confused.

This mineral is a relatively unimportant ore of manganese, but is not infrequently present in deposits consisting chiefly of psilomelane or pyrolusite.

WAD (INCLUDES BOG MANGANESE)

Composition: An impure hydrous (contains water) mixture of various oxides of manganese, containing variable proportions of the oxides of cobalt, copper, iron, barium, and a number of other elements. The proportion of MnO_2 (manganese dioxide) varies between thirty and 75 percent, but is usually relatively low. The percentage of the other oxides mentioned varies to such an extent that no general figures can be given, but amounts exceeding twenty percent of some of them are sometimes present. The substance should probably be regarded as a mixture of several minerals rather than a distinct mineral species.

Color: Brown, reddish brown, brownish black.

Luster: Dull, earthy.

Color of Powder: Usually some shade of brown.

Hardness: Very soft. Cannot be handled without soiling the fingers badly, and can be used like soft charcoal to mark on paper.

Fracture: Uneven.

Specific Gravity: 2.5 to 4.2. It is usually so porous as to seem very light.

Occurrence: Occurs in soft, light, earthy masses or coatings, which are usually rather porous, and are sometimes, although rarely, finely-fibrous or scaly in texture.

Blowpipe and Chemical Tests: These tests vary with the composition, although all varieties yield the chlorine test described under psilomelane and pyrolusite. The borax and soda bead tests (see page 17) are usually unsatisfactory because of the interference of elements present as impurities, which themselves impart distinctive colors to such beads.

Miscellaneous: The extreme softness and lightness, combined with the prevailing brown tint of the powder, should suffice to distinguish wad from other manganese minerals with which it may be confused.

Wad is usually too impure to have any value as an ore of manganese, but it sometimes contains sufficient copper, lead, or other valuable base metals to constitute it an ore.

BRAUNITE

Composition: $3Mn_2O_3$, $MnSiO_3$ (sesquioxide and silicate of manganese). When pure it contains 78.3 percent of Mn_2O_3 (manganese sesquioxide), 11.7 percent of MnO (manganese monoxide) or a total of 63.6 percent of metallic manganese, and ten percent of silica. Water and other oxides may be present as impurities in amounts up to a percent or two.

Luster: Dull metallic.

Color: Dark brownish or grayish black.

Color of powder: Usually dark brownish black.

Hardness: Same as for psilomelane.

Fracture: Individual grains or crystals break or cleave easily and smoothly in several directions yielding flat surfaces which reflect light brilliantly. Masses made up of an aggregate of such grains or crystals have an uneven fracture.

Specfic Gravity: 4.75 to 4.82.

Occurrence: In coarse to fine granular masses and in octahedral crystals, often mixed with psilomelane.

Thiel [2] states that braunite may be formed by crystallization from an igneous intrusive, by metamorphism of manganiferous sediments, and by alteration of manganese silicates; and that secondary braunite replaces, or is formed by the recrystallization of pyrolusite, psilomelane, hausmannite, rhodonite, and rhodochrosite.

Blowpipe and Chemical Tests: Braunite is infusible in a blowpipe flame. When dissolved in hydrochloric acid, it gives the chlorine test described under psilomelane and pyrolusite, leaving a residue of gelatinous silica after complete evaporation of the acid. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The hardness, dark brown powder, and tendency to show flat, glistening surfaces when broken should suffice to distinguish braunite from other manganese minerals with which it may be confused. The gelatinization with acid will distinguish it from all other manganese minerals.

Braunite is never mined alone as an ore of manganese, but is frequently present as an impurity in other manganese minerals, especially psilomelane. Its abundance at Bisbee has been noted by Hewett (See page 54).

RHODOCHROSITE

Composition: $MnCO_3$, (manganese carbonate). When pure it contains 47.8 percent of metallic manganese, or 61.7 percent of MnO (manganese monoxide), and 38.3 percent of CO_2 (carbon dioxide). Iron carbonate is usually present, and, less frequently, carbonate of calcium, magnesium, or zinc. Cobalt carbonate is a relatively rare impurity. Iron carbonates may be present in amounts up to forty percent or more, and the percentage of calcium carbonate may exceed the percentage of manganese carbonate. The proportion of the other compounds mentioned is usually considerably smaller than the figures just given.

Luster: Glassy when transparent to stony or rather dull when translucent.

Color: Deep rose-red when glassy and transparent, and pink to almost white when translucent; occasionally fawn colored. Turns black when exposed to damp air.

Color of Powder: White.

Hardness: Easily scratched with a knife, but too hard to be scratched with a finger nail.

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[2] Thiel, Geo. A., work cited, p. 124.

Fracture: Individual grains or crystals break or cleave easily and smoothly in three directions, yielding flat surfaces which reflect light brilliantly. Masses made up of an aggregate of such grains or crystals have an uneven fracture.

Specific Gravity: About 3.5.

Occurrence: Occurs in coarsely-cleavable masses, coarse to fine granular masses, and as crystals which when complete are usually bounded by six lozenge- or diamond-shaped faces and which are sometimes bent or warped. Openings or vugs in the massive material are usually lined with fine crystals. Often associated with fluorite (fluorspar), pyrite (iron sulphide), galena (lead sulphide), and other metallic ores. Commonly primary, but in places is believed to be secondary.

Blowpipe Chemical Tests: Rhodochrosite is infusible in a blowpipe flame, but turns black and often flies to pieces. Dissolves with effervescence or boiling in hot, concentrated hydrochloric acid. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The color, the softness, the fracture, and the acid test usually suffice to distinguish rhodochrosite from any mineral which it may resemble.

Rhodochrosite had no commercial importance in this country until about 1918, but large quantities have since been shipped from Butte, Montana, and elsewhere to metallurgical manufacturers. Owing to the absence of silica, and to the fact that a part of the carbon dioxide may be eliminated by roasting, it seems likely that deposits of rhodochrosite may become increasingly important as sources of manganese.

BEMENTITE

Composition: $8MnO.7\ SiO_2.5H_2O$ (hydrous manganese silicate). Pure material contains approximately 32.5 percent of metallic manganese and 39 percent of silica. Small amounts of iron, magnesium, lime, alumina, lead, and zinc may be present as impurities.

Luster: Pearly.

Color: Pale grayish yellow to brown. Darkens on weathering.

Hardness: Hard enough to scratch ordinary glass, but, due to its friable character, may seem to be softer.

Fracture: Individual grains or crystals break or cleave easily and smoothly in three directions, yielding flat surfaces. Often splits like mica.

Specific Gravity: 2.98 to 3.10.

Occurrence: In radiated stellate masses with small foliated structure. Sometimes in very fine felted aggregates of fibers or plates, intergrown with quartz, rhodonite, and manganocalcite.

Blowpipe and Chemical Tests: Readily fusible to a black glass. Soluble in hot acids. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The cleavage, color, and fusibility suffice to distinguish bementite from other manganese minerals.

Bementite has, it is believed, been mined as an ore of manganese only in the state of Washington.

RHODONITE

Composition: $MnSiO_3$ (manganese silicate). When pure it contains 42 percent of metallic manganese or 54.1 percent of MnO (manganese monoxide), and 45.9 percent of SiO_2 (silica). It almost never contains as much as fifty percent of MnO, however, since CaO (lime) is practically always present in an amount exceeding three percent, and iron is also a very common impurity. Either lime or iron may, in fact, form ten percent or more of the mineral. MgO (magnesia) is nearly always represented but in amounts usually under two percent, and zinc is a rather rare impurity.

Luster: Glassy when transparent to stony or rather dull when translucent.

Color: Deep rose-red to light pink; occasionally flesh colored or brownish red. Turns black when exposed to damp air.

Color of Powder: White.

Hardness: Cannot be scratched with a knife, although the blade will sometimes sink between grains of finely-granular varieties, and may seem to scratch such specimens. Even such material will scratch a knife blade, however.

Fracture: Individual grains or crystals break or cleave rather easily and smoothly in several directions, sometimes yielding flat surfaces which reflect light brilliantly. This cleavage is less noticeable upon stony than upon glassy lustered varieties, and may not be evident at all upon fine-grained material. Coarsely granular specimens have an uneven fracture, while very fine-grained varieties may show a smoothly rounded or curving fracture.

Specific Gravity: 3.4 to 3.68.

Occurrence: In fine-grained, compact masses; less frequently coarsely granular, in crystals, or as disseminated grains. Often associated, like rhodochrosite, with deposits of metallic minerals. Sparingly present in pegmatite veins. Sometimes formed by metamorphism. Alters to psilomelane, braunite, and wad.

Blowpipe and Chemical Tests: Rhodonite blackens and fuses easily in a blowpipe flame. Partially soluble in hydrochloric acid, and the undissolved residue becomes white. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The color, the hardness, and the usual association with metallic minerals suffice to distinguish rhodonite from any mineral which it may resemble.

It is not known that rhodonite has ever been mined as an ore of manganese, and it seems improbable that it will ever become an important source of this metal unless an economical method of eliminating the silica can be discovered. It has, however, been mined and used in the manufacture of silicomanganese and silicospiegel.

HAUSMANNITE

Composition: Mn_3O_4 (manganese oxide). When pure it contains 72 percent of manganese and 28 percent of oxygen.

Luster: Dull metallic.

Color: Brownish black.

Color of Powder: Chestnut brown.

Hardness: Somewhat difficult to scratch with a knife.

Fracture: Individual grains or crystals break or cleave rather easily and smoothly in one direction, yielding a flat surface, and indistinctly in two other directions. Masses made up of an aggregate of such grains of crystals have an uneven fracture.

Specific Gravity: About 4.85.

Occurrence: In fine to coarse crystals of tetragonal form; also in granular aggregations and disseminations. Associated with manganese silicates, in some primary vein deposits; with braunite, psilomelane, barite, or rhodochrosite. According to Thiel, [3] hausmannite replaces manganiferous carbonates and manganosite; is replaced by psilomelane, braunite, and pyrolusite; and shows intergrowths with psilomelane.

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[3] Thiel, Geo. A., work cited, pp. 128-129.

Blowpipe and Chemical Tests: Infusible in a blowpipe flame. When heated in a closed glass tube, hausmannite yields water. When powdered and dissolved in hydrochloric acid (HCl), it gives off greenish-yellow chlorine gas which has a very unpleasant, stifling odor. Gives a deep red solution when fragments are placed in concentrated sulphuric acid. The finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The hardness, crystal form, cleavage, and sulphuric acid test suffice to distinguish hausmannite from other manganese minerals with which it may be confused.

Hausmannite is not mined alone as an ore of manganese.

ALABANDITE

Composition: MnS (manganese sulphide). When pure it contains 63.1 percent of manganese and 36.9 percent of sulphur.

Luster: Dull metallic.

Color: Black or very dark gray. Tarnishes brown on exposure to damp air.

Color of Powder: Dark green.

Hardness: Easily scratched with a knife, but too hard to be scratched with a finger nail.

Fracture: Individual grains or crystals break or cleave in three directions at right angles to each other, exactly like the cleavage of galena, although alabandite does not cleave as easily or as perfectly as galena, and the resulting flat surfaces do not reflect light as brilliantly. Masses made up of an aggregate of such grains or crystals have an uneven fracture.

Specific Gravity: 3.95 to 4.04.

Occurrence: In coarse to fine granular masses, and in crystals which are often cubical. A primary vein mineral with metallic sulphides.

Blowpipe and Chemical Tests: When heated in an open glass tube or on charcoal, this substance yields the odor of burning sulphur. Soluble in dilute hydrochloric acid with the evolution of hydrogen sulphide, a gas with the odor of bad eggs. After roasting, the finely-powdered mineral imparts distinctive colors to borax and soda beads, as described on page 17 of this bulletin.

Miscellaneous: The color of the powder and the cleavage suffice to distinguish this mineral from all others which it may resemble.

In nature, it reacts readily with acids, and decomposes faster than do most other sulphides.

Alabandite ore must be roasted before it can be used, and the expense involved in this operation is usually prohibitive.

TESTS FOR MANGANESE

Borax Bead Test: A very little finely-pulverized oxide, carbonate, or silicate of manganese, if added to a drop or bead of melted borax, will cause the borax to assume an amethyst color when cold.

The most satisfactory method of making this test is to heat the end of some 26-gauge platinum wire in an alcohol lamp, touch it to some powdered or granulated borax, and repeat the process until a bead about as large as the head of a glass-headed pin has been formed. If this bead is not too large, it will show no tendency to drop from the wire. When a bead of the proper size has been formed, heat it until it is transparent, and then touch it to a few grains of the mineral to be tested. Finally heat the bead for a minute or two in the tip of the alcohol flame, and examine its color with a lens.

If platinum wire is not available, a bead may be formed by melting a little borax on a piece of charcoal with a blowpipe flame.

This test is very delicate, and the inexperienced operator is apt to introduce so much ore into the bead that the latter becomes black and opaque. When this occurs, the best plan is to start again with a new bead, and to use less ore the second time.

If an ore contains considerable iron, the resulting bead will be orange or reddish brown rather than amethyst in color; while the presence of considerable percentages of cobalt or copper will result in blue beads which may or may not have a purplish tint.

A sulphide ore of manganese should be thoroughly roasted (pulverized and heated at a red heat until sulphur fumes are no longer noticeable) before attempting to make the borax bead test.

Sodium Carbonate Bead Test: If sodium carbonate is substituted for borax in the test above described, the result will be an opaque bluish-green bead, but a little nitre must be added to the bead if the ore is a sulphide, and has not been roasted.

Chlorine Test: All the oxides of manganese yield the so-called chlorine test which should be conducted as follows: Place a little of the powdered material in a glass beaker or a porcelain teacup, and pour some dilute hydrochloric acid over it. If manganese dioxide is present, the mixture when heated will evolve greenish-yellow chlorine gas which has a very unpleasant, stifling odor.

Other Tests: For more highly technical tests, the reader is referred to the following: Thiel, Geo. A., The manganese minerals: Their identification and paragenesis: Economic Geology, vol. 19, pp. 107-145. March, 1924.

Smitheringale, Wm. V., Notes on etching tests and X-ray examination of some manganese minerals; Economic Geol., vol. 24, pp. 481-505. Aug., 1929.

TO CONVERT PERCENTAGES OF MANGANESE DIOXIDE TO PERCENTAGES OF MANGANESE, AND *VICE VERSA*

In quotations and chemists' reports the manganese content of an ore is sometimes reported as metallic manganese, and sometimes as MnO_2 (manganese dioxide). To convert manganese dioxide to metallic manganese, multiply the percentage of manganese dioxide by 0.632. To convert metallic manganese to manganese dioxide, divide the percentage of metallic manganese by 0.632. Thus an ore containing 54.5 percent of manganese dioxide contains 0.632x54.5 percent which equals 34.4 percent of metallic manganese; and an ore containing 42.1 percent of metallic manganese contains 42.1 percent $\div$ 0.632 which equals 66.6 percent of manganese dioxide.

GEOLOGIC OCCURRENCE AND ORIGIN OF MANGANESE ORES

While manganese is a very widely-distributed element which occurs in minute quantities in nearly all kinds of rock, formed or deposited in all geological periods, the metal when thus scantily disseminated cannot be mined profitably, and economically important ore is found only where some form of natural concentration or segregation has occurred. Such workable deposits are of four types which may be designated (1) deposits resulting from the alteration and decomposition of manganese-bearing rocks, (2) deposits occurring as veins or other related forms, (3) bog manganese deposits, and (4) sedimentary deposits.

DEPOSITS RESULTING FROM THE ALTERATION AND DECOMPOSITION OF MANGANESE-BEARING ROCKS

The manganese in ore formed in this way was originally disseminated through rocks that have been subjected to weathering on or near the earth's surface. As a result of this process, the valueless rock constituents are gradually softened and decomposed, are eventually removed by mechanical erosion or in solution, and the heavier manganese minerals gradually accumulate in beds or blankets of varying thickness and purity. At the same time, more or less of the manganese compounds thus released from the decomposed rocks may find their way downward in solution in rainwater, and may be deposited in joints or other openings below the surface. In many places, the deposition from such solutions starts at certain centers, and, around such nuclei, layer after layer of manganese minerals are deposited to form rounded nodules of concretions. These concretions may be rather widely scattered, or they may be sufficiently large, numerous, and confined to relatively thin zones to form beds of valuable ore. Commonly, when the manganese compounds in solution come in contact with certain rocks (especially limestones), the rock constituents pass off in solution, the manganese minerals are deposited in their place, and more or less complete replacement of portions of the rocks is attained.

The manganese minerals found in deposits formed as just outlined are mainly oxides, usually psilomelane, and are apt to be more or less closely associated with limonite (hydrous oxide of iron).

This is probably the commonest and most important type of manganese deposit, and several manganese ore bodies in Arizona, as described further on in this bulletin, have so originated.

DEPOSITS OCCURRING AS VEINS OR OTHER RELATED FORMS

Many ore deposits in the form of veins, shear zones, brecciated zones, etc., together with connected replacements of surrounding rocks, contain primary manganosiderite (manganese-iron carbonate), rhodochrosite, rhodonite, manganiferous calcite, and occasionally alabandite, associated with ores of gold and silver. In the oxidized zone near the surface, the manganese ordinarily becomes highly concentrated in the form of oxides, and is usually mixed with much limonite (hydrous oxide of iron) and more or less silica. The outcrops of such deposits are usually black or very dark brown. Most of the manganese deposits known to exist in the western part of the United States are of this type, as are the majority of those in Arizona.

Operators of mines in deposits of this kind should remember that the oxides are certain to give place to the less valuable carbonate or sulphide, or the valueless silicate, at a depth that is usually measurable in a few scores or hundreds of feet, although the oxides persist to greater depths in some arid or semi-arid regions.

RELATION OF MANGANESE DIOXIDE AND GOLD ENRICHMENT

If a vein or similar form of deposit contains gold, manganese dioxide, and pyrite; *does not occur in limestone or contain calcite (lime carbonate)*; and rainwater percolates down through the ore, certain chemical reactions are very apt to occur near the surface, which cause most of the gold to be dissolved, carried downward in solution, and precipitated at or a little below the groundwater level. In this way very important enrichments of gold have been formed, and the possibility of striking such enrichments at or near the water level should always be considered by miners of deposits of the type described. The oxidized portion of such a deposit always contains a little gold, and occasional small pockets may be good gold ore. Considerable limonite (hydrous oxide of iron) is also always present, and often a little residual pyrite. No valuable gold enrichment need be expected if practically no gold exists in the oxidized zone, if there is very little or no limonite present, or if lime carbonate, in the form of either calcite or limestone, exists in or adjacent to the deposit.

RELATION OF MANGANESE DIOXIDE AND SILVER ENRICHMENT

Quoting from "Ore Deposits," Transactions of the American Institute of Mining Engineers, by W. H. Emmons, upon a summation of the evidence of various ore deposits, "There appears to be two types of enrichment in deposits of manganiferous gold and silver ores. In one of them silver chloride is concentrated in the manganiferous oxidized ores of the upper levels and gold is concentrated below. In the other, silver chloride is subordinate, while both gold and silver are concentrated below the oxidized zone. Possibly the difference could be explained if the amount of chlorine were determined in the waters of deposits of both types. Silver chloride is soluble in an excess of alkaline chloride. Those deposits in which horn-silver is not present may have been leached by waters unusually rich in chlorides."

BOG MANGANESE DEPOSITS

Spring waters and, rarely, surface waters may contain manganese in solution, and, accumulating in swamps or marshes, may then deposit this metal in the form of the earthy, soft, impure hydrous oxide, wad, in layers up to several feet thick. In places, the bog ore consists of a skeleton of hard psilomelane with the cavities filled with earthy or powdery mineral. Less commonly, rhodochrosite forms, but it soon becomes oxidized and hydrated on exposure to the atmosphere. Bog manganese ore may be overlain with soil and gravel, and in places underlain by, or occurs in alternate layers with, bog iron ore (limonite) that has formed in the same way. Bog manganese is, however, much rarer than bog iron, and because of its impurity, limited extent, and prevailing thinness, very rarely forms valuable deposits.

SEDIMENTARY DEPOSITS

It is a well recognized fact that sandstone shale, clay, limestone, and other sediments derived from the wearing down of old land areas in many places contain more or less manganese oxides or carbonates, as stains or concretions, which seem to have been deposited at the same time as the sediments. It is possible that some valuable beds of manganese ore have been laid down in this way in lakes or seas, and subsequently covered with other sediments, but it is more likely that some form of enrichment after deposition has occurred in deposits which appear to be of this type.

PART II.—GENERAL COMMERCIAL FACTORS [4]

By Eldred D. Wilson

USES OF MANGANESE [5]

More than ninety percent of the manganese ore consumed in the United States goes into steel-making. Manganese is used also in the manufacture of: Pig iron; various non-ferrous alloys; dry batteries; certain chemicals and disinfectants; coloring agents in certain dyes, cloth, glass, pottery, and structural materials; decolorizers for glass; driers in paints; and agricultural fertilizers.

Uses in steel: Manganese has no satisfactory substitute in steel manufacture. Proper amounts increase the tensile strength, while, by its deoxidizing action on the liquid steel, it promotes soundness in steel castings, and, by its desulphurizing action, it promotes forgeability or ability of steel to be rolled. Plain carbon steels usually do not contain more than one percent of manganese. If the manganese content is from three to about seven percent, the steel is glass-brittle and useless, but, by increasing the content to ten or fifteen percent and by proper heat treatment, a tough hardness is attained. Such manganese alloy steel is utilized in mining and ore-dressing machinery, railway tires and rails, agricultural implements, etc. Recent developments in tool steels enable high manganese steel to be machined without the difficulties that formerly obtained. [6]

Before being used in steel manufacture, manganese is alloyed with iron, carbon, and silicon. The four standard alloys of this type are as follows: [7]

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4 Acknowledgments are due Dr. W. R. Crane, of the United States Bureau of Mines, for critically reading Part II of this bulletin.

5 Dr. T. G. Chapman, of the University of Arizona, supplied important data upon the metallurgical uses.

6 Written communication from Dr. Jerome Strauss, Chief Research Engineer, Vanadium Corporation of America.

7 Weld, C. M., Manganese: U. S. Bureau of Mines, Bull. 173, p. 6, 1920; also Newton, Edmund, Manganiferous iron ores of the Cuyuna district, Minnesota: Univ. Minn. Bull. 5, 1918.

	Percent of manganese	Percent of iron	Percent of carbon	Percent of silicon
Ferromanganese	50-80	40-8	5-7	0.5 - 1.5
Spiegeleisen	10-35	85-60	4-5	About 1.0
Silicomanganese	55-70	20-5	0-0.35	About 25.0
Silicospiegel	20-50	67-43	1.5-35	4-10

Several firms in this country now produce high-carbon ferromanganese containing from six to seven percent of carbon and from 78 to 82 percent of manganese, and low-carbon ferromanganese containing from 0.4 to 0.7 percent carbon and from 80 to 85 percent of manganese. The low-carbon variety is used extensively in making high-manganese low-carbon steels.

Steel manufacturers of the United States use mainly ferromanganese and spiegeleisen. Ferromanganese has the advantages of high manganese-low carbon content and brittle form, while spiegeleisen has a lower manganese-carbon ratio, is not so easily broken up, and may have considerable adhering sand. Furthermore, ferromanganese can be added directly to molten steel from the converter or open hearth furnace, while spiegeleisen must be pre-melted and is therefore better suited to the Bessemer process. More than eighty percent of the domestic steel now produced is made in the open hearth.

Until recently, the domestic steel made with silicomanganese and silicospiegel was not of the quality to meet general trade requirements. At present, however, a limited, but increasing, amount of high-manganese low-carbon steel of high quality is being manufactured with silicomanganese in the United States. Silicomanganese and silicospiegel may be made from silicate manganese ores.

Uses in pig iron: Manganese not only tends to remove oxides and sulphur from iron, but also makes it harder, more malleable, and less fusible. Manganese is desirable in irons destined for steel-making, and the iron ores containing from three to five percent of manganese are in growing demand.

Uses in non-ferrous alloys: Manganese has a limited, but increasing, use in alloys with bronze, brass, copper, aluminum, silver, and other substances. Brass, with usually less than four percent of manganese, forms a strong, non-corrodible alloy, "Manganese Bronze," useful in marine equipment. [8] "Man-

[8] See Phalen, W. C. in U. S. Bureau of Mines Bull. 173, pp. 24-26, 1920.

ganin," containing 82 percent of copper and fifteen percent of manganese, has high electrical resistance and a very low temperature coefficient. Manganese is utilized as a deoxidizer in the preparation of numerous other alloys. For this purpose, manganese-silicon, which contains from 20 to 25 percent of manganese, a maximum of 1.5 percent of iron, and less than 0.25 percent of carbon, is becoming recognized.

Use in the Electrolytic Zinc Process: Mr. J. B. Tenney, of the Arizona Bureau of Mines, has furnished the following summary upon this comparatively recent use of manganese dioxide:

"In the sulphuric acid leaching of zinc calcines, as practiced at Anaconda and Great Falls, Montana, and at Silver King, Idaho, manganese dioxide is added to the calcines to insure the oxidation to the ferric state of the iron in the calcines. The first step in the process is to neutralize the solutions, thereby insuring the precipitation of the iron as ferric hydroxide. Manganese ores consisting of the minerals pyrolusite, psilomelane, manganite and wad are suitable for this purpose. The silicate braunite will not serve."

Agricultural uses: Since manganese is now recognized as one of the mineral elements essential to plant growth, considerable research is being done to determine its chemical and biological action in fertilizers. As the amount of this element necessary is rather small, many soils contain it in quantities sufficient for crop production, while other soils lack it to a degree that is detrimental to normal plant growth. Research upon this question has already resulted in very material gains to commercial tomato growers in certain southern sections of the United States, and to oat growers in other regions.

Other uses: In dry batteries, manganese dioxide is essential for depolarizing the hydrogen. More than four percent of the manganese ore consumed by the United States during 1925 went into their manufacture. The further uses already mentioned need no discussion here.

SPECIFICATIONS REQUIRED FOR VARIOUS USES

Rather strict specifications are required of domestic ores, because of the generally variable character of the material shipped. The following general data on the specifications of manganese ore required for various uses were largely furnished by

Mr. J. Carson Adkerson, [9] President of the American Manganese Producers' Association.

Ferromanganese manufacture: In past years, ore above 45 percent of metallic manganese, with a maximum of eight percent of silica and eight percent of iron, has been specified. In the last year or so, however, ore containing as low as forty percent of metallic manganese has been used. The phosphorous content must be very low.

Spiegeleisen manufacture: Ore for the manufacture of spiegeleisen will usually run from 12 to 25 percent of metallic manganese.

Pig iron manufacture: Iron ores containing anywhere from one to fifteen percent of metallic manganese are desirable because of their manganese content.

Chemical purposes: For the manufacture of chemicals, the ore should contain at least eighty percent of manganese dioxide, less than one percent of iron, less than four percent of silica, and practically no nickel, cobalt, copper, and arsenic.

Dry cell batteries: The ore should contain approximately eighty percent of manganese dioxide and otherwise have approximately the same specifications as for chemical uses. However, chemical analysis alone is not sufficient to determine the suitability of an ore for this purpose. The ore should be somewhat porous, because a dense ore, even if of ideal chemical composition, is usually not satisfactory. An actual trial test is the only sure method for determining the suitability of supposed battery ore. For example, ore from Phillipsburg, Montana, containing as low as seventy percent of manganese dioxide with about eleven percent of silica and probably three percent of iron, has supplanted foreign ore of higher chemical standards for dry cell manufacture.

Glass manufacture: Desirable ore runs from 85 to 90 percent of manganese dioxide and less than one percent of iron.

Pure manganese metal manufacture: The ore should contain approximately 87 percent of manganese dioxide, with less than 0.5 percent iron and practically no other impurities.

CLASSIFICATION OF MANGANIFEROUS ORES

The following classification of manganese-bearing raw materials has been in general use within the United States since early 1918. Hewett [10] says: "It was the purpose of the new classi-

[9] Written communication.

[10] Hewett, D. F., U. S. Geological Survey Mineral Resources, 1918, pt. 1, p. 622, 1920.

fication to group the raw materials according to manganese content so that the quantities of material capable of certain specific uses would be indicated........................ Actually the grade of alloy which may be made from an ore depends largely upon the percentages of manganese, iron, and silica that are present. If a classification were to indicate truly the use to which the material could be put, it should properly be based upon assigned limits to each of these ingredients. In the United States, however, there are few large deposits of manganiferous materials of any grade which appear to be capable of shipping regularly over long periods material which shows the narrow ranges in composition that much foreign material shows. The actual work required in a classification of the shipments from individual mines, according to a system based upon the percentages of manganese, iron, and silica, is too great to permit its ready adoption by the industry. In spite of certain obvious objections, therefore, the adopted classification is based upon the manganese content alone."

Manganese ore: Materials containing more than 35 percent of manganese are considered manganese ore. *Chemical* and *metallurgical* ores belong in this class. *Chemical ore,* which to the trade, means ore suitable for the manufacture of dry batteries as well as for chemicals, has been defined on page 25. Two divisions of high-grade *metallurgical* ore of late have been recognized. One division, which usually includes washed ore, contains more than fifty percent of manganese, and the lower division includes ores containing from 45 to 50 percent.

Ferruginous manganese ore: Iron ores containing from ten to 35 percent of manganese are considered ferruginous manganese ore. No natural dividing line exists between *manganese ore* and *ferruginous manganese ore,* but the arbitrary division depends upon the use to which the material is to be put.

Manganiferous iron ore: Iron ore containing from five to ten percent of manganese is considered manganiferous iron ore.

Manganiferous silver ore: Materials, either oxides or carbonates, containing more than five percent of manganese and sufficient silver to make them more valuable as a source of silver than of manganese, are termed "manganiferous silver ore."

CONCENTRATION OF MANGANESE ORES

As may be expected, deposits of low-grade manganese ore are relatively much more abundant than are those of commercial grade. However, a low-grade manganese ore is of little value unless a high degree of cheap concentration or a simple process of chemical extraction becomes possible.

No concentration or beneficiation, other than hand sorting, of manganese ores is carried on at present in Arizona, although some was done during the World War. It is beyond the scope of this bulletin to describe the processes used elsewhere, but those interested in such processes are referred to the technical literature upon the subject. As Newton [11] states, "In order to interpret properly the possibility of concentrating at a profit any type of manganese-bearing material, many technical and economic factors must be considered. For a particular property, district, or class of material it is necessary to obtain data on these factors: character and size of deposit; conditions affecting mining and marketing; character of ore material as affecting the possible improvement of grade; metallurgical value of crude ore and possible concentrate; and commercial considerations."

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Zapffe, Carl, Leaching manganese from the siliceous iron ores of Minnesota: Eng. and Mining Jour., vol. 127, pp. 1039-1041; vol. 128, pp. 14-19. 1929.

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[11] See Weld, C. M. (and others), Manganese: U. S. Bureau of Mines. Bull. 173, pp. 30-31, 1920.

MARKETING [12]

Domestic manganese ore for metallurgical purposes is shipped in carload lots of thirty tons or more, and delivered f.o.b the furnaces. Chemical or battery ore is sold by the gross ton.

Sampling of shipments by car lots is done by the buyer at the point of delivery, usually by taking samples from the surface of the lot or from the face of the exposed bank of ore in the car as it is removed by shoveling or otherwise. The grade of the ore is determined by analysis of material dried to 212 degrees F. Settlement is made after the premiums and penalties are adjusted.

Terms of payment vary considerably. It has been customary for the purchaser to advance seventy to eighty percent of the estimated value of a shipment, based on railroad scale weights and a certificate of analysis by an approved chemist. The balance is payable on receipt of the ore by the purchaser.

MEANING OF THE TERM "UNIT" AS USED IN MANGANESE QUOTATIONS

A unit, as the term is applied to manganese quotations, is equivalent to one percent of a long ton (2240 pounds) of the ore, or 22.4 pounds. In other words, if the ore contains 47 percent of metallic manganese and is quoted at thirty cents per unit, its value, exclusive of penalties, is 47 multiplied by 30 cents or $14.10 per long ton. Likewise, the price per ton of a manganese ore, divided by its percentage of metallic manganese, equals its price per unit.

PRICES

Prior to the World War, the price of metallurgical ore containing more than 35 percent of metallic manganese was 23 to 30 cents per unit. In 1917, it was one dollar or more per unit, and, in 1918, it was fixed at 86 cents to $1.30. Following the Armistice, manganese ore prices dropped sharply, and reached a low level of 21 cents per unit in January, 1922. The duty of one cent per pound on metallic manganese in material containing more than thirty percent of metallic manganese, which became effective in September, 1922, increased the price by 22.4 cents per unit.

Prices (exclusive of duty) per long ton unit of imported metallurgical ore containing more than 35 percent of metallic

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[12] Abstracted from Crane, W. R., in Spurr, J. E. and Wormser, F. E., The marketing of metals and minerals: McGraw-Hill Book Co. 1925.

manganese, as quoted by the Engineering and Mining Journal from 1923 to Sept., 1929 are as follows:

1924	41-45 cents	1927	38-40 cents
1925	42-45 cents	1928	35-40 cents
1926	About 40 cents	To Sept. 1929,	30-38 cents

These prices generally were for ore containing a minimum of 47 percent of metallic manganese, c. i. f. (cargo, insurance, and freight paid) North Atlantic ports. The values per long ton unit of domestic ores of equivalent grade would be 22.4 cents higher than these figures.

Imported chemical ore, containing from 82 to 87 percent of metallic manganese, since 1924 has been quoted at from $70 to $80 per long ton. Montana chemical ore, containing from 70 to 75 percent of metallic manganese, since June, 1928, has been quoted at the same price. Other domestic chemical ores, since 1926 have, however, been quoted at from $40 to $50 per long ton.

PRINCIPAL PURCHASERS OF MANGANESE ORE WITHIN THE UNITED STATES (1929)

American Steel Foundries, 410 N. Michigan Ave., Chicago, Illinois.

Colorado Fuel and Iron Co., Denver, Colo.

Columbia Steel Corporation, Provo, Utah.

A. C. Daft, Oliver Building, Pittsburgh, Pa. (Jobbers.)

Foote Mineral Co., Inc., 1609 Summer St., Philadelphia, Pa.

Chas. Gitlan & Co., Inc., 66 Broad St., New York.

Import Chemical Co., 164 First St., Jersey City, N. J.

Kelley & Tennant, Inc., Tube Concourse Bldg., Jersey City, New Jersey.

Lavino Furnace Co., Bullitt Bldg., Philadelphia, Pa.

Metal & Thermit Corporation, 120 Broadway, New York.

Mineral Products Sales Corporation, 135 Front St., New York.

National Sales Corporation, 31-35 East 13th St., Cincinnati, Ohio.

Pacific Coast Borax Co., 51 Madison Ave., New York.

Philipp Brothers, Inc., 233 Broadway, New York.

Frank Samuel & Co., 15th and Market Sts., Philadelphia, Pa.

Tennessee Coal, Iron, and Railroad Co., Brown-Marx Bldg., Birmingham, Ala.

Electro Metallurgical Co., 30 E. 42nd St., New York.

National Carbon Co., 30 E. 42nd St., New York.

PRODUCTION IN THE UNITED STATES

According to the United States Bureau of Mines, [13] 46,636 long tons of manganese ore containing more than 35 percent of metallic manganese and valued at $1,212,679 were produced within the United States during 1928. Of this amount, only 31,206 tons, valued at $591,387, was metallurgical ore, and the total probably was less than two percent of the world's production for that year. In addition, 90,711 long tons of ferruginous manganese ore (containing from 10 to 35 percent of manganese), valued at $406,889, and 1,085,401 long tons of manganiferous iron ore (containing from five ot ten percent of manganese), valued at $2,645,165, was shipped. The principal production of ferruginous manganese ore came from New Mexico and Colorado, and most of the manganiferous iron ore from Minnesota, Michgian, and New Mexico. The following table [14] shows Arizona's importance during 1928 as a producer of metallurgical ore containing more than 35 percent of metallic manganese, compared with that of the other principal producing states:

State	Long tons	Value in dollars
Arizona	3,507	35,500
Arkansas	3,623	81,862
Georgia	4,727	Not stated
Montana	12,044	Not stated
New Mexico	2,672	Not stated
Virginia	2,847	47,932

In addition, 15,430 tons chemical ore, valued at $621,292, were produced, mainly from Montana.

A total of 427,708 tons of manganese ore, valued at $5,395,-949, was imported during 1928, compared with 622,067 tons during 1927. The principal exporting countries are Russia, Brazil, and India.

For a condensed description of the principal sources of production in the United States and in foreign countries, the reader is referred to the section on manganese in Part I of the 1927 "Mineral Resources of the United States," published by the United States Bureau of Mines.

[13] Press Report.
[14] Data from U. S. Bureau of Mines press report.

PART III.—ARIZONA MANGANESE DEPOSITS

ACKNOWLEDGMENTS

As most of the manganese deposits of Arizona have not been worked since the close of the World War, only the few properties active in 1928-29 were visited for the purposes of this bulletin. Fortunately, however, most of the deposits of the State had already been studied, at the time of their greatest development, by Jones and Ransome, of the United States Geological Survey. Their description [15] and those of a few others have been quoted wherever necessary for the completeness of the present bulletin. Thus, a large portion of the following description of Arizona manganese deposits is a compilation.

Acknowledgement is made also of the information and courtesies generously extended by the operators of the properties visited. Their names, together with those of the other mining men who supplied data, are mentioned in the descriptions that follow.

DISTRIBUTION

As indicated on the accompanying map (Figure 1), Arizona's principal manganese deposits are in the southwestern half of the State, in a northwest-southeast belt that includes part of the Mountain Region [16] and part of the adjoining desert Plains Region.[16] Only one group of the deposits described is in the Plateau Province.[16]

HISTORY OF MINING

For many years, manganese has been known in Arizona, particularly in the Bisbee, Tombstone, Globe, Patagonia, and other old mining regions. In 1915 and 1916, manganese ore as such was first mined in the Tombstone, Bisbee, and Globe regions, but prior to that time it had been mined with silver ores and used as flux for local smelters. During 1916, 1917, and 1918, due to the increased demands and prices of the War period, manganese prospecting and mining were greatly stimulated in all the regions of the State known to contain the metal. Market conditions after the Armistice, however, have permitted very little manganese

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[15] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710-D, 1920.

[16] These physiographic divisions of Arizona have been designated by Ransome, F. L., in U. S. Geological Survey Ray Folio, p. 1, 1923.

mining in Arizona, and only from one to five operators each year have been shipping.

Claim Names: Where more recent data are not available, the old names of the claims and groups, together with the names of the 1918 holders, are given for sake of designation, even though those locations possibly have lapsed or changed hands.

PRODUCTION

According to the Mineral Resources of the United States, [17] Arizona's production of manganese ore containing more than 35 percent of metallic manganese has been as follows:

Year	Number of shippers	Long tons, gross	Year	Number of shippers	Long tons, gross
1915	1	339	1922	2	203
1916	5	3,060	1923	1	245
1917	22	14,802	1924	1	42
1918	35	17,612	1925	3	294
1919	4	529	1926	2	2,684
1920	3	2,402	1927	3	3,905
1921	2	328	1928	5	3,507
			TOTAL		49,952 long tons, gross

In addition to this amount, some 7,000 tons of ore containing from 10 to 35 percent of metallic manganese was shipped during 1916-1918, inclusive, and 214 tons during 1928. Also, some 51,500 tons of fluxing ore, part of which was high in silver content, was shipped during 1915-1920, inclusive.

Most of Arizona's manganese production since the end of the World War has been from the Bisbee district, but a few carloads were shipped during 1927, 1928, and 1929 from the Long Valley (Coconino County) region, and an equally small amount during early 1928 from the Rawhide (Mohave County) district.

ESTIMATED RESERVES

The manganese ore reserves of Arizona have been roughly estimated by Furness. [18] Assuming an index price of $50 per ton, he places the indicated possible reserves of Arizona mate-

[17] Published annually by the United States Geological Survey up to the end of 1923, and subsequently by the United States Bureau of Mines.

[18] Furness, J. W., The manganese situation from a domestic standpoint: U. S. Bureau of Mines Information Circular No. 6034, p. 16. April, 1927.

rial containing 35 percent or more of manganese at: 59,200 to 79,200 tons crude; 15,000 to 20,000 tons concentrate; 74,200 to 99,200 tons total. The recoverable manganese content of this total amount would be from 33,400 to 44,600 tons.

TYPES OF DEPOSITS

The following four general types of manganese ore deposits in Arizona were recognized by Jones and Ransome [19]: Irregular bodies associated with fissuring in limestone; veins and brecciated zones; bedded deposits; and irregular deposits associated with travertine.

IRREGULAR BODIES ASSOCIATED WITH FISSURING

Irregular bodies, principally of psilomelane, generally in close association with fissures in the Mississippian and Pennsylvanian limestone, contain the manganese ore of the Bisbee district, and are described on pages 34-46 of this bulletin. Irregular pipes or "chimneys," principally of psilomelane, along zones of fissuring in limestone, contain that of the Tombstone district, and are described on pages 47-50.

VEINS AND BRECCIATED ZONES

The veins and brecciated zones, which occur in both igneous and sedimentary rocks, may, according to Jones [19], be divided into two classes—those associated with silver-bearing minerals and those free from silver.

As representative of the argentiferous type, he cites the Hardshell deposit of the Patagonia district, which is described on pages 91-94 of this bulletin; the deposits of the Globe district (see pages 59-62); and certain deposits of the Superior district (see pages 81-86). The manganese oxides of this class of deposit are psilomelane, pyrolusite, braunite, manganite, and wad.

As representative of the essentially silver-free type, he cites the Ash Peak district (see pages 62-64); the Feldman region (pages 87-89); the Florence area (pages 89-91); many deposits in the Aguila district (pages 65-70); and certain deposits in Mohave County (page 76). Psilomelane, pyrolusite, and manganite occur in this class of deposit.

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[19] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710-D, 1920.

BEDDED DEPOSITS

According to Jones, the bedded deposits, which differ in character and in associated rocks at each locality, occur in the Needle Mountains, southeast of Topock (pages 78-81); in the Artillery Mountains, north of the Wililams River (pages 71-76); on the Santa Maria River (page 102); in the Superior district (pages 81-85); and at Long Valley, Coconino County (pages 55-58). The manganese minerals in this type of deposit are psilomelane, pyrolusite, braunite, and wad.

DEPOSITS IN TRAVERTINE

Jones noted manganese ore associated with travertine about twelve miles southeast of Mayer, Yavapai County (pages 96-97).

COCHISE COUNTY DEPOSITS

The principal manganese deposits of Cochise County are in the Bisbee and Tombstone districts.

BISBEE, OR WARREN, DISTRICT

The Bisbee, or Warren, mining district is in the Mule Mountains of southeastern Arizona, a few miles north of the Mexican boundary, and is accessible by excellent highways as well as by a branch of the Southern Pacific Railroad.

The Mule Mountains, which are about thirty miles long by twelve miles in maximum width, rise abruptly from their southern margin to an elevation of 7,400 feet above sea level or nearly 3,000 feet above the adjacent desert plains, but subside more gradually northward.

GEOLOGY[20]

Ransome gives the following generalized section, from top to base, of the rocks exposed in the Bisbee district:

Cretaceous, Comanchean:

Cintura formation, 1,850 feet thick: Red nodular shales with cross-bedded, buff, tawny, and red sandstones. A few beds of impure limestone near base. Unconformably overlain by fluviatile Quaternary deposits.

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[20] See Ransome, F. L., The geology and ore deposits of the Bisbee Quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, 1904; U. S. Geol. Survey Geol. Atlas, Bisbee Folio (No. 112), 1904, 1914. Bonillas, Y. S., Tenney, J. B., and Feuchére, L., Geology of the Warren Mining District: Am. Inst. Min. Eng., Trans., vol. 55, pp. 284-355, 1917. Tenney, J. B., The Bisbee Mining District, fifty years young: Eng. and Min. Jour., vol. 123, p. 837-841, May 21, 1927.

Mural limestone, 650 feet thick: Thick-bedded, hard, gray, fossiliferous limestone, and thin-bedded, arenaceous, fossiliferous limestone.

Morita formation, 1,800 feet thick: Buff, tawny, and red sandstones and dark red shales, with an occasional thin bed of impure limestone near top.

Glance conglomerate, 25 to 500 feet thick: Bedded conglomerate with rather angular pebbles, chiefly of schist and limestone. Rests on irregular surface produced by erosion.

Carboniferous, Pennsylvanian:

Naco limestone, 3,000 feet thick: Chiefly light-gray, compact limestone in beds of moderate thickness. Contains abundant fossils. Cut by granite porphyry.

Carboniferous, Mississippian:

Escabrosa limestone, 700 feet thick: Thick-bedded, white and light-gray limestone. Contains abundant crinoid stems. Cut by granite porphyry.

Devonian:

Martin limestone, 340 feet thick: Dark-gray, fossiliferous limestone in beds of moderate thickness. Cut by granite porphyry.

Cambrian:

Abrigo limestone, 770 feet thick: Thin-bedded, impure, cherty limestones. Cut by granite porphyry.

Bolsa quartzite, 430 feet thick: Moderately thick, cross-bedded quartzsites, with basal conglomerate. Cut by granite porphyry.

Pre-Cambrian:

Pinal schist: Sericite schist. Cut by granite and granite porphyry.

Regarding the structure of these rocks, Ransome says: [21] "The rocks are much faulted, and the structure is complex in detail. The controlling structural element, however, as regards the deposition of the copper ores, is a synclinal block of Paleozoic beds south of the town of Bisbee. This block was faulted down in pre-Cretaceous time by the Dividend fault, so that the curved beds comprising it dip towards and abut on the north-northeast against the pre-Cambrian Pinal schist and the porphyry of Sacramento Hill, which was intruded into the fault zone. The syncline pitches southeast and passes under the Cretaceous beds, which occupy the eastern part of the district. The deposition of the copper ores closely followed the intrusion of the porphyry

[21] U. S. Geol. Survey, Bull. 710-D, pp. 100-101, 1920.

.... The depth to the general groundwater level at Bisbee when mining began was probably from 1,000 to 1,100 feet."

GENERAL CHARACTER AND DISTRIBUTION OF DEPOSITS

Ransome states: "Deposits of manganese ore, as indicated by black streaks or patches in the generally well-exposed Paleozoic limestones, are widely distributed over the southwestern part of the Bisbee quadrangle. Most of those deposits........ opened to supply war needs lie, however, close to the towns of Bisbee and Warren, in the vicinity of the large copper mines. The ore, principally psilomelane, [22] occurs in irregular bodies, generally in close association with fissures in the Escabrosa and Naco limestones. Some deposits follow the fissures and are lode-like in form; others extend laterally from the fissures along certain beds of limestone that have been more susceptible than others to the process of replacement. Most of the deposits are superficial, few of them descending to a greater depth than fifty feet........"

Ransome continues: "None of these deposits are far from the railroad, and most of them are probably within half a mile of it. Owing, however, to the situation of some and the comparatively temporary character of the operations on all, it has not proved practicable to build roads to them, and a considerable part of the ore is brought down to the nearest wagon road or railway siding on pack animals."

INDIVIDUAL DEPOSITS

Twilight Claim: Ransome [23] has described this deposit as follows:

"The deposit on the Twilight claim........is half a mile west-southwest of the center of Bisbee, at about 6,100 feet above sea level, in the steep limestone bluff directly south of the .... main adit of the Higgins copper mine. The bluff is composed of the Escabrosa limestone, here occupying its normal stratigraphic position above the Martin limestone, which crops out on the steep lower slope of the hill. The Escabrosa, however, is traversed by a zone of nearly east-west fissuring along which there has been some minor faulting followed by considerable silicification. In consequence of this silicification and of the disposition of the manganese ore along the fault zone, the limestone has resisted erosion and presents a rugged front to the lower country on the north.

[22] D. F. Hewett, of the United States Geological Survey, writes that considered braunite is present (see page 54).
[23] Work cited, pp. 105-106.

"Along the zone of fissuring manganese deposits extend for a distance of over 1,000 feet, partly within the boundaries of the Hendricks claim of the Phelps Dodge Corporation and partly within those of the Twilight claim. These ore bodies are irregular replacement masses whose longest dimension is not invariably parallel with the fissure zone as a whole. The individual ore bodies may follow subsidiary divergent fissures. The largest mass of ore mined on the Twilight claim, although very irregular, coincides with a series of nearly vertical fissures that strike as a whole about N. 60° W. This body appears to be about 200 feet long and as much as thirty feet wide, and has been mined by open cuts to a depth of about forty feet. It probably does not extend, with anything like these dimensions, for more than ten to twenty feet below the floor of the principal open cut from which ore was being taken in 1918. The deposit has no definite walls, but shows all gradations from solid black ore to gray limestone in which thousands of minute reticulating fractures are accentuated by the deposition of manganese oxide. Many of these fractures are so minute as to show no actual filling and yet by the deposition of manganese oxide within their walls they appear as dark, feathery lines of appreciable width.

"The best ore is hard, compact, nearly black psilomelane. In places the psilomelane contains small sheaves and irregular bunches of barite, with which are commonly associated aggregates of a bright yellow-green crystalline mineral (Higginsite).............

"A soft black manganese mineral, probably pyrolusite, occurs sparingly.

"The material mined probably contains about thirty percent of manganese, but it is sorted for shipment so as to yield a product containing about forty percent. Screenings containing about 37 percent of manganese are shipped as second-class ore.

"The general composition of the ore is shown by the following ten smelter analyses:

Mn	45.78	42.27	41.98	40.84	40.39	40.01	39.59	39.20	37.32	37.28
Fe	7.21	8.80	8.98	10.33	8.69	9.90	9.37	9.40	9.89	9.90
SiO_2	13.34	14.95	11.78	11.66	15.47	11.99	11.31	18.44	11.85	15.33
P	.047	.059	.022	.062	.043	.057	.061	.051	.043	.055

"The smelters exact a penalty for silica in excess of eight percent.

"The ore is carried on pack animals a short distance down to the Higgins mine and thence is hauled in motor trucks over a good road to the El Paso & Southwestern Railroad at Bisbee. At the beginning of March, 1918, there had been shipped from the Twilight claim 6,087 tons of ore from a total of fully 30,000 tons of material mined. The ore was consigned to the Miami Metals Co. and the Southeastern Iron Corporation, Chicago.

"No close calculation of the quantity of ore remaining in the deposit could be made, but it was roughly estimated on March 4, 1918, at 10,000 tons of shipping ore."

When visited in August, 1929, this deposit was being worked by Mr. David H. White, to whom it had been leased by the Phelps Dodge Corporation since 1925. Workings consisted of an irregular, untimbered stope that extended for some 250 feet southeasterly from an open cut. The ore body, which follows the zone of fissuring mentioned by Ransome, is very irregular, but, as mined, was probably about 35 feet by 35 feet in maximum cross section. Considerable hematite is present along the fissures, but the higginsite here appears to be relatively most abundant nearest the surface.

Through the courtesy of Mr. D. Moreau Barringer, Jr., Assistant Geologist for the Phelps Dodge Corporation, the following data on production of manganese ore from the Twilight deposit since 1924 are given:

Year	Production in long tons	Percent of manganese
1925	84	43.63
1926	2,223	40.26
1927	3,632	40.41
1928	3,350	40.64
1929 (First half)	1,762	41.73
Total	11,051	

According to Mr. White, this ore was shipped to the Tennessee Coal, Iron, and Railroad Company, Birmingham, Ala.

Ransome [24] continues:

Hendricks Claim: "The deposits on the Hendricks claim of the Copper Queen division of the Phelps Dodge Corporation are in part an eastward continuation of those on the Twilight claim and in part lie a little south of that zone of deposits, in the Naco and Escabrosa limestones. Comparatively little mining has been

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24 Work cited, pp. 106-110.

done on the Hendricks manganese deposits. The total shipments from several small openings amounted on March 1, 1918, to about 350 tons. About half of this ore was of good grade and went to the Tennessee Coal, Iron & Railway Co., Bessemer, Ala. The lower grade material was shipped to the Miami Metals Co. (Iroquois Iron Works), Chicago. The Hendricks ore contains a little copper and lead, according to Mr. David H. White, in charge of manganese mining for the Phelps Dodge Corporation, whose assistance in the investigation is here gratefully acknowledged."

Golden Gate Claim: "The Golden Gate deposit is situated half a mile southwest of the center of Bisbee, on a spur of Escabrosa Ridge, just west of Queen Hill. It is an irregular lode along a fissure zone which strikes N. 80° W. and dips 80° N. The country rock is apparently Naco limestone, but the deposit is close to the rather indefinite boundary between the Naco and Escabrosa limestones, and may be partly in the Escabrosa. The average width of the lode is about five feet. The ore is chiefly psilomelane with some barite, and occurs partly as the filling of fissures and partly as a replacement deposit after limestone. It has been mined by shallow open cuts from which about 300 tons has been extracted. The general character of the ore is shown by the following chemical analyses made in the laboratory of the Copper Queen division of the Phelps Dodge Corporation. As in nearly all analyses made in this laboratory, the manganese content is considerably lower than that given in smelter analyses of the same material. The SiO_2 is supposed to include any BaO present.

Mn	Percent	38.0	39.3	S	Percent	Trace	Trace 5
SiO_2	Percent	21.1	19.6	Cu	Percent	1.65	2.1
Al_2O_3	Percent	3.4	2.0	Au	Ozs. per ton	None	None
CaO	Percent	5.0	0.5	Ag	Ozs. per ton	.32	Trace
Fe	Percent	4.2	5.6				

"The ore from the Golden Gate claim, from 800 to 900 tons, was carried by pack animals to the railroad near Bisbee, and most of it was shipped to Bessemer, Ala."

Mammoth Claim: "The deposits on the Mammoth claim are on a low spur that extends eastward from the Gardner shaft, just south of Sacramento Hill. They are irregular replacement bodies in fractured Naco limestone close to the contact with the altered porphyry of Sacramento Hill. In the porphyry are perhaps some included masses of altered Pinal schist.

"Mining has been conducted at two places. At the northwesterly pit about 500 tons of ore had been obtained at the time of visit, and it was roughly estimated that about as much more was available. From 600 to 700 feet southeast of this pit another pit had been recently opened from which it was expected to obtain at least 1,500 tons of ore. The ore shows no definite walls and does not follow any persistent zone of fissuring.

"The ore is psilomelane with nests of barite and small bunches of a green copper-arsenic mineral which is probably the same as that observed in the Twilight ore. Occasionally a little chalcocite is found. The following analyses, made in the Phelps Dodge laboratory at Bisbee, exhibit the general character of the ore:

Mn	Percent	41.3	38.4	4.23	43.7
SiO_2	Percent	6.8	14.3	10.2	10.2
Al_2O_3	Percent	3.1	2.9	2.8	2.0
CaO	Percent	5.1	7.1	5.4	4.3
Fe	Percent	3.6	7.3	3.4	6.9
S	Percent	0.5	Trace	0.5	Trace
Cu	Percent	1.11	.5	1.05	1.6
Au	Ozs. per ton	None	Trace	None	None
Ag	Ozs. per ton	.18	.14	.12	.08

New Era, Cochise, Topgallant, Nellie, Illinois, and St. Louis Claims: "On the group of claims belonging to the Calumet & Arizona Mining Company, southeast of the Briggs shaft, the most active work in progress at the time of visit was apparently on the New Era claim, on both sides of the electric line between Bisbee and Lowell. These deposits are all in the Naco limestone, and most of them are closely associated with nearly north-south fissures. Whether these fissures are identical with the fissures of like direction with which the deep-lying copper ores of this part of the district are genetically connected is not known, but they at least belong to the same system. At the two places close to the car line where the most ore had been obtained these north-south fissures are crossed by some nearly east-west fissures, and the fracturing of the limestone in the vicinity of this intersection evidently furnished the conditions favorable for the deposition of ore......... The limestone beds dip to the east........ and the ore occurs mainly as a replacement of a single bed. It is variable in thickness up to a maximum of four feet. An inclined underhand stope had been carried down for about 25 feet from the surface at the time of visit. On the west side of the track the beds........ are more nearly horizontal......... There are probably within an area 200 yards square (40,000 square yards) half a dozen other smaller pits from which some ore had been taken.

"About 700 feet west of these openings some good ore had been taken from an irregular replacement mass along a north-south fissure. Here a shaft twenty feet deep had been sunk and a drift run for about 35 feet to the south. The ore apparently was of low grade at this depth.

"The ore from all the openings in this group is of the usual character........hard, compact psilomelane, which requires sorting to free it from limestone.

"Smelter determinations on about twenty lots of sorted ore from this group of claims show from 40 to 54 percent of manganese, and from 9 to 24 percent of combined silica and alumina."

Waterloo Claim: "The deposits on the Waterloo claim of the Calumet & Arizona Mining Company crop out on a hilltop three-quarters of a mile south of the Briggs shaft and a quarter of a mile east of the main line of the Bisbee branch of the El Paso & Southwestern Railroad. Here three or four open cuts have been made along at least two nearly north-south fissures in the Naco limestone, and from these cuts, 1,200 to 1,500 tons of ore has been shipped. The pits are all shallow.

"Smelter determinations on twenty lots of Waterloo ore show a range from 34 to 53 percent of manganese and from eight to eighteen percent of silica and alumina. The earlier shipments in 1916 averaged about fifty percent of manganese and thirteen percent of silica and alumina."

Danville and Hanchette Fraction Claims: "On the Danville and Hanchette Fraction claims of the Phelps Dodge Corporation, the deposit, which is about 1,000 feet south-southwest of the Briggs shaft, consists of irregular replacement masses along a N. 10° W. zone of fissuring in the Naco limestone. Ore has been taken out from a number of shallow cuts and pits along a distance of about 500 feet. The principal and deepest excavation is close to the railway spur to the Cole mine......... This ore is of good grade. It consists of compact psilomelane and the principal impurities are residual inclusions of limestone and some vein calcite. Analyses also show as much as two percent of copper. The total product at the time of visit was about 600 tons, most of which was shipped to Bessemer, Ala.

"A few typical analyses of the Danville-Hanchett ore, made in the Copper Queen laboratory at Bisbee, are given below. The manganese determinations made at Bessemer, Ala., given for comparison, are generally higher than the Bisbee results."

Mn (Bessemer) .... Percent	49.2	49.7	47.5	49.4	46.4	47.9	47.5
Mn (Bisbee) .... Percent	42.3	43.8	38.9	45.0	36.3	41.4	45.6
SiO_2 .... Percent	10.2	8.4	6.9	7.4	8.4	6.6	7.6
Al_2O_3 .... Percent	1.4	1.3	1.8	1.3	1.9	1.8	1.7
CaO .... Percent	8.1	3.5	10.5	5.2	15.6	4.6	7.4
Fe .... Percent	2.8	2.1	3.2	3.4	3.8	2.7	2.5
S .... Percent	None	None	Trace	Trace	Trace	Trace	0.5
Cu .... Percent	2.09	1.93	1.90	1.72	.95	.44	1.62
Au .... Ozs. per ton	None	None	None	None	None	None	None
Ag .... Ozs. per ton	Trace	Trace	Trace	Trace	Trace	Trace	0.10

On the southeast side of this railway spur is a small open cut and a shallow inclined shaft leading to a few short tunnels that run northwesterly beneath the track. These workings were on psilomelane ore that was about fifteen feet wide at the surface, but pinched out within a distance of some 75 feet. According to Mr. David H. White, approximately 800 tons of ore was shipped from there during 1919 and 1920.

Ransome [25] continues:

Atlas Claim: [26] "The deposit on the Atlas claim of the Calumet & Arizona Mining Company lies about 900 feet south of the Cole shaft and, like most of the other deposits in this part of the district, is on a north-south fissure zone in Naco limestone. It is similar in general character to the deposits on the Waterloo and Danville claims and like them has been worked by cuts or trenches along the fissure zone. About 800 tons had been shipped from the Atlas at the time of visit. The earlier shipments contained about 45 percent of manganese with fourteen to twenty percent of silica and alumina. Later shipments were of lower grade."

Crown King and Unknown Claims: "Along the east face of Escabrosa Ridge west of the Cole mine manganese ore has been mined at a number of places along a series of three or more fissure zones that strike a little east of north. This strike is almost coincident with the strike of the beds of Naco limestone, but the beds dip 25°-35° E., whereas the fissures are nearly verti-

[25] Work cited, pp. 110-112.

[26] Although the deposit here described is recorded by the Calumet & Arizona Mining Co. as being on the Atlas claim, it appears from a comparison of the topographic map of the district with a claim map to be in part at least on the W. M. A., Bay State, and John D., Jr., claims, which adjoin the Atlas on the west.—F. L. R.

cal. From 600 to 700 tons of ore, ranging from 38 to 48 percent of manganese and from five to twenty percent of silica and alumina, had been mined by the Calumet & Arizona Company from these fissure zones prior to March, 1918, but no work was in progress at the time of visit."

Boreas Claim: "The deposits on the Boreas claim [27] are situated on the south end of Escabrosa Ridge, about 2,000 feet west-southwest of the Cole shaft. They are on one of the zones of fissuring just described as passing west of that shaft, but the psilomelane is very bunchy and is not everywhere closely associated with recognizable fissures. Some irregular replacement masses are in solid crystalline limestone, apparently the Escabrosa limestone. A little prospecting had been done on this claim, and some ore had been found at the time of visit, but, so far as known, no shipments had been made. A carload of "float" ore, supposed to have been derived from the Boreas claim, was gathered up on the Irish and Hygiene claims, south of the Boreas."

No. 4 *and Summit Claims*: "The deposit worked in 1918 by the Phelps Dodge Corporation on the No. 4 claim is on the southwest slope of Escabrosa Ridge, a quarter of a mile northeast of the Whitetail Deer mine. Here, at the time of visit, a cut had been made about fifteen feet wide, 125 feet long, and 45 feet high at its face, which was then practically at the north boundary of No. 4 claim. The deposit continues northward into the Summit claim of the Calumet & Arizona Mining Co., but had not then been worked by that company.

"The ore occurs along a nearly north-south fissure zone, which here traverses the upper part of the Escabrosa limestone, and has replaced the limestone irregularly on both sides of the zone.........

"The ore is psilomelane, and requires less sorting than that from any other deposit worked by the Phelps Dodge Corporation. About 1,500 tons had been shipped early in March, 1918, and the deposit showed no indication of exhaustion. All but two carloads had been sent to Bessemer, Ala.

"A few typical analyses of No. 4 ore, made in the Copper Queen laboratory at Bisbee, are given below, with the Bessemer determinations of the manganese contents for comparison.

"Most of the analyses show a little silver, the maximum half an ounce per ton."

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[27] "The name is spelled Boras on some claim maps, and that may be the recorded designation."

Mn (Bessemer)	Percent	45.84	48.03	47.60	47.88	47.94	48.53
Mn (Bisbee)	Percent	42.0	43.8	42.3	43.8	42.4	40.5
SiO_2	Percent	16.0	14.8	17.8	14.6	15.6	14.6
Al_2O_3	Percent	.3	1.0	1.2	1.3	1.3	1.5
CaO	Percent	5.5	4.0	1.3	2.4	5.4	5.5
Fe	Percent	6.7	7.0	5.8	6.4	7.0	6.9
S	Percent	None	Trace	.5	.8	Trace	.5
Cu	Percent	.38	.26	.71	.47	.75	....

According to Mr. David H. White, production from this deposit continued until early 1921, and during 1919 and 1920 amounted to approximately 1,500 tons.

Ransome [28] continues:

Gold Hill: "The deposit owned by the Houghton Development Company on the south slope of Gold Hill has yielded one carload of ore. The psilomelane, associated with iron oxide, barite, and calcite, occurs in small irregular replacement masses in the Naco limestone in the vicinity of a northwest-southwest fissure.

"The analysis of the single shipment of about fifty tons made in the Copper Queen laboratory, with the Bessemer determination of the manganese, is as follows:

Mn (Bessemer)	Percent	47.65	CaO	Percent	5.0
Mn (Bisbee)	Percent	36.6	Fe	Percent	15.0
SiO_2	Percent	9.8	S	Percent	Trace
Al_2O_3	Percent	1.0	Cu	Percent	.30

"So much sorting was necessary to obtain ore of shipping grade that work was abandoned."

Marquette Group: "On claims belonging to the Marquette & Arizona Copper Company, in the southeastern corner of the Bisbee quadrangle, manganese ore is rather widely distributed in the Cretaceous Glance conglomerate. The deposit on which most work has been done is a vein that strikes N. 23° E. and dips 80° W. At the time of visit it had been superficially trenched for a distance of 350 feet. This work exposed a vein of nearly pure psilomelane as much as nine inches wide accompanied on both sides by conglomerate in which the finer interstitial material had

[28] Work cited, pp. 112-113.

been largely replaced by psilomelane. In places the ore, including the metallized conglomerate was four feet wide. A shipment is reported to have been made, but at the time of visit work had been abandoned. The ore is evidently more siliceous than that in the limestone.........

"In the vicinity of this vein, particularly west of it, for a distance of 500 feet or more, the Glance conglomerate contains small irregular bunches of psilomelane, and similar occurrences in the Glance conglomerate were reported south of the locality examined."

Junction Mine: "The exceptional body of manganese ore in the Junction Mine of the Calumet & Arizona Mining Company was found on the 1,300-foot level, about 800 feet northwest of the Briggs shaft, in the Martin limestone, along a north-south fissure. It appeared to be from twelve to fifteen feet thick and at least forty feet long from north to south and to extend for 75 or 100 feet above the level. Not enough work had been done at that time, however, to determine the size and shape of the deposit, and no shipments had been made. East of the manganese, the limestone contains considerable disseminated pyrite, sphalerite, and galena.

"The ore is chiefly psilomelane, but is more cavernous or spongy than most of the surface ores. Sixteen partial analyses, made in the laboratory of the Calumet & Arizona Mining Company, show from 35 to 53 percent of manganese and from 6 to 34 percent of silica. The average of these determinations is 49.8 percent of manganese and 6.2 percent of silica."

PRODUCTION

"In the early part of 1918 the Bisbee district was yielding from 1,500 to 1,600 tons of manganese ore a month. All of this was sorted shipping ore, but the amount of sorting necessary to obtain a forty percent product differed considerably at different workings.

"The annual production of manganese ore in the Bisbee district to the end of 1918 was as follows:

Year	Over 35 percent Mn	10 to 35 percent Mn
1916	703	......
1917	8,618	......
1918	10,643	927
	19,964	927"

Production from Phelps Dodge ground since 1918 according to figures supplied by Mr. D. Moreau Barringer, Jr., has been as follows:

Year	Long Tons	Year	Long Tons
1919	No record	1923	
1920	254	1924	
1921	100	1925—June, 1929, incl.,	11,051
1922	1,000	(See page 38 for details)	

Production from Calumet and Arizona ground since 1918, according to Mr. E. E. Whiteley, Assistant Manager, has been as follows:

Year	Long Tons	Grade
1926	302	39.64 percent
1927	431	41.74 percent

This ore was mined and shipped by lessees.

FUTURE MANGANESE ORE POSSIBILITIES AT BISBEE

Mr. J. B. Tenney, Geologist with the Arizona Bureau of Mines, and formerly Chief Geologist of the Copper Queen Branch of the Phelps Dodge Corporation, has supplied the following speculations on future possibilities for manganese ore at Bisbee:

"Manganese mining in the camp during the high war prices, and the little mining since, has been done on the most easily mined and accessible deposits. Practically no attempts have been made to develop them, and little is known definitely of their extent. It has, however, long been realized that manganese deposits of medium grade, and some of high grade, are commonly associated with nearly all the oxidized caps of the larger ore bodies of the camp, usually at a higher horizon than the typical limonite-silica gossans cut by the upper development levels.

"With the recent success in the flotation of manganese oxides in laboratory experiments, the lower grade deposits at Bisbee attain greater importance than heretofore. At the Shattuck Mine of the Shattuck-Denn Mining Corporation, where probably more work has been done than at any other property on the levels above the major ore bodies, manganese deposits have been cut at depths up to 500 feet from the surface. It is probable that the unprospected upper zones at nearly all the mines in the district would yield similar deposits.

"With a stable manganese market, it is quite possible that manganese reserves could be developed in Bisbee comparable in size to those developed at Butte, of probably higher grade than the Butte ores."

TOMBSTONE DISTRICT

The Tombstone mining district is in the Tombstone Hills, about 21 miles north-northwest of Bisbee, and is accessible by excellent highways as well as by a branch of the Southern Pacific Railroad that leaves the main line at Fairbank.

This group of hills, which may be regarded as the northwestern termination of the Mule Mountains, is about six miles long by three miles in maximum width, and arises to a maximum height of about 5,300 feet above sea level or about 1,000 feet above its bordering plains.

GEOLOGY[29]

Ransome found that the Paleozoic section at Tombstone in general closely resembles that at Bisbee. He found above the Naco limestone, however, a series of conglomerates, shales, quartzites, and thin limestones of probable Cretaceous age but of constitution decidedly different from the Cretaceous at Bisbee. Irregular masses of quartz monzonite and rhyolite porphyry intrude all the sedimentary formations mentioned.

Regarding the structure, he says [30]: "The rocks of the Tombstone district, like those at Bisbee, have been intensely faulted......... The fault block south of Tombstone which is surmounted by Military and Ajax hills shows, from west to east, an ascending sequence of eastwardly dipping beds from the pre-Cambrian rocks to the Naco limestone......... With relation to this block all other parts of the district have been faulted down......... The effect of this faulting has been to depress the Paleozoic formations west of the fault zone and to make the Mesozoic beds and the monzonitic porphyry surface rocks in the southwestern part of the district."

GENERAL CHARACTER AND DISTRIBUTION OF DEPOSITS[31]

"In the Comet, Bunker Hill, Lucky Cuss, Lucksure, and Oregon mines in the Tombstone district much of the oxidized silver ore is highly manganiferous, and on this account, even when the silver content was too low to give them value purely as silver ores, they have been in demand as flux at the Douglas smelters.

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[29] See Ransome, F. .L, U. S. Geol. Survey Bull. 710-D, pp. 101-103, 1920.
[30] Work cited, pp. 102-103.
[31] Work cited, pp. 113-114.

From these ores, only silver, gold, lead, and copper have been extracted; the manganese, having served its purpose as flux, has been lost in the slag. There is no sharp line between such ores and those that have been mined for manganese. The chief source of manganese ore in the Tombstone district has been the Oregon mine, about 1½ miles southwest of Tombstone........ although small quantities have been obtained from the Lucky Cuss and other mines.

"The manganese ores of this district are chiefly psilomelane and occur in irregular pipelike masses or 'chimneys,' in limestone, distributed along zones of fissuring."

Oregon Mine: "The Oregon and Prompter workings, here described as one mine, are on the Prompter fault fissure, a branch of the strong east-west fault which passes north of Military Hill......... In the vicinity of the mine the fault brings the Naco limestone on the north against the Abrigo limestone, Bolsa quartzite, and pre-Cambrian granite on the south. Deposits of manganese ore and of manganiferous silver ore occur at many places along this fault, mainly in the Naco limestone. Manganiferous silver ores chiefly have been mined in the Bunker Hill mine, and argentiferous manganese ores chiefly in the Oregon mine. The Prompter fault fissure dips 65°-70° S., and the fault is thus of the reverse type. The fissure is occupied for at least a part of its length by a decomposed porphyry dike.

"The Prompter workings constitute the eastern part of the Oregon mine. They consist of an inclined shaft on the fissure, 300 feet deep, with two levels. On the upper or 160-foot level the main ore shoot is at least 300 feet long and as much as eighteen feet wide. The bottom level had not been driven to the ore body at the time of visit. West of this ore shoot and also in the main fault zone is a shorter ore body which has been stoped in places to a width of 25 feet. These ore bodies are mainly replacement masses in the Naco limestone on the footwall side of the porphyry dike.

"From a point near the collar of the Prompter incline a tunnel has been run through the hill........to the Oregon shaft on the other side. This shaft is 300 feet deep and is vertical. It is not on the main fault fissure but on a close fissure, known locally as the Oregon slip, which branches in a N. 60° W. direction from the Prompter fault fissure and is entirely in the Naco limestone. The Oregon slip dips 70°-85° NE., and as a rule is accompanied by no gouge or breccia. From the 300-foot level of the Oregon an inclined winze goes down on a body of ore to an additional depth of 300 feet.

"The ore bodies in the Oregon workings occur as irregular, more or less tortuous pipes of rudely circular cross section. At least eight of these bodies are known. The average diameter appeared to be about ten feet, and some of them have been mined from the surface to the level of underground water, which stands 630 feet below the collar of the shaft. They occur generally along lines of intersection of the Oregon slip with less conspicuous cross fissures. In the angle between the Oregon slip and the Prompter fault fissure there are at least two other fissures approximately parallel with the Oregon slip. Some small bodies of ore have been mined on them. All the Oregon ore bodies are mainly replacement deposits in the Naco limestone. They occur some on one side, some on the other side, and some on both sides of the Oregon slip. They have no definite walls save where they happen to be bounded on one side by a wall of the main fissure.

"At the time of visit, early in March, 1918, the Oregon mine was yielding about 2,000 tons of ore a month. It had been in operation about two years and had produced about 50,000 tons in all."

Regarding the concentration of this ore, as practiced in 1918, Ransome says [32]: "The material from the high-grade bodies is sorted, and the hard lumps of comparatively pure psilomelane are shipped for the manufacture of ferromanganese. The residue from this sorting and the material from the lower-grade bodies is run over grizzlies, and the oversize lumps are again sorted. The rejected material from this sorting with the fines is sent through the concentrating mill near Tombstone. Here the material is concentrated about eight to one. The higher-grade concentrates, running from 70 to 85 percent of MnO_2 are shipped as 'chemical manganese,' of which three grades are made. The lower-grade concentrates, generally running from 40 to 43 percent of manganese, are shipped as furnace ore to steel works in Pennsylvania. The tailings and slimes are partly dried and are shipped to Douglas, Arizona, where they are used for their silver contents and fluxing value. Only such ore is mined as will give tailings that are sufficiently argentiferous to pay for shipment. In other words, the manganese ores of the Oregon mine could not be profitably exploited or even mined without loss if they were not argentiferous. In 1917 these ores contained, on an average, 7.78 ounces of silver to the ton."

Production: Ransome [33] gives the production from Tomb-

[32] Work cited, p. 115.
[33] Work cited, p .116.

stone, exclusive of manganiferous silver ores which were used as flux from which no manganese compounds were obtained, as follows:

Year	Over 35 percent of manganese	10 to 35 percent of manganese
1915	380	....
1916	2,355	5,544
1917	3,776	....
1918	843	37
Total long tons, gross	7,354	5,581

He gives the following chemical analyses typical of the lower-grade concentrates that were shipped from Tombstone as furnace ore in 1917 (from records of the Bunker Hill Mines Co.):

		Sample 1	Sample 2	Sample 3	Sample 4
Mn	Percent	49.90	44.11	43.96	41.87
SiO_2	Percent	4.84	9.82	?	9.84
P_2O_5	Percent	0.014	0.020	0.028	0.024
H_2O	Percent	3.45	6.3	6.60	10.20

He also gives the following chemical analysis typical of manganiferous silver ore shipped from the Oregon Mine to the Douglas smelter of the Phelps Dodge Corporation, presumably made at the smelter:

Gold	0.013 oz. per ton	Lime	10.1 percent
Silver	21.10 oz. per ton	Silica	20.0 percent
Copper	0.99 percent	Alumina	2.0 percent
Iron	2.8 percent	Silver chloride	0.3 percent
Manganese	27.3 percent		

According to Mr. J. H. Davis, [34] of the Phelps Dodge Corporation, most of the manganese ore shipped by the Bunker Hill Mines Co. between 1915 and 1918 was in the form of concentrates that contained about sixty percent of manganese dioxide. Only 400 or 500 tons of it was high grade chemical manganese. No shipments of straight manganese ore are known to have been made from Tombstone since 1918.

ORIGIN OF THE BISBEE AND TOMBSTONE DEPOSITS

Ransome [35] states:

"The field investigation of the Bisbee and Tombstone manganese deposits was directed to immediate practical ends in connection with the estimation of the quantity of domestic manganese ores available under war conditions. The examina-

[34] Written communication.

[35] Work cited, pp. 116-119.

tion was brief, and the collection of data bearing on the origin of the deposits was incidental to the main purpose of the visit. Consequently the discussion of genesis that follows is suggestive rather than conclusive.

"That the manganese deposits of the Bisbee district are in some way connected in their origin with the copper deposits appears probable from the fact that they occur most abundantly in the particular part of the district in which copper ores have been found. Many of them, moreover, are directly above deep-lying copper deposits and occur along fissure zones that, at greater depth, have influenced the deposition of copper ores. Most of them also contain a little copper. The manganese ores, however, are not directly connected with the bodies of copper ore and do not hold with respect to them the relation of gossan. They are, however, unquestionably supergene (formed from above) and accumulated during one or more periods of erosion and oxidation. No deposits of particularly manganiferous unoxidized material have been found in the course of the very extensive underground exploration of the district, and the unoxidized copper ores are apparently no more manganiferous than the inclosing limestones. No chemical analyses, however, have been made to determine this point. Many of the manganese ores, moreover, contain considerable barite, and barium minerals, so far as known, are absent from the unoxidized copper deposits.

"Manganese ores have been deposited in the Bisbee district during at least two periods, as shown by the occurrence of boulders or fragments of psilomelane in the Glance conglomerate and by the presence within the conglomerate of deposits such as those on the Marquette group of claims, southeast of Bisbee. (See page 44). Most of the deposits in the Paleozoic limestones are believed to have accumulated during the extensive erosion that prepared the surface on which the Glance conglomerate was laid down. It would be very difficult to prove, however, that some of them or parts of them were not deposited during the erosion that stripped that conglomerate from portions of the district.

"In a narrow sense they can not be classed as residual deposits—that is, they do not represent the residuum left, with more or less downward concentration, from pre-existing bodies of unoxidized manganiferous material that occupied substantially their present position. The manganese apparently has been transported by supergene waters and has been concentrated during the generol process of erosion.

"Under the microscope, in thin section, the psilomelane in limestone that has not been wholly replaced by it shows clearly that its deposition was conditioned by fissuring. It follows microscopic cracks and zones of crushing. The psilomelane is not, however, confined to the actual openings of these fissures but occurs on both sides of them in unfissured grains of calcite, as minute black specks, generally less than 0.01 millimeter in diameter, and as irregular aggregates of feathery or mosslike outline. In one thin section many of the black particles show angular outlines suggestive of cubic or octahedral form. No evidence was found, however, of the derivation of the manganese oxide from some other manganiferous mineral, such as the carbonate, rhodochrosite. There is nothing in the generally irregular outlines of the mineral to suggest that it is pseudomorphic, and the mode of occurrence indicates that, if manganese oxide was not deposited directly from solution, the mineral originally deposited must have changed rapidly to psilomelane while the process of deposition was still in operation.

"If the deposits were not derived directly from the copper deposits and are not of hypogene origin—that is, deposited by ascending solutions from deep sources—what can be their genetic relation to the copper ores? Two points of connection are suggested. In the first place, it appears probable that the oxidation of the sulphides of the original copper deposits, particularly of the pyrite, supplied sulphate solutions and that the manganese, gathered partly from the limestones themselves and partly perhaps from earlier concentrations, was transported as manganes sulphate. As Dunnington [36] has shown, manganese sulphate in solution is not readily acted upon by limestone unless there is free access of air and might be carried for considerable distances through underground channels in a limestone country. In the presence of both air and calcium carbonate, however, the manganese is precipitated as oxide.

"In the second place, the same set of fissures that at an earlier period provided channels for the movement of hypogene copper-bearing solutions probably continued to be planes of weakness in the rocks and to be penetrable to some extent by waters of superficial origin. They would thus be the places where manganese-bearing solutions would begin the replacement of limestone.

"The association of manganese ores with silver ores in the Tombstone district is much closer than that of the manganese ores with copper ores at Bisbee. In fact, as already pointed out, no real distinction is recognizable between the manganiferous

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36 Dunnington, F. P., on the formation of deposits of oxides of manganese: Am. Jour. Sci., 3d ser., vol. 36, pp. 175-178, 1888.

silver ores and the argentiferous manganese ores. Moreover, their relations as regards position are more intimate, and in some places one kind of ore passes into the other. There is apparently some ground for regarding the manganese ores of Tombstone, in part at least, as the oxidized upper portions of silver deposits, from which some materials have been leached or abstracted and in which some of the manganese from formerly existent higher parts of the deposit has been concentrated.

"Not all the Tombstone silver deposits are associated directly with manganese ores or with manganiferous silver ores, and few of the unoxidized silver ores contain any recognizable manganiferous mineral. In the Lucky Cuss mine, however, one ore body was found which contained abundant alabandite, the manganese sulphide. The oxidation of such a body would undoubtedly yield an argentiferous manganese ore.

"The manganese ores of Tombstone are probably not entirely residual. Some of the manganese, as at Bisbee, has probably gone into solution as sulphate, has migrated into the adjacent limestone, and has been deposited in fissures and solution channels and by replacement of the limestone. A part of the manganese is believed to have been derived, as at Bisbee, from the Carboniferous limestones and not from bodies of silver ore."

Later mining at Bisbee has disclosed alabandite occurring at a distance of about 300 feet beneath the Twilight manganese ore body. According to Emmons, [37] alabandite reacts readily with acid solutions and decomposes more rapidly than the sulphide of any other common metal. Mr. D. F. Hewett, of the United States Geological Survey, has kindly furnished [38] the following statement in regard to the possible derivation of the manganese oxides from alabandite:

"Even though the presence of alabandite is recorded in only one mine in the Bisbee district, the Higgins tunnel, there are good reasons for believing that it is the principal source of the manganese in the oxide deposits that occur over a wide area in the district.

"On the basis of an investigation in 1918 Ransome recorded the details of the occurrence of the manganese oxides on 21 claims in the district (U.S.G.S. Bull. 710-D). From this investigation it appears that the deposits are disposed in a broad arc of which the center is Sacramento Hill. In a general way, the de-

[37] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 440. 1917.

[38] Written communication.

posits form a zone that lies adjacent to or above the copper deposits, but more remote from the intrusive mass that underlies Sacramento Hill. The Higgins mine lies at the northwest end of this zone:—As stated by Ransome, the ore occurs in irregular bodies, generally in close association with fissures in the Escabrosa and Naco limestones. In the absence of such manganese minerals as rhodochrosite in the unoxidized copper deposits, it seemed that the manganese now present as concentrated bodies of oxides was derived from the nearby and overlying masses of limestone.

"When the writer visited the district in 1928, the presence of a large body of alabandite rock in the Higgins tunnel had been discovered by O. N. Rove, geologist of the Phelps Dodge Corporation, and the question had arisen whether such material might be the principal source of the manganese. The details of the occurrence of this alabandite appear in an article by Mr. Rove and the writer. [39] Stated briefly, it appears that alabandite and a manganese carbonate have replaced several beds of the Martin limestone for a distance of forty to fifty feet near several cross-cutting fractures. The principal body of manganese oxides in the Bisbee district lies 300 feet higher and almost vertically above the body of alabandite rock. Since 1916, it has yielded about 20,000 tons of material that has averaged about forty percent manganese, ten percent iron, and twelve percent silica. This body is largely the mineral braunite, and, when freshly broken, most of the fragments show myriads of minute octahedrons characteristic of this mineral. The ore contains a little free silica, but it will be recalled that braunite contains about ten percent silica. Further, unlike most deposits of manganese oxides in limestone in the arid regions, there are very few and rather sparse open cavities. In many deposits elsewhere in the Bisbee district, nodules and irregular masses of solid manganese oxides are imbedded in solid limestone in such a way as to conceal the channels of access. If one calculates the shrinkage in volume involved in the alteration of alabandite, rhodochrosite, and rhodonite to the common oxides, manganite, pyrolusite, and braunite, it will be found that the least shrinkage is involved in the oxidation of alabandite.

"Even apart from the proximity of a large body of alabandite to the largest body of manganese oxides thus far found in the district, the volume relations of the primary and secondary

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[39] Hewett, D. F., and Rove, O. N., Occurrence and relations of alabandite: Economic Geology (In Press). 1930.

minerals suggest that the source of a considerable part of the oxides of the district was the mineral alabandite."

RESERVES OF MANGANESE ORE AT BISBEE AND TOMBSTONE

Ransome [40] says:

"The large number of the deposits in the Bisbee district, their irregular form, the lack of systematic development, and the methods of mining and handling the ore make any reliable estimate of available tonnage utterly impossible. In normal times it probably will not pay to work deposits of the character here described. Under necessity, however, or with unusually high prices for manganese ore, perhaps 50,000 tons of forty percent ore would be available. This estimate, which is admittedly rough, is believed to be more nearly a minimum than a maximum. Considerably more material might be obtained by concentration, but it is difficult to see how any profit could be made under ordinary conditions by concentrating the manganese ore.

"In the Tombstone district there appears to be less manganese ore available than at Bisbee. It is doubtful whether the district could be relied upon to yield more than 5,000 to 10,000 tons of shipping ore and concentrates, in addition to what was produced to the end of 1918. In 1918 operations were said to be barely paying expenses, and under normal conditions the manganiferous ores of Tombstone can probably not be mined and treated profitably for their manganese contents."

COCONINO COUNTY

Although manganese mineralization is manifest at many different places in Coconino County, particularly within its southern portion, the only known deposits of present commercial interest are in the vicinity of Long Valley.

LONG VALLEY REGION

Deposits of manganese occur in an area of approximately 1¼ square miles in the Long Valley region, some 1½ miles west of Clints Well.

Here, the Mogollon Plateau, which is part of the great Plateau of Arizona, is, in general, about 7,200 feet above sea level. It is drained by broad, shallow valleys that, within a few miles, grade into deep canyons. Some eight miles south, the plateau abruptly terminates with an erosional escarpment, locally known as the "Rim," which is 1,000 feet high and separates the Plateau and Mountain provinces.

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[40] Ransome, F. L., work cited, p. 119.

In this region, the plateau is floored by Permian Kaibab limestone, which in places is covered by irregular remnants of Tertiary lavas or mantled by thin soil. In places, the Kaibab limestone is rather dolomitic, but cherty and sandy phases also are common. In the vicinity of Long Valley, the total thickness of this formation is estimated at approximately 250 feet. Exposed beneath the Kaibab limestone in most of the canyons is the cross-bedded Coconino sandstone, which overlies the Permain Supai red beds and in this vicinity is approximately 1,000 feet thick.

These strata dip gently northeastward. Folding and faulting are not noticeable on the surface, but, in underground workings, a general northeast-southwest breccia zone is apparent and may be due to faulting.

Annual precipitation here, which is about 24 inches, falls partly as violent summer rains and partly as winter snows that may block the highway. It supports a heavy, tall growth of Western Yellow Pine, together with lesser amounts of oak and other trees. A few small springs issue in the valleys, mainly along the contact of the Coconino sandstone with the Kaibab limestone, but most of the domestic water of the region is obtained from shallow wells and artificial tanks.

McCloskey Claims: The McCloskey group of five unpatented claims includes most of the former Black Diamond group and covers the principal surface showings of manganese ore in the Long Valley region. These claims are situated in Iron Mine Canyon, which is a shallow gulch in the Kaibab limestone, about one-half mile south of the Flagstaff-Pine highway. By road Flagstaff and Winslow, which are on the Santa Fe Railway, are nearly sixty miles distant.

These manganese deposits are shown by old diggings to have been known for many years, and ore from them probably was used for flux in some of the early furnaces along the Verde River. Relocation and some development of the deposits took place during 1917 and 1918, but little, if any, ore is known to have been shipped during that time. In 1927, five claims were relocated by Mr. Ben W. McCloskey, who [41] has made the following shipments of sorted ore to Birmingham, Ala., via Winslow, Ariz.:

1927	28. (Used for coloring)	Not stated
1927	28.99	48.32
1928	32.22	46.83

[41] Figures furnished by Mr. McCloskey.

1928	26.97	46.34
1928	26.75	46.44
1929	23.31	45.71
1929 (First nine months)	50, approx.	Not Recd.

The first 1929 shipment listed contained [41] 3.60 percent of iron, 8.70 percent of silica, 2.37 percent of alumina, 0.066 percent of phosphorus, and 3.47 percent of water.

When visited in October, 1928, workings upon the group consisted of a few shallow shafts, open cuts, and short tunnels.

Jones [42] has described the deposit as follows:

"The deposits of manganese ore occur near the surface as replacement bodies in decomposed limestone and sandstone and in breccias of the same formations. The greatest developments are on the Black Diamond group, where there are ten or more shafts and open cuts recently worked, in addition to the old workings. The deepest shaft is 25 feet deep. On the Thurer group and the Star and Long Valley claims the developments consist only of shallow discovery holes. As shown in a number of shafts and open cuts, the limestone and sandstone are decomposed several feet below the surface and stained in shades of yellow, red, brown, and black from iron and manganese oxides.

"Manganese oxides occur in nodules and masses in the decomposed rock, replace the limestone and sandstone in varying degrees, and form the cementing substance of breccias. Nodules and masses of manganese oxides composed largely of psilomelane are scattered over the surface and are found in decomposed rock to a depth of a few feet. Some of the masses are two feet in diameter and weigh hundreds of pounds. The psilomelane has a peculiar structure; most of the specimens that were collected are vesicular and ropy in appearance but when broken open are found to be composed of columnar rods one or two inches long deposited in concentric crusts. Brown iron oxide has been deposited in the interstices of this ore.

"Below the bunches and masses of the purer psilomelane ore found near the surface, are masses of manganese and iron oxides which partly replace limestone and sandstone along the bedding planes. In some places the manganese and iron oxides are mixed, but generally the manganese oxides are in streaks and masses incased by iron oxides. In one deposit the ore appears to be a

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[42] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710-D, pp. 127-128, 1920.

black granular homogeneous mass, but on close examination it is found to replace sandstone. Numerous small rounded quartz grains are embedded in psilomelane and pyrolusite which have replaced the cementing substance of the sandstone. In most of the workings the streaks and masses of ore in replacement deposits extend only a few feet from the surface.

"The breccia consists of fragments of sandstone and chert cemented by manganese and iron oxides. Some of the rock fragments are very small, and in some specimens the matrix itself is granular and suggests sandstone largely replaced by oxides. Breccia was found in three of the workings which are in alinement in a northeasterly direction on the Black Diamond group; and on the Long Valley claim, 1½ miles N. 30° E. from the Black Diamond group. The depth to which the ore extends in the zone of brecciation has not been determined, but a shaft 25 feet deep is still in ore. Psilomelane and pyrolusite are the manganese oxides.

"Except for a little calcite of secondary origin, no minerals accompany the manganese and iron oxides.

"The developments are insufficient to permit an estimate of ore reserves in the several claims, but on the dumps of the Black Diamond group there are about 100 tons of ore containing forty percent of the manganese in addition to a large tonnage of lower-grade material.

"The ore on the whole is siliceous, though a considerable quantity of psilomelane could be sorted.........

"The source of the manganese oxides can not be established until more development work has been done on the deposits, particularly in the brecciated zones. Two hypotheses, however, seem plausible—(1) that the manganese oxides have been deposited in their present position as oxides from the solution of manganese minerals originally disseminated in overlying rocks that have since been eroded, and (2) that the oxides are residual from weathered manganese minerals originally deposited in a fault or brecciated zone, solutions from which permeated the adjacent sediments and replaced them. The evidence of the origin of these deposits, however, seems to favor residual origin rather than vein filling. No minerals were observed in the breccia other than the iron and manganese oxides and secondary calcite, and the fact that the oxides extend deeper in the brecciated zones than elsewhere is, of course, due to the more ready circulation of surface water in such zones. Some of the workings are more than 1,000 feet from the known zone of fracturing, and replacement by manganese oxides shows a decided decrease from the surface downward."

GILA COUNTY

Gila County's principal manganese deposits, which are in the Globe district, have been described by Jones [43] as follows:

DISTRIBUTION OF DEPOSITS

"The manganese deposits of the Globe district are grouped in a small area in the Globe Hills about four miles north of Globe. They are principally covered by claims of the Globe Commercial Copper Company (California), Superior & Globe, and Mineral Farm groups......... The deposits are readily accessible to Amster, the nearest shipping point on the Arizona Eastern Railroad.

GEOGRAPHY

"The Globe Hills in the immediate vicinity of the manganese deposits have low relief, though south of Globe the Pinal Mountains are high and are deeply dissected. The manganese deposits are at altitudes of 4,100 feet above sea level, at the base of hills which rise a few hundred feet above them. Pinal Peak, ten miles south of Globe, has an altitude of 7,850 feet. Pinal Creek, an intermittent stream a few miles west of the manganese deposits, drains northward. Gulches on the east side of the deposits drain to the east and south, but they contain water only after periods of storms.

"The climate is arid, and the average rainfall is probably not more than ten inches a year. The hills support a sparse growth of shrubs typical of the desert areas.

GEOLOGY

"The rocks in the vicinity of the manganese deposits consist of quartzite belonging to the Apache group, [44] .... intruded by masses of diabase. Exposures are poor, and the formations are cut by numerous faults, which in places bring quartzite and diabase into juxtaposition. Along several of these faults, which strike east-northeast, the ore bodies are formed chiefly by the replacement of diabase, and to a minor extent they fill fissures and replace the quartzite.

ORE DEPOSITS

"The manganese oxides are associated with limonite, calcite, and unreplaced minerals of the diabase, principally quartz and feldspar, and fragments of quartzite. The manganese oxides are

[43] Work cited, pp. 165-169.

[44] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, 1903.

wad and needle-like crystals of manganite; the manganite occurs as narrow seams and lines small cavities in the ore. The ore is black, dark brown, and reddish, and in most of it that lies on the dumps the presence of manganese minerals is little suspected because they are enveloped by the soft limonite, which breaks to a powder. When the ore is freshly broken the manganese oxides are apparent as seams or as finely crystalline aggregates that line cavities. The best ore was obtained from the surface.

"Water level has nowhere been reached in the extraction of manganese ores; the deepest work is about 45 feet below the surface. There are some deeper shafts in the vicinity, but no information was to be had with regard to the depth of the water level.

"As explored, the ore shoots of the deposits are lenticular masses with a maximum length of 200 feet and a maximum depth of 45 feet. The ore at the point where this depth was attained, however, was of poor grade, and it is probable that the ore will not persist much below this depth in any of these veins.

"The replaced rock of the manganese deposits is greatly altered, so that its original character is difficult to recognize, but it appears probable that the diabase was replaced to a greater extent than the quartzite, as the texture of most of the replaced rock more nearly resembles that of the diabase than of the quartzite."

MINES AND CLAIMS

"Globe Commercial Copper Co. (California group): The California group of the Globe Commercial Copper Company lies in the southeastern part of the manganese-bearing area north of Globe. The property is said to have produced some silver ore many years ago......... In 1916 the claims were leased to Buckingham & Wright, who shipped 24 cars of manganese ore from September, 1916, to February, 1917. Later the claims were worked by Jamison & Bailey, who shipped nine cars of ore to June, 1917, but since then work has been suspended. In all about 1,500 tons of ore was shipped to the Miami Metals Co., of Chicago, and to the Seaboard Steel & Manganese Corporation, of Temple, Pa., for use probably in alloys. Assays of the best and poorest carload shipments from this property are as follows: Manganese, 35.52 and 16.70 percent; iron, 11.31 and 8.77 percent; silica, 8.47 and 38.55 percent; phosphorus, 0.031 and 0.204 percent; and moisture, 6.04 percent in one sample only. The best ore was obtained near the surface, and the poorest is said to have come from the bottom of a shaft 45 feet deep, the greatest depth to

which the ore was mined. The ore is said to contain about two ounces of silver to the ton. Most of the ore of better grade has been mined from the veins in this property, but on the assumption that ore extends to a depth of fifty feet, there is in reserve probably 1,000 tons of ore with a content of twenty to thirty percent of manganese.

"Several manganiferous veins are inclosed by the California group. They strike about east and dip 30°-60° N. The vein that has yielded most of the manganese ore strikes N. 75° E. and dips 60° N. 15° W. In general, it lies at the contact of quartzite and diabase, but at the east end of the workings it is inclosed by diabase. The average width of the vein is eighteen inches, and it has been exploited to shallow depths for 200 feet along its strike. The greatest depth attained was in a shaft 45 feet deep, but there the ore was of low grade, being high in silica. The ore is soft black to dark-brown material. The manganese oxides are mostly in the form of wad, pyrolusite, and manganite. The cavities which occur sparsely in the ore are lined with short crystals that are probably manganite.

"*Superior & Globe*: The Superior & Globe group adjoins the California group on the northwest. One shipment of 47 tons of ore was reported to have been made from this group in June, 1917, and it gave the following assay: Manganese, 25.7 percent; iron, 10.62 percent; silica, 11.44 percent; phosphorus, 0.67 percent; moisture, 1.45 percent. From the meager developments, there is estimated to be in reserve from 1,000 to 5,000 tons of ore with a content of twenty percent of manganese. Several veins are exposed on both banks of an arroyo that drains westward. They have been explored by several short tunnels, open cuts, and shallow shafts. Two men were at work on the property in August, 1917. North of the arroyo an old shaft of the Superior & Globe Copper Co. was sunk in diabase to a depth of 900 feet in search of copper ore. The manganese-bearing veins strike northeast and dip 20°-60° NW. They are contained in diabase and quartzite or occur at the contact of these rocks. They can not be traced on the surface beyond the banks of the arroyo, but where exposed by the workings the manganese-bearing shear zones are from two to ten feet wide. The greatest depth attained on these veins was twenty feet, and at that depth the ores are very siliceous and the manganese content much lower than at the surface. The ore is dark brown to reddish brown but on fresh fractures shows the seams of black manganese oxides traversing it, with here and there a vug lined with small crystals of manganite.

The red and brown colors are due to limonite or hematite. The ore for the most part replaces the diabase, and the silica content varies according to the degree of replacement. Secondary calcite is a common mineral of the ore.

"*Mineral Farm Group*: The Mineral Farm group of 21 claims lies east of the Superior & Globe Commercial Copper Co.'s properties, in a small basin at the head of a gulch draining southward to Pinal Creek. No manganese ore has been produced from this property except for a small quantity said to have been used as a flux in the Old Dominion smelter at Globe. The manganese deposits are unexplored, so there is little on which to base an estimate of the ore reserves. The outcrops, however, indicate several thousand tons of manganiferous iron ore containing probably twenty percent of manganese. Numerous veins occur in this group, and they strike from north to northeast. They cut diabase and quartzite, and their courses are marked by outcrops of gossan and by abundant float of iron and manganese oxides, which can be traced for several hundred feet. The veins range in width from two to ten feet. The iron is in the form of limonite and specular hematite containing bunches and stringers of pyrolusite. Quartz is abundant in the croppings."

GREENLEE COUNTY

Jones [45] describes a manganese deposit in southwestern Greenlee County as follows:

"*Thurston & Hardy Mine*: A group of six manganese claims owned by R. V. Thurston and Joseph Hardy is in the Ash Peak district, Greenlee County, a short distance north of Ash Peak, The claims were visited May 16, 1918. The nearest shipping point is Sheldon, on the Arizona Eastern Railroad, eight miles east of the deposit, and it is accessible by a good wagon road. Production from these deposits was begun in 1917, and to August 31, 1918, over 500 tons of ore containing more than forty percent of manganese had been shipped to smelters east of Mississippi River.

"The deposits are in a moderately dissected area near the summit of the Peloncillo Mountains, at an altitude of 4,500 feet above sea level. The hill at the base of which lie the manganese deposits rises about 200 feet above them, and the higher peaks in the vicinity, one of which is Ash Peak, may reach 5,000 feet. Eastward the hills slope to Gila River, and westward the mountainous area gives way to a gently sloping detritus-filled valley.

[45] Work cited, pp. 130-132.

None of the gulches or arroyos that head in the Peloncillo Mountains contain flowing water except after heavy rains, and only a few springs are known in the range. The climate is arid, and the vegetation is very sparse, though the higher mountains support grasses sufficient for the subsistence of cattle.

"The country rocks in the vicinity of the manganese deposits consist of Tertiary lava flows—a gray to brownish-red vesicular basalt overlain by white to pink rhyolite which forms the capping of the small hill above the manganese deposits. The basalt is much decomposed and contains a white mineral of secondary origin which fills the cavities and vesicles, and in the shear zones it is altered to a crumbly and clayey material from which the manganese oxides can be readily separated by washing.

"The manganese deposits are contained in two shear zones about 1,200 feet apart, which cut the basalt and perhaps the rhyolite also, but no ore has been found in the rhyolite. The north shear zone trends N. 70° W. and dips steeply to the south. It has been traced for about 1,500 feet, and shallow, open cuts 1,200 feet apart show the character of its mineralization. Between these workings, manganese float occurs sparsely, but the length of the ore shoots has not been determined. At the east end of this zone an open cut shows the sheared rock to cover a width of thirty feet, in which six principal stringers of manganese oxides as much as three inches wide are distributed. The open cut near the west end of the zone shows ten feet of sheared basalt, with a few seams of manganese oxides, the largest of which is six inches wide.

"The south shear zone, which has been the source of the manganese ore so far recovered, is explored by shafts and open cuts through a distance of 900 feet, but the ore shoots are not continuous for this distance. At the east end the zone strikes N. 55° W. and dips 70° NE; at the west end it strikes N. 80° W. and dips 70° N. Two shafts thirty feet and 84 feet deep have been sunk on the east end of the shear zone, and in addition open cuts and drifts have explored the zone and proved it to be ore bearing for 200 feet. Here the shear zone is about ten feet wide, and the ore is found in discontinuous or lenslike veinlets, which in places are two feet wide. At the west end of this shear zone there is a shaft sixty feet deep, and open cuts and drifts aggregating 200 feet. Here the ore is contained in a fairly distinct vein about fourteen inches wide.

"The manganese minerals consist of the oxides psilomelane and pyrolusite. Psilomelane predominates, and it occurs in the veinlets inclosed in soft altered basalt. Nodules of pyrolusite are found here and there in the shear zone, and from one pocket seven tons of pyrolusite is said to have been mined and shipped for use as chemical ore. The manganese oxides are generally free from association with iron oxides, but at the west end of the shear zone limonite became so abundant that the mining of manganese ore was suspended there, because the grade of ore was lowered to the point where little or no profit could be made. Calcite is abundant, particularly in the west end of the south zone, where it makes up a large part of a vein of coarse crystals about one foot wide.

"The maximum depth to which the manganese oxides extend has not been determined, although the ore was found in the bottom of the eighty foot shaft. Work in this shaft was suspended because the vein material could not be hoisted by hand from this depth and treated at a profit.

"In mining these deposits, a large amount of material must be handled. A partial separation of ore and waste is made on the mine dumps, where the material is screened, and the larger chunks of ore and waste material are removed. The finer material is then hauled to a well a quarter of a mile distant, where three hand jigs have been set up and a further separation is made. Each jig consists merely of a sixteen-mesh screen about two by four feet, operated by hand power. The ore is thrown on the screen and on being worked or jigged in water the clayey substance is washed off, leaving the manganese concentrates. About 1,000 pounds of manganese concentrates per man per day can be produced in these jigs. The concentrates contain about 45 percent of manganese, two percent of iron, and four percent of silica."

According to Mr. R. V. Thurston, [46] the property during the War period produced about 1,000 tons of ore that contained an average of 45 percent of manganese, two percent of silica, no sulphur, and only a trace of phosphorus, but considerable barium. It has produced nothing since 1918.

MARICOPA COUNTY

The principal manganese deposits of Maricopa County, which are in its northwestern portion, have been described by Jones [47] as follows:

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[46] Written communication.
[47] Work cited, pp. 132-143.

AGUILA DISTRICT

"Manganese deposits occur in the Aguila district at the north end of the Big Horn Mountains, in Maricopa County......... The deposits in the Big Horn Mountains, extending east and west for several miles, are from twelve to sixteen miles south of Aguila......... Some of these deposits were examined by the writer on September 11 and 12, 1917, but after that time several other deposits were discovered, and the district was revisited in May, 1918. The deposits are readily accessible by wagon road to Aguila, the nearest shipping point on the Atchison, Topeka & Santa Fe Railway. Motor trucks are generally used in transporting the ore to the railroad, but owing to the softness of the road material, which allows chuck holes to form, the maintenance of the roads is a considerable expense......... To May, 1918, about 2,500 tons of ore containing about 35 percent of manganese, two percent of iron, and fifteen percent of silica had been shipped from the Aguila district.

GEOGRAPHY

"The desert region west of Wickenburg, traversed by the Atchison, Topeka & Santa Fe Railway, consists of broad detrital plains above which rise isolated mountain ranges. Among these ranges are the Harcuvar, Harquahala, Big Horn, and Vulture mountains. The Harcuvar and Harquahala Mountains arise to heights of several thousand feet above the surrounding plains; the Big Horn Mountains have a relief of only a few hundred feet. Most of the manganese deposits in the Big Horn Mountains are at altitudes of 2,000 to 2,500 feet above sea level. West of Hassayampa River at Wickenburg there are no permanent streams along the railway route, but the mountains are drained by numerous arroyos and washes which flow to the plains. Where the broad valleys become constricted between mountains, water may generally be obtained from wells at shallow depths. Near the manganese deposits in the Big Horn Mountains, water is developed in a well on the Rogers ranch, and other though unreliable sources of water supply are the 'tanks' or natural reservoirs worn in the bedrock in some of the arroyos.

"The climate is arid, with a rainfall of only a few inches a year, and in consequence mining conditions are rendered unfavorable by the lack of wood and water and the intense heat of the summer. Mesquite, greasewood, paloverde, and ironwood grow abundantly in the arroyos and valleys, and several varieties of cactus grow on the hills.

GEOLOGY

"........The Big Horn Mountains are composed of pre-Cambrian granite, gneiss, and schist overlain by Tertiary lava flows, which in the northern part of the mountains are dominantly red biotite andesite. Most of the manganese deposits of the Big Horn Mountains are found in the lava flows, but on the Pittsburgh group and the Flynn & Gallagher property the veins occur in granite and schist.........

MINES AND CLAIMS

"*J. M. Meadows Group*: The Meadows group of seven claims is at the northeast end of the Big Horn Mountains, at an altitude of approximately 2,400 feet above sea level. The claims were located in 1916, but no ore has been shipped, and the development work consists only of a number of discovery shafts, each ten feet deep.

"The manganese deposits occur in some low hills composed of reddish biotite andesite with a little dacite. The deposits are found in a number of veins and brecciated zones that strike from N. 70° W. to due west and are vertical. Most of the veins are less than one foot wide, and the ore shoots are only a few feet long. The largest ore shoot observed on the surface is 25 feet long and two feet wide, but at a depth of six feet the deposit is only six inches wide. The manganese oxides are manganite and pyrolusite, deposited about fragments of country rock or as fissure fillings. Calcite generally accompanies the ore, but the manganese oxides are commonly free from admixture with iron oxides.

"The deposit is capable of producing a few hundred tons of material from which, it is estimated, 100 tons of ore containing forty percent of manganese could be sorted.

"*Manganese Development Co.*: The Manganese Development Co.'s claims lie west of the Meadows group and sixteen miles southeast of Aguila. The deposit has been worked by several operators, and at the time of visit was operated by E. C. Lane and J. Genung. Several carloads of ore were shipped in 1917, and a car was being loaded in May, 1918. The claims lie across a north-south ridge composed of red biotite andesite. The summit of the ridge is about 200 feet above its base, at a point where the manganese deposits cross it. Two fissures that strike nearly due east and dip steeply south contain the manganese deposits. They can be traced for about 1,000 feet, and are limited on the west near the base of the ridge by a strong northward-trending fissure. Several ore shoots have been opened on these veins, the largest of which was mined for 125 feet on the strike of the vein to a maximum depth of ten feet. The veins are narrow, showing a maximum width of two feet of solid ore. The material is hand sorted and screened to obtain a marketable product. The manganese oxides are manganite, pyrolusite, and psilomelane. Manganite occurs in short prismatic crystals deposited in layers locally intercalated with psilomelane about fragments of andesite. The andesite is in part replaced by the manganese oxides. Calcite is abundant in the ore, but very little iron oxide occurs. Shipments of ore are said to have assayed 46 percent of manganese with low silica and iron.

"*Wheeler Claims*: The Wheeler claims adjoin those of the Manganese Association on the south. A small quantity of ore was produced in 1917, but no work was being done at the time of visit. The deposit consists of a narrow east-west fissure which has been explored to a shallow depth of forty feet along its strike, and practically all the ore has been removed. The geologic relations and the ore are similar to those at the deposit of the Manganese Development Company.

"*U. S. Group*: The U. S. group of seven claims, owned by John Rogers, of Aguila, is in the north end of the Big Horn Mountains, about fifteen miles S. 15° W. from Aguila. In 1918 the property was under lease to Woods, Huddart & Gunn, who shipped nine carloads of ore during the first quarter of the year, but work had been suspended at the time of visit in May, 1918. The country rock composing the small hills in which these claims lie is red biotite andesite. Four veins and brecciated zones from one foot to six feet wide have been found on the property, but only two of them have been prospected. They strike from north to N. 45° W. and dip east or west. The zone in which these veins occur is about 600 feet wide, and in its manganese-bearing fissures can be found for at least two miles south of the U. S. group. Two of the veins have been displaced to the west about thirty feet by east-west faults. Development work has been done on two of the veins only; from one vein ore was removed from a deposit forty feet long and twenty feet deep, and on the other a shaft was sunk fifty feet. The lengths of the ore shoots have not been fully determined. It seems quite probable, however, that several thousand tons of ore containing forty percent of manganese could be won from the veins, but in order to obtain this grade of ore, sorting and screening of the vein material would be necessary. The dominant manganese oxides are manganite and pyrolusite. Calcite is very common in the ore, but iron oxides are generally absent. The depth to which the oxides extend has not been fully proved, but probably little ore will be found below fifty feet.

"*Gallagher & Flynn Claims*: Four claims owned by Gallagher & Flynn lie about a mile S. 20° E. from the end line of the U. S. group, and they evidently cover part of the same vein zone as that of the U. S. group. In 1918 about seventy tons of ore containing over forty percent of manganese was shipped from the property. When it was visited in May, 1918, lessees were mining a small quantity of ore. The claims lie in low hills composed of granite, though patches of the Tertiary lava flows are found here and there on the claims and completely overlie the granite a short distance to the north. The principal workings are at an altitude of about 2,400 feet, and the maximum relief is 200 feet. The known deposits on this group consist of three veins or brecciated zones. The two outer veins are 850 feet apart, strike from N. 5° E. to N. 10° W., and dip steeply west. Very little development work has been done, and the length of the ore shoots is not known, but the brecciated zones are about ten feet wide. One vein is explored by two holes twenty feet apart, each twelve feet deep, and another vein by a shaft thirty feet deep sunk below an open cut. The veins or breccias are contained in granite and schist. Rarely the ore consists of manganese oxides as much as six inches wide, but most of it is in narrow seams of oxides that cement together and partly replace fragments of granite from one inch to one foot in diameter. The manganese oxides are manganite as stubby prismatic crystals, pyrolusite as a soft powder, and psilomelane in hard crusts showing concentric deposition with some intercalated narrow layers of manganite crystals. The maximum depth to which the manganese oxides extend has not been determined, but they are found in the bottom of the thirty foot shaft, and they probably extend thirty feet or more deeper, for the brecciated zone is wide and affords a good circulating medium for the meteoric waters to effect oxidation. Calcite accompanies the manganese oxides, but iron oxides are very scarce.

"*Armour Group*: The Armour group of claims lies in the northwest end of the Big Horn Mountains, about fifteen miles S. 15° W. from Aguila, at an altitude of approximately 2,100 feet above sea level. The claims have been leased to several operators. In April, 1917, Jack Marden shipped five carloads of ore; in August, 1917, the claims were leased to the Noble Electric Steel Co., of San Francisco, which shipped 26 carloads of ore. In May, 1918, the deposit was being worked by T. H. Rosenberger, of Los Angeles. The country rock is dominantly red biotite andesite, but a short distance south of the workings hornblende schist, gneiss, and granite are exposed. The deposit is a brecciated zone about ten feet wide, which strikes north and dips steeply west. As shown by the workings the zone is about 800 feet long, but it does not lie in a continuous course, for a segment of the vein 200 feet long is displaced seventy feet to the east by two east-west faults. Several shafts have been sunk on the vein, the deepest of which is fifty feet deep, and ore has been removed from numerous open cuts. Although the zone is mineralized as far as exploited, the commercial bodies of ore occur in lenses to a maximum length of fifty feet. The manganese oxides are dominantly manganite and pyrolusite, but a little psilomelane occurs near the surface. Most of the ore is a breccia, and in order to obtain a product containing 32 percent or more of manganese it is necessary to sort the ore by hand and screen it. The finer particles that go through the screen are retained; the coarser material, consisting of andesite fragments with adhering crusts of manganese oxides, is rejected. The process is very wasteful and makes only a small increase of manganese from that in the vein material. The concentrates assay from 32 to forty percent of manganese, and the reject screenings are said to assay 24 percent of manganese. There is approximately 1,200 tons of reject screenings on the dumps, and the managers intend to install a Stebbins dry concentrator in an endeavor to concentrate this material. In addition, probably several thousand tons of ore remains in the deposit.

"*Pittsburgh Group*: The Pittsburgh group of seven claims is abount two miles south of the Armour group, from which a road must be made in order to market the ore. The claims lie in some low hills carved in granite and schists of pre-Cambrian age. The deposits are owned by Uhlik, Cuendet & Irish. They were discovered several years ago, but the development work is small and scattered......... The manganese deposits consist of a number of veins and brecciated zones that vary widely in strike and dip. One vein strikes N. 20° W. and dips 60°-75° SW.; another strikes N. 50° W. and is vertical; another strikes east and dips 70° S.; and another strikes N. 50° W. and dips 40° NE. Some of these veins may be traced more or less continuously for 2,000 feet along their strike; the ore shoots, however, so far explored are not over 100 feet long. The material of the brecciated zones is composed of fragments of granite and schist a foot or more in maximum diameter, cemented together and partly replaced by manganese oxides. In places veins of solid ore are six inches or more wide, and such ore can be readily hand sorted from waste, but in most of the ore the seams of manganese oxides adhere tightly to the rock fragments, making it necessary to crush the ore. Psilomelane, pyrolusite, and manganite are the manganese oxides. Psilomelane is relatively more abundant than in other deposits in the Big Horn Mountains, and on one of the veins it has been found to a depth of thirty feet. Calcite, as a secondary mineral, generally accompanies the manganese oxides, but iron oxides occur only in a few of the ore shoots. It is impossible to estimate the quantity of ore from the little development work that has been done on the veins, but a minimum of several thousand tons of ore is indicated by the open cuts and shafts on the assumption that the ore extends to a depth of 25 feet.

"*Hatton Claims*: Two claims located by J. Hatton are in the Big Horn Mountains about thirty miles southeast of Aguila. They are accessible from Aguila or Wickenburg by a road that extends within two miles of the deposit. The claims are under lease to the Noble Electric Steel Co., of San Francisco, which in June, 1918, had a force of eight men engaged in the development of the deposit. No ore had been shipped at that time.

"The deposit lies in some low hills at an altitude of 2,000 feet above sea level. The local relief is only a few hundred feet. Several arroyos drain to the detrital plain east of the Big Horn Mountains, but they contain no permanent water supply except that which accumulates in the natural rock reservoirs. One of these, known as Wood Chopper Tank, is about five miles east of the deposit. The rainfall is very light, and it supports only the desert shrubs and cactus common to the region.

"The hills in the vicinity of the manganese deposit are composed of lava flows, and the rock which incloses the deposit is fine-grained rhyolite.

"The manganese deposit occurs in a vein that strikes N. 20° E. and dips 75° W. It has been trenched for 300 feet along its strike and is shown to be about two feet wide. A shaft fourteen feet deep at the time of visit was being sunk on the vein. Another vein 200 feet east of the shaft cuts the rhyolite, but it contains no ore. The vein material on the surface is composed of manganese and iron oxides with some secondary calcite. The manganese oxide, pyrolusite, is intimately mixed with the iron oxides. In the shaft the carbonate vein matter is more abundant than in the surface ore, and it is evident that the oxidized ore will not extend much deeper. Selected samples of the surface ore are said by Mr. Schoonover, the superintendent of the property, to assay from 35 to 40 percent of manganese, ten percent of iron, and less than one percent of silica. The material from the shaft probably does not contain more than 25 percent of manganese, and only a few hundred tons is indicated by the development work."

MOHAVE COUNTY

The principal manganese deposits of Mohave County are in its southern portion, in the Artillery Mountains and along the Colorado River south of Topock.

ARTILLERY MOUNTAIN REGION

Between Artillery Peak and Williams River, notable manganese mineralization is present within an area about five miles long by one and one-half miles wide, and slight mineralization is present over a larger area.

HISTORY AND PRODUCTION

For many years, manganese claims have been located in this area, and, during the World War, considerable development of them was attempted by Messrs. W. J. Graham, T. R. McComas, J. Shanahan, S. K. Barbee, J. Carr, and others. However, the end of the War and the drop in manganese prices came before any ore could be shipped. According to Mr. Lee Eaton, [48] several claims were held by himself, together with Messrs. L. Johnston and N. L. Goulding, between 1926 and 1929.

Production from this region, according to Mr. Eaton, amounted to about four carloads of sorted ore, containing from 41 to 45 percent of manganese, which was shipped via Congress Junction to Birmingham, Ala., in early 1928.

Early in 1929, the Chapin Exploration Company obtained control of 58 claims lying in Secs. 3, 4, and 5, T.11N., R.13W., Gila and Salt River Meridian, and in Sec. 33, T.12N. R.13W., and the whole of Sec. 32, T.12N., R.13W. [49].

ACCESSIBILITY

This region is accessible by about 51 miles of fair desert road that leads westward from the Santa Fe Railway at Congress Junction, and crosses the Williams River at the deserted

[48] Oral communication.
[49] Oral communication from Mr. Benj. N. Webber.

village of Alamo. This crossing, however, is impracticable during flood seasons. Another road, several miles longer and more tortuous, leads into the region from the Santa Fe Railway at Yucca.

TOPOGRAPHY, CLIMATE, AND VEGETATION

The Artillery Mountains rise from dissected bajada and lava-capped slopes north of the Williams River, which is approximately 1,000 feet above sea level at Alamo crossing, and culminate in Artillery Peak, whose summit is some 3,300 feet above sea level.

Here, an average of five inches or less of rain falls yearly, and the summer climate is hot. Except along the Williams River, which is the only perennial stream of the region, vegetation is rather sparse.

GEOLOGY

Coarse-grained granitic rocks of probable pre-Cambrian age extend from the Hualapai and Aquarius ranges into the Artillery Mountains. Next younger is a thick series of probable Tertiary sandstones, shales, limestones, and conglomerates, all more or less lenticular. Lying in places upon the tilted, beveled edges of these beds, and in places upon the irregularly eroded surface of the granite, are relatively small areas of lava flows of probable Tertiary age. Capping many of the mesas are dark-stained basalt flows, usually less than 100 feet thick, of probable Quarternary age.

According to Mr. Benj. N. Webber, [50] Geologist with the Chapin Exploration Company, the sedimentary series in general strikes S. 55°-80° E.and dips from 10°-20° SW.; but notable variations from these figures obtain, as, for example, near Alamo crossing of the Williams River, where considerable minor faulting and close folding are apparent. Elsewhere in the area, faulting is mainly of minor magnitude and not abundant.

BEDDED DEPOSITS

Most of the manganese in this area occurs in bedded deposits. Regarding them, Jones [51] says: "............. The richest of these deposits lie on the surface or are concealed by angular débris; the lower-grade deposits are those which have not long been exposed to weathering or are overlain by other beds. As shown by thin sections of specimens from several deposits, the cementing substance of the standstone is first replaced by man-

[50] Written communication.

[51] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710-D, pp. 146-147. 1920.

ganese oxides, then the feldspar grains or clayey substances, and last, the quartz grains. The ore is hard though granular. Some specimens show abundant subangular or rounded quartz grains embedded in a matrix of black psilomelane; in others the sand grains are apparently replaced completely by manganese oxides, but the specimens glisten from calcite, which has also been deposited as crystals in vugs in the ore. The most weathered masses of ore are botryoidal and crusted forms composed mainly of psilomelane, but at shallow depths pyrolusite predominates. The botryoidal masses, however, are composed of concentric layers of psilomelane in alternation with short prismatic crystals of manganite. The outer layer is psilomelane."

Mr. Benj. N. Webber [52] states: "The manganese in the basal conglomerate consists of veinlets and stockworks of manganese oxide minerals, banded with quartz, calcite, and gypsum. Veins up to two feet in width in the basal conglomerate were examined .... but are of doubtful vertical continuity.

"The sandstones and shale lying directly on the basal conglomerate are barren. The limestone capping these beds is mineralized, and it is from the limestone deposits that all of the commercial ore shipped to date has been obtained. In Section 33, T. 12N., R. 13W., at the outcrop from which ore has been shipped, the replacement of limestone by manganese minerals has been so complete that the texture of the limestone has been almost completely destroyed. This ore consists of psilomelane and pyrolusite occurring in slaggy vesicular aggregates. The only gangue minerals observed were gypsum and small amounts of chalcedony. The limestone along the strike, both northwest and southeast from this point of outcrop, is not so well mineralized, for, although some beds contain manganese minerals in bunchy aggregates, other beds appear barren.

"The whole series of shales capping the limestone is manganiferous except near the base. One section sampled for a thickness of 45 feet contains 7.92 percent of manganese, and picked beds throughout this section averaged several percent higher. The manganiferous shale is fine-grained and compact, is colored black by manganese, and resembles cannel coal in appearance. Small aggregates of higher-grade material occur in the shale and some thin beds of shale within the manganiferous shales are barren. The manganese impregnation of the shale is not continuous along the strike, for, in the southeastern portion of the area, the shale is barren. However, the mineralization can be traced for about one and one-half miles along the strike.

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[52] Written communication.

"Several beds of sandstane above the shale are manganese-bearing. This mineralization of the sandstones seems persistent in extent, but not in intensity, along the strike, as the grade is lower about one and one-half miles southeast of the main outcrops."

A series of samples taken by Mr. Webber ranged in manganese content from 1.11 percent to 25.52 percent, and averaged 8.5 percent.

Detailed descriptions of certain portions of this area have been given by Jones. [53]

Graham Claims: Jones describes the claims then held by W. J. Graham and associates as follows: "The manganese deposits .... are in the west-central part of Sec. 33, T. 17N., R. 13W., ... in an arroyo draining to Williams River. In 1917 Graham and his associates acquired the rights to three claims .... and in 1918 they had established a camp and were attempting to mine and ship the ore.

"There are two deposits in the group; one lies on a small hill at an altitude of 2,100 feet, about 250 feet above the arroyo and a quarter of a mile east of it; the other deposit is cut by the arroyo, but the greater part extends west of it to the base of the mesa and is partly covered by basalt talus. .... The deposit on the small hill is exposed for about 250 feet on its strike, with an average width of fifty feet, and is three feet thick................ The whole deposit appears to lie principally in sediments along schist and granitic rocks adjacent to the younger sandstone and basalt. .... Red and brown, slightly indurated sandstones underlie the manganese bed and dip about 15° SW. This ore body is the highest-grade deposit of this type in the region, and it contains from 35 to 44 percent of manganese with a probable averave of 38 percent. This deposit was estimated to contain about 3,500 tons of ore of this grade." (According to Mr. Webber, a substantial tonnage of lower grade ore is present.)

"The deposit on the west side of the arroyo can be traced for 1,000 feet and is from 50 to 400 feet wide. It lies on the surface as a shell from one to three feet thick. Float ore is difficult to distinguish from fragments of the basalt talus which extend over part of the deposit. The ore contains about 25 percent of manganese and is high in silica. About 20,000 tons of ore of this grade is in sight."

(According to Mr. Webber, a large tonnage of low grade ore may be expected from the unenriched portion of this bed.)

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[53] Work cited, pp. 147-149.

"Analyses by the Southern Manganese Corporation, of Anniston, Ala., of three specimens of ore from the Graham deposit are given below. Nos. 1 and 2 are samples from the small hill and No. 3 is from the deposit in the arroyo."

	1	2	3
Mn	44.45	43.13	28.78
Fe	1.00	1.40	1.60
SiO_2	8.60	10.50	22.30
Al_2O_3	2.97	4.70	4.78
Lime	1.20	0.00	14.61
Mg	0.07	0.72	0.12
BaO	4.07	3.41	4.27
P	0.05	0.05	0.03

"A thin section from a specimen of low-grade ore on the Graham deposit was examined under the microscope. The sandstone is composed of quartz and feldspar grains, which occupy about one-half the volume of the section, and they are embedded in the manganese oxides. Quartz is the predominant mineral of the grains, but feldspars are also abundant, and they consist of orthoclase, microcline, and plagioclase. Some of the plagioclase grains have undergone decomposition to sericite and calcite, and in these grains manganese oxides have been deposited along cleavage cracks. Most of the grains are angular to subangular and prismatic, although a few are irregularly rounded. The continued angularity of the grains as they are diminished in volume by replacement must mean that the replacement proceeded largely along the cleavage and crystal planes. Calcite occurs interstitially in the grains, and numerous minute prisms of manganese oxides extend into the secondary calcite."

McComas Claims: Jones continues: "The deposit located by T. R. McComas is in Sec. 3., T. 11N., 8 13W., about 1½ miles southeast of the Graham deposit, and it is dissected by the same arroyo .... The manganese-bearing bed, from two to six feet thick, is the topmost layer of a series of red sandstone and shale which strike N. 20° W. and dip 25° SW. The ore body is exposed for 375 feet, but on the west side of the arroyo it is covered with detritous a few feet back from its outcrop, and the depth to which ore extends is not known. There is some high-grade ore in the form of psilomelane float, but the deposit as a whole contains about 25 percent of manganese. The ore is identical with that of the larger deposit of the Graham claims. The deposit is estimated to contain about 7,500 tons of ore.

Shanahan Claims: Jones continues: "The manganese deposit located by J. Shanahan is also in Sec. 3, about a quarter of a mile south of the McComas deposit and in the same arroyo. Like the McComas deposit, it is the topmost stratum of red sandstone that is partly replaced by manganese oxides. This bed is three feet thick and is exposed on the west bank of the arroyo for 600 feet, and for a short distance it forms a dip slope into a tributary gulch. The sandstone beds strike N. 25° W. and dip 25° W. The ore bed is displaced a few feet in several places by northerly faults that dip steeply east. Little development work has been done on the property,............ but the deposit probably includes 9,000 tons of material that contains 25 percent of manganese."

Mr. Webber states that a large tonnage of material containing less than 25 percent of manganese probably is present.

VEINS AND BRECCIATED ZONES

Deposits of manganese oxides in veins and brecciated zones in the basalts and red sandstones are described by Jones [54] as occurring in the western part of Sec. 12, T. 11N., R. 13W., and in Sec. 1, T. 11N., R. 14W. These deposits are of interest in that they show the manganese veins cutting probable Quaternary basalt flows, but are of little present commercial importance.

NEAR COLORADO RIVER

Jones [55] has described some manganese deposits in Little Chemehuevis Valley as follows:

Arizona Manganese Group: The Arizona Manganese group of eleven claims is in Little Chemehuevis Valley, about half a mile from Colorado River, in Mohave County. The property was visited by the writer May 24, 1918. It is difficultly accessible by a wagon road about 35 miles long from Franconia and Powell, stations on the main line of the Atchison, Topeka & Santa Fe Railway, but it is best reached by boat from Parker, the distance along the river being about forty miles............ The ore was hauled (in 1917) by wagon half a mile to the loading platform and there transferred to a gasoline launch and transported to the landing at Parker, where again it was transferred to wagons and hauled to railroad cars for shipment. The deposit was not being worked at the time of visit, but probably 150 tons of ore had been transported to Parker and about 300 tons on the dumps awaited shipment.

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[54] Work cited, pp. 149-150.
[55] Work cited, pp. 151-153.

"Little Chemehuevis Valley is a narrow area of bottom lands and low-lying hills along Colorado River.................. The altitude of the bottom lands is about 400 feet above sea level, and that of the manganese deposit in the adjacent low hills is about 600 feet. The low hills on the Arizona side of Colorado River are cut by numerous shallow arroyos that drain to the river, but near the manganese deposit none of them contain water except after heavy rains. The rainfall is less than five inches a year, and in consequence only a few desert shrubs are found on the hillside, but in the bottom lands of Colorado River mesquite, willow, and a few cottonwood trees grow.

"The rocks of the small hills consist of an older series of gneiss, diorite, and granitic rocks, of pre-Cambrian age, and a younger series of basalt and sandstone, of Quaternary or late Tertiary age. The relation of the basalt to the sandstone has not been studied in detail, but near the manganese deposit the basalt is seemingly intruded into the sandstone. The basalt is........ decomposed, and the abundant amygdules are filled with black calcite that is manganiferous......... Fragments of the black calcite were studied under the microscope and found to inclose minute rods and growths of manganese oxides that were apparently deposited contemporaneously with the calcite.

"The managnese deposits consist of several veins and brecciated zones that cut the basalt or lie on the contact of basalt and sandstone. Most of these veins lie in a zone which trends west-northwest and dips steeply northeast, but one vein was observed which strikes a little east of north and dips southeast. They have been prospected by ten or more open cuts through a distance of 3,000 feet, and the development shows that the ore occurs in small shoots in the fissures. The open cuts are from twenty to eighty feet long and have a maximum depth of ten feet....... From most of the shoots the ore has been mined, but one shoot 45 feet long and four feet wide remains in one open cut. The veins and brecciated zones range from a few inches to five feet in width. In places the ore and associated minerals are wholly fissure fillings, but most of the deposits are breccias.

"The manganese minerals are psilomelane and pyrolusite, associated with calcite and iron oxides. The iron content varies; in some of the ore shoots the manganese oxides are quite free from iron, but in others it is abundant and intimately mixed with the manganese oxides. Psilomelane occurs near the surface and forms concentric crusts about fragments of basalt. At shallow depths it gives way to the soft oxides of manganese. Calcite is everywhere abundant in these manganese deposits; in places it forms well-defined veins in the ore body. In one of the open cuts a vein of calcite in coarse crystals is one foot thick, but where exposed in most of the workings the calcite is intimately mixed with the ore and underlies it. Some of the calcite is white, but most of it is coarse brown to black crystals, its color being due to filaments and fernlike growths of manganese oxides.

"The manganese of the ore bodies may have been derived from two sources, but the evidence for either is not conclusive. One hypothesis is that the oxides are the residual products from the weathering of manganiferous calcite deposited by ascending hot solutions in the veins, and the other is that the oxides were deposited with calcite by meteoric waters which derived the minerals from the decomposition of the basalt. The altered basalt adjacent to the fissures is in favor of the first hypothesis, but the fact that no manganese minerals other than the oxides were found and that the oxides appear to have been deposited contemporaneously with the calcite lend support to the second hypothesis.

"The oxides are very superficial, and as shown in the numerous open cuts little ore is found below a depth of ten feet. The ore that was shipped and that now stacked on the dumps is judged to contain about 35 percent of manganese and about eight percent of iron. Little care was exercised in sorting it, and the silica content is high owing to included fragments of basalt. Several thousand tons of this material remains in the deposits, but it is doubtful if it can be profitably mined, even under the high prices for manganese ores that prevailed in the summer of 1918."

TOPOCK DISTRICT

This district has been described by Jones [56] as follows:

"The Topock manganese district is eight miles in a direct line southeast of Topock, on the southeast side of a group of pinnacled peaks known as the Needles. It is included in the area mapped by the United States Geological Survey as the Needles quadrangle. The area in which manganese deposits have been found covers three square miles, and in it many claim groups have been located. Two days in June, 1918, were spent by the writer in the examination of this district. The nearest shipping point to the district is Powell, a station on the Atchison, Topeka & Santa Fe Railway, eight miles to the north. Between this point

[56] Work cited, pp. 153-159.

and the deposits a............ road follows a wash, but the ground is soft, and there is a considerable grade for most of the distance. Another road passes two miles east of the southern part of the district, and a connection could readily be made with it, but the haul to the railroad is five miles farther than by the other road.

"Most of the claim locations on the manganese deposits of the Topock district were made in the fall of 1917, but up to June, 1918, no ore had been shipped and the development work consisted principally of shallow surface cuts.

GEOGRAPHY

"........ The manganese deposits are at altitudes ranging from 1,100 to 1,200 feet above the sea level, about 200 feet lower than the summits of adjacent hills........... Numerous shallow washes or arroyos drain from the Needles to Colorado River or to the surrounding detrital plains, but none of them contain water, and the nearest source of supply to the manganese district is Colorado River. The region is arid, and the rainfall is probably nearly the same as at Needles, Calif., where the mean annual precipitation since 1892 is 2.47 inches. The soil supports a few desert shrubs.

GEOLOGY

"The rocks range in age from pre-Cambrian to Quaternary. The Needles are composed chiefly of lava flows, volcanic ash, and breccias of Tertiary age, but in places these effusive rocks have been eroded and the underlying pre-Cambrian granite and gneiss have been exposed. One such area of pre-Cambrian rocks is north of the manganese district, on both sides of the road that goes to Powell. The mesas and detrital plains that partly surround the low hills in the manganese district are underlain by sandstone beds, exposed where arroyos have cut through the overlying rock debris............. Some of these beds dip about 25° SW., and others lie flat. They are younger than the lavas and evidently were deposited during a stage of aggradation in Colorado River. This formation is probably the same as that which occurs extensively along Colorado River.............

"Extensive faulting has occurred in the manganese area. The faults are difficult to trace, but are indicated by the tilted lava flows and sandstone beds and the isolated hills of lava surrounded by detritus of sandstone. Some of the faulting occurred after the deposition of the Temple Bar conglomerate and hence is of Quaternay age."

Mr. Alvin B. Carpenter, who made a geologic study of this district during May, 1929, in the interests of the Chapin Exploration Co., gives the following information [57]: "Probable andesite is overlain in many places by tuff, tuffaceous shale, and sandstone. Above this tuff is a thick bed of gray-colored rhyolite with, at its base, a breccia which at the north end of the area shows a thickness of more than 100 feet, yet does not appear at any point south of the steep canyon which terminates at the upper end of the manganese deposit. Covering the gray rhyolite and the andesite, and extending northwestward over a considerable area with a thickness of more than 200 feet, is a red volcanic agglomerate. Small, irregular deposits of manganese oxides occur scattered through lower portions of this formation as partial replacements of the cementing material. The proportion of manganese to the included andesite and rhyolite of the coarser agglomerate is low, but, in the finer-grade beds, the replacement has included a large part of the finer grains as well as the cementing material.

ORES

"The semi-developed portion of the deposit lies in Sec. 17, T. 15N., R. 20W., Gila and Salt River Meridian, and extends into Sec. 20. The sandstone beds at the northeast edge of the area are highly impregnated and largely replaced with manganese oxides. A seven-foot face of this material gave an analysis of fourteen percent of manganese, 56 percent of insoluble, and two percent of iron.

"At the north end of the deposit is a pit that shows a complete replacement of the sandstone. The analysis of a sample from this pit gave 25 percent of manganese, 35 percent of insoluble, and 3.5 percent of iron. Ore from a short tunnel 200 feet farther south gave an analysis of thirty percent of manganese, 25 percent of insoluble, and 1.8 percent of iron. This area is abruptly terminated on the south by a nearly vertical fault, between which and the tunnel are smaller parallel faults. Near the main fault the manganese bed shows a thickness of eight feet. In this disturbed portion of the deposit the proportion of manganese to iron varies greatly; a sample from one pit shows four percent of manganese and thirty percent of iron, while a sample from a nearby pit gave 22 percent of manganese with two percent of iron.

"In a shallow hole, 130 feet southeast of the tunnel, a mineralized bed is shown dipping southeasterly beneath the outwash

[57] Written communication.

debris. An analysis of a sample of this ore gave nineteen percent of manganese, 37 percent of insoluble, and two percent of iron. The potential value of this whole area depends upon the degree of continuous extent of this bed beneath the outwash debris.

POSSIBLE ORE

"The main deposit, owing to poorly defined lateral limits, is considered to a depth of only three feet. Present workings in it suggest an estimate of some 24,000 tons of probable ore containing approximately twenty percent of manganese, 35 percent of insoluble, and 3.5 percent of iron. If the bed discovered beneath the outwash is continuous, it may contain an enormous tonnage of similar grade."

PINAL COUNTY

Pinal County's principal manganese deposits are in the Superior and Florence districts, and in the region adjacent to the San Pedro River, south of Winkelman. Jones [58] has described these deposits as follows:

SUPERIOR DISTRICT

GENERAL FEATURES

"The copper deposits and stratigraphy of the district were described in 1913 by Ransome [59].

"The manganiferous deposits are in a zone four miles long, extending about the same distance north and south from Superior, on the westerly slope of a group of unnamed hills........ Most of the deposits within this zone were examined, but the lack of development on them precluded any systematic or thorough study.

"Among the mining groups containing manganiferous ores, named from north to south, are the Magma Chief, Magma, Superior & Arizona, Queen Creek Copper, Magmatic Copper Co., Consolidated Holding & Trust Co., and Grand Pacific.

HISTORY

"The history of the Superior district dates from the location of the Silver King and Silver Queen mines in 1875. The Silver

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[58] Work cited, pp. 159-165, 169-174.

[59] Ransome, F. L. Copper deposits near Superior, Ariz.: U. S. Geol. Surv. Bull. 540, pp. 139-158, 1913.

King mine, credited with a production of $8,000,000 or more in silver, is about three miles north of Superior. It has lain idle for many years.........

"The Silver Queen mine, now owned by the Magma Copper Co., and generally known as the Magma mine, is a large producer of copper, and to its operation the existence of Superior is largely due. The Superior & Arizona also produces some copper ore, and there are many prospects in search of copper that have not reached the productive stage. Attention has been directed to deposits of manganiferous iron ores which outcrop prominently in the district, but no bodies of ore that could be profitably mined have yet been found.

ACCESSIBILITY

"Superior is accessible by the Arizona & Magma Railroad, ... which connects with the Arizona Eastern Railroad at Magma. Most of the mining properties are accessible to Superior by wagon roads from one to four miles long.

SURFACE FEATURES

"Superior lies at an altitude of 3,000 feet above sea level, at the base of the steep westerly slope of a northward-trending ridge on the north bank of Queen Creek, where it emerges from its canyon. The canyon is carved across the structure of the ridge. The summit of Apache Leap is about 4,700 feet above sea level, and Kings Crown Peak, a few miles northwest of Superior, attains an altitude of 5,530 feet. Eastward from the summit of Apache Leap extends a gently sloping sfurace that represents a flow of Tertiary eruptive rocks.

"Queen Creek, an intermittent stream, drains westward toward Gila River. Springs are found in the gulches near the base of the steep westerly mountain slope, and most of them are probably situated along strong northerly faults. A few trees grow along Queen Creek, and the hills support only a sparse growth of desert vegetation. The original water level of the Magma mine is reported to have been about 400 feet below the surface, but the old shafts of the Silver King mine, at an altitude of approximately 3,500 feet, are said to have filled with water.

GEOLOGY

"The steep hillside immediately west of Superior gives an excellent exposure of the rocks of the district. As outlined by Ransome these formations are, in ascending order, (1) an intrusive sheet of diabase, (2) the upper of the two pre-Devonian quartzites, (3) the Devonian limestone, (4) the Carboniferous limestone, and (5) a flow of dacite which forms the crest of Apache Leap and is the prevailing rock over a desolate country for five or six miles to the east. The general dip of these rocks is 35° E. South of Superior, near the shaft on the Magmatic Copper Co's. property, diabase intrusions occur also in Devonian limestone.

"A prominent structural feature of the district is a strong fault that strikes a little west of north and passes at the base of the steep west front of Apache Leap. It is concealed by alluvium south of Superior, but north of Superior the fault can be plainly traced, passing a short distance west of the Magma shaft and through a pronounced gap in two mountain blocks toward the Silver King mine. The fault dips west, and the mountain block west of it has been normally displaced, bringing Carboniferous limestone west of the fault adjacent to diabase and quartzite east of the fault. Other northward-trending faults were observed south of Superior. Eastward-trending faults, though of moderate or small displacement, are important because of their relation to the ore deposits. The one of greatest displacement is probably that along wihch the ore body of the Magma mine was deposited, in conjunction with an intrusion of granitic rock. The vertical displacement of this fault is about 150 feet. Smaller faults are visible on the steep westerly hill slope east of Superior. The eastward-trending faults are probably older than the northward-trending faults, for the Magma fault and dike are reported to end abruptly against the major northerly faults.

MANGANESE DEPOSITS

"The manganiferous ore bodies occur in the fault planes of the two systems and in bedding planes of limestone adjacent to the faults. The Devonian limestone immediately above the quartzite presents a horizon especially favorable for the occurrence of deposits in the bedding planes. The deposits vary greatly in size; some can be traced for several hundred feet along their strike, but others are lenses whose outcrops are only a few feet in length. These ore bodies have a vertical range in occurrence of 1,000 feet from the base of the west slope of Apache Leap, approximately 3,000 feet above the sea, to altitudes of 4,000 feet.........

"The quantity of low-grade ores in the district is large, though no single deposit may be expected to yield more than a few thousand tons, and many deposits contain only a few hundred tons. No deposit has been sufficiently developed to afford data for an accurate estimate of tonnage.

MINES AND CLAIMS

"*Magma Chief*: The Magma Chief mine is about two miles north of Superior. On the Baltimore claim........ an inclined shaft 35 feet deep shows two to three feet of manganiferous ore in the bedding planes of massive limestone. The limestone strikes N. 70° E. and dips 50° S. A tunnel 175 feet below the outcrop is being driven to intersect the deposit but at the time of examination had not reached it. Assays of material from the inclined shaft are reported to contain from 23 to 39 percent of manganese, four to fourteen percent of iron, and forty percent or more of silica. Bodies of manganese ore crop out also in the bedding planes of limestone on either side of an eastward-trending fault at an altitude of 3,800 feet. A tunnel that forms the principal development of the Magma Chief mine is directed eastward along this fault, and in June, 1918, it had intersected the manganiferous ore bodies at a depth of 400 feet. One of these ore bodies is about five feet wide on the surface and can be traced for several hundred feet along the strike of the beds, but the material is very siliceous. On the tunnel level the sheared vein matter is about twenty feet wide, and it consists of iron and manganese oxides, jasper, and silicified limestone, but it is judged to contain not more than ten percent of manganese, about fifteen percent of iron, and more than fifty percent of silica. This material is not adapted to mechanical concentration.

"*Magma Group*:......On the Monarch claim of the Magma Consolidated Mining Company an old tunnel driven from the level of Queen Creek follows a fissure which trends S. 25° E. and dips 60° S. and cuts massive limestone. The limestone strikes N. 10° W. and dips 35° E. Along the fissure for 320 feet are lenses and masses of iron and manganese oxides as much as three feet wide. Some of the material is of fair grade and may contain thirty percent of manganese, but much of it is highly siliceous. There is approximately 500 tons of ore containing 25 percent of manganese above the tunnel level, but the depth to which the oxides extend has not been determined.

Magmatic Copper Co.: The Magmatic Copper Co.'s group of seven claims is about two miles south of Superior, in low-lying hills at the base of the westerly slope of Apache Leap, at an average altitude of 3,000 feet above sea level. The developments consist of a working shaft 130 feet deep, several old shafts from fifty to eighty feet deep, and a tunnel 100 feet long. The rocks exposed on these claims are quartzite, limestone, diabase, and dacite. The quartzite forms the base of the series, and it is overlain by several hundred feet of massive limestone. Intrusive into the limestone on the east side of the claim group is a large mass of diabase. South of the working shaft, between two faults, is an area of dacite identical with the rock forming the crest of Apache Leap. The dacite was probably brought to its present position by faulting. The sedimentary rocks strike about north and dip 35° E. A prominent northward-trending fault can be traced for several thousand feet on the claims. It cuts the limestone and south of the shaft brings dacite into contact with the limestone. A fault that strikes northwest probably joins the northward-trending fault a short distance north of the shaft. Other faults or fissures of small displacement trend about east.

"The manganese deposits occur in the fault fissures or along bedding planes of limestone adjacent to the faults. No persistent body crops out, but lenses of manganiferous iron ore a few feet long occur along the faults, associated with silicified limestone and jasper. The largest body occurs in the block of ground covered by the dacite flow between the northwesterly and northerly faults. At a depth of 93 feet the working shaft encountered a body of manganiferous material in limestone which persists to a depth of 107 feet. This body apparently dips about 40° W., so its thickness is about ten feet, but no work has been done to determine the length of the shoot or its persistence in depth. An old shaft 500 feet southeast of the working shaft on the northwesterly fault shows about five feet of manganiferous material a few feet below the collar, but whether this material is continuous between the two shafts has not been determined.

"The material from the working shaft is granular and dark brown. On exposure to the air it crumbles to a powder. Fresh pieces show specks and narrow seams of manganese oxides in the predominant reddish-brown iron oxides. Many pieces show partly decomposed coarse crystals of a brownish spar, which may be manganiferous siderite. The material is comparatively free from silica. Analysis is said to have shown eighteen percent of manganese, thirty-four percent of iron, and four percent of silica.

"*Consolidated Holding & Trust Co.*: The Consolidated Holding & Trust Company owns a group of numerous claims, commonly known as the Daggs group, on the westerly slope of Apache Leap. There are some extensive workings on the property driven in a search for copper ore, chief among which are a shaft 700 feet deep and a tunnel that connects with the shaft at a depth of 150 feet. Very little work has been done here in recent years. In June, 1918, lessees were mining an ore body in the tunnel.

This body is valuable chiefly for its lead content, but it also contains manganese oxides and two rare minerals—wulfenite, the molybdate of lead; and vanadinite, the vanadate of lead.

"The ore body, which was encountered about 800 feet from the portal of the tunnel, occurs in limestone just above the contact with the underlying quartzite near a prominent fault that strikes N. 70° W. and dips steeply southwest. The ore body has been explored for 100 feet on the dip of the bed and fifteen feet on its strike and is from one to three feet thick. It consists of manganese and iron oxides with variable amounts of cerussite, wulfenite, and vanadinite crystals. The cerussite and rare lead minerals are more abundant next the quartzite; vanadinite in short tabular hexagonal crystals is commonly found adhering to the quartzite or in fissures in the quartzite; then follows a porous mass of yellow wulfenite, white cerussite, and calcite crystals a few inches thick, more or less stained with manganese and iron oxides. The upper and larger part of the deposit consists of an intergrowth of psilomelane, manganite, and perhaps some braunite with minor amounts of iron oxides and crystals of wulfenite and cerussite, in cavities in the ore. Some of the manganite is in bundles of fine fibers that somewhat resemble asbestos in texture. A partial assay of selected manganese ore by the Colorado Fuel & Iron Company is said to have yielded 34 percent of manganese, but the ore is said to be objectionable because of its lead content.

"About a quarter of a mile east of the main tunnel of the Daggs group, at an altitude of 4,000 feet above sea level, an old tunnel was driven on a vertical fissure that strikes N. 20° W. and cuts massive limestone. Some copper ore was stoped from the vein, but the workings are now caved, and the size and nature of the deposit could not be determined from an examination of the surface. In addition to some copper-stained rock the dump contains ten tons of manganese-bearing material. Specimens consist dominantly of a massive aggregate of coarse platy black crystals with a little psilomelane and minute seams of manganite which cut the other oxides. The platy crystals are hard and give a dark-brown streak. Small particles of the mineral are attracted by the magnet, and a chemical test reveals some gelatinous silica and iron. The mineral is probably braunite."

VICINITY OF SAN PEDRO RIVER

"Mogul Group: The Mogul group of five claims, owned by J. W. Norton, is in the Black Hills three miles west of San Pedro

River, at a point fifteen miles south of Winkelman. In order to ship ore it would be necessary to build a road from the deposit to San Pedro Valley, but this could be accomplished at little expense by following an arroyo for most of the way.

"The claims were located early in 1918, but to the time of visit only a small amount of development work had been done and no ore had been shipped.

"The principal workings are in an upland surface of moderate relief, at an altitude of 3,300 feet. The hills and bench land slope gradually eastward to San Pedro Valley, which at a point west of the deposit is about 2,200 feet above sea level. Numerous arroyos drain to San Pedro Valley, but none of them contain water. The climate is arid, and the rainfall probably is not more than five inches a year. A few desert shrubs, grasses, and cacti grow on the hills and in the arroyos.........

"The manganese deposit is contained in a vein of coarse-grained calcite which projects in places a foot or two above the decomposed granite country rock. The vein strikes N. 45° W. and dips 45° SW. It can be traced continuously for 350 feet, and its greatest width is ten feet. The ore occurs principally in the hanging-wall side of the vein, and the ore shoot is about 250 feet long and two feet wide Two holes have been dug on the deposit, the largest of which is 25 feet long and six feet deep.

"The manganese oxides on the surface are principally masses of psilomelane, showing concentric structure. At depths of a few feet softer manganese oxides appear, which in places merge into dark-colored calcite. Calcite is the dominant gangue mineral, and no quartz was observed, although analyses of the ore are said to yield about four percent of silica. By careful hand sorting an ore containing forty percent of manganese may be obtained, but most of the vein matter as mined is judged to contain about 25 percent of manganese. Very little iron occurs in this deposit. The abundance of calcite in the deposit and its dark color in parts of the vein suggest very strongly that the manganese oxides were derived from the decomposition of manganiferous calcite.

"*Tarr & Harper Mine*: The Tarr & Harper group of five claims is in Camp Grant Wash, about a mile west of its junction with San Pedro River. It is accessible by a good wagon road thirteen miles long from Winkelman, on the Arizona Eastern Railroad......... The deposit was first worked by the Arizona Rare Metals Co., which produced 408 tons of ore in 1917. In 1918 R. D. Harper resumed operations and from February to April had shipped four carloads of ore; the fifth car was being placed on April 24.

"The mine is at the mouth of a draw tributary to Camp Grant Wash, at an altitude of 2,300 feet above sea level. The hills in the immediate vicinity of the mine rise about 300 feet above it. San Pedro River is an intermittent stream, and Camp Grant Wash contains water only in Putnam Springs, about three miles from its mouth, and for a short time after rains. The climate is arid, and the average rainfall is about five inches a year. A few cottonwood trees grow along San Pedro River, and desert shrubs and several varieties of cactus grow in the arroyos and on the hillsides.

"San Pedro River flows northward in a broad valley disproportionate in width to the size of the present stream......... Bench lands rise abruptly from the bottom lands and........ in parts of the valley .... are several miles wide. The bench lands are composed of slightly indurated and poorly stratified sand, pebbles, and angular rock fragments. These sediments are at least 200 feet thick and may be much thicker......... They (older sedimentary rocks)............consist of limestone at the base, intruded by a diabase sill, overlain by conglomerate, which grades into gritstone and hard white quartzite. The formations strike northwest and dip northeast. They are flanked on the east by the flat-lying sand and conglomerate beds, and west of the mine they overlie granite of pre-Cambrian age.

"The manganese deposits are contained in fissure veins which cut both the older sedimentary rocks and the younger sands and conglomerate. The fissure in the older rocks trends N. 45° W. and dips 45° NE., and lies in the bedding or cuts the beds at an acute angle; the fissure in the gravel beds strikes about N. 10° W. and is nearly vertical.........

"Most of the ore has been obtained from the deposit in the older rocks on the north side of Camp Grant Wash, where a shaft eighty feet deep was sunk and about 275 feet of tunnels driven. On the south side of the wash only a few shallow holes have been dug. On the north side of the wash the fissure is known to contain manganese ore for 1,500 feet or more along its strike, but the ore has been mined only between points 500 feet apart, where the fissure is contained in limestone and quartzite above a diabase sill. The vein is from a few inches to four feet wide. In places there are two ore-bearing streaks a few feet apart, separated by brecciated material of the fault zone. The foot-wall of the zone in the present working tunnel is a slickensided plane with well-defined striae, the direction of the movement being northeast but at a small angle from the dip of the fissure. Above 500 feet northwest of the workings the vein is inclosed in diabase where the ore is mixed with iron oxides and is of much lower grade than in the limestone and quartzite. Ore is reported to extend to the bottom of the eighty-foot shaft, but it is believed not to extend to that depth in most places in the fissure.

"The manganese oxides are pyrolusite, manganite, and psilomelane. They have been deposited in the open spaces of the fissure and have also replaced the crushed wall rocks to some extent. Iron oxides occur sparsely in that part of the vein that is being worked, but they are abundant where diabase is the inclosing rock of the fissure and are intimately mixed with manganese oxides. Calcite is an abundant mineral of the ore, and it likewise is of secondary origin. The original manganese minerals of the fissure were not noted, but the abundance of secondary calcite makes it appear probable that manganiferous calcite was present. The ore is sorted by hand and screened in order to obtain a product carrying forty percent of manganese. Much of the material of the dumps contains thirty percent of manganese, but it is high in silica. The meager development indicates that several thousand tons of ore containing forty percent of manganese could be recovered from the deposit in the older rocks on the north side of the wash.

"The deposit in the gravels on the south side of the wash is indicated for 300 feet along the strike of the vein or shear zone, but its average width and the depth to which the manganese oxides extend have not been determined. A small quantity of ore was mined from a hole about ten feet deep. At the surface where this hole was dug the vein material was about one foot wide, but the walls diverge downward and at the bottom of the hole it is at least six feet wide. The deposit consists of small pebbles and angular rock fragments of the gravel beds cemented together and partly replaced by pyrolusite, manganite, and subordinate psilomelane. Apparently there is no clean ore in masses large enough to pay to sort, and in order to make a marketable product the material would require concentration.

FLORENCE DISTRICT

"*Chamberlain Mine*: The Chamberlain Mine is in a desolate region twelve miles southeast of Florence. The deposit is small, and only a short time was spent in its examination on September 5, 1917. Development work on it consists only of shallow open cuts. Two carloads of ore amounting to 74 tons were shipped from the property early in 1917, but in September no work was being done. Florence, the nearest railroad station on the Arizona Eastern Railroad, is readily accessible by a good wagon road. The climate is arid and supports only desert shrubs and several varieties of cactus. Shallow channels that contain water only for short periods during storms drain toward Gila River to the north. The depth to water level is not known.

"The surface features consist of a broad detrital plain sloping gently to the north, above which rise a few isolated low hills. The manganese deposits occur on one of these hills that is about 500 feet in diameter and stands at an altitude of 2,000 feet above sea level, or fifty feet above the plain.

"The hill is composed of a coarse-grained hornblende granite with small remnant patches of red andesite. Several small fissure veins in the granite, which strike N. 20° W. and dip 70° SW., contain the manganese ore. The veins are from a few inches to one foot wide, and the longest ore shoot as shown by an open cut is 125 feet in length. In places along the veins the granite is brecciated, and the fragments are cemented by manganese oxides.

"The manganese oxides are principally hard crusts of psilomelane, but softer oxides occur as the decomposition product of black calcite. Detrital material about the hill contains numerous fragments of psilomelane which under the action of the elements are polished and rounded and look not unlike weathered fragments of dark volcanic glass. Some of the psilomelane is botryoidal, with concentric layers. For the most part it was deposited in the fissure as crusts, but it also partly replaced fragments of granite inclosed in the veins. Calcite is abundant in the veins, and it occurs as two generations; the primary calcite is a dark-colored variety which on decomposition apparently yields manganese oxides and masses of sparkling white crystals and small veinlets of secondary calcite. Barite also occurs as visible crystals in the ore, and as shown in the analysis barium is a considerable constituent of the ore and in part probably is in chemical combination in the psilomelane.

"The depth of oxidation is not known, as the deepest workings are but six feet beneath the surface. It is apparently shallow, for in places the black calcite, the source of the manganese oxides, is only partly decomposed.

"The ore is sorted by hand. Analyses of the ore shipped supplied by Mr. Chamberlain gave the following results: Manganese, 40.75 percent; iron, 0.82 percent; silica, 3.37 percent; phosphorus, 0.37 percent. A more complete anaylsis, also obtained from Mr. Chamberlain, gave in addition $CaCO_3$, 15.12 percent; $MgCO_3$, 2.75 percent; and BaO, 13.14 percent.

"The veins are small, and they pinch and swell. Whether they persist beyond the limits of the hill in which they crop out has not been determined, for a deep detrital plain surrounds the hill. The ore shoots range from a few feet to 125 feet in length and have an average width of six inches. On the assumption that the oxidized ores extend to a depth of 25 feet about 250 tons of ore containing forty percent of manganese could be won from these deposits."

SANTA CRUZ COUNTY

According to Dr. R. J. Leonard, [60] of the Geology Department of the University of Arizona, manganese mineralization is generally apparent in the ore deposits of the Patagonia Mountains, but is of present economic interest only in certain limestone replacement bodies. Thus, the ores of the Hardshell, Mowry, North Mowry, Hermosa, and Black Eagle mines are notably manganiferous. Alabandite is present on the Josephine dump of the Trench group, but its underground place of occurrence has long been inaccessible.

Most of the manganese ore produced in Santa Cruz County came from the Hardshell and Mowry mines.

Hardshell Mine: According to Mr. Howard Welch [61] the Hardshell Mine during the World War shipped approximately 500 tons of manganese ore and approximately 500 tons of concentrates, all of which was above forty percent in manganese content.

Jones [62] has described the Hardshell deposit as follows:

"The Hardshell group, comprising 42 claims, is on the easterly slope of the Patagonia Mountains, about one mile southwest of Harshaw. The ore deposit was discovered in 1879, and it has produced a large amount of lead-silver ore......... On April 30 and May 1, 1918, the writer made a brief examination of the outcrops and such of the workings in the Hardshell mine as were accessible.

"The deposit lies............ at the foot of the steep southerly slope from Table Mountain, the summit of which is 6,145 feet above sea level. From the foot of Table Mountain southward for several miles an area of dissected igneous rocks of moderate re-

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60 Oral communication.

61 Oral communication.

62 Work cited, pp. 174-177.

lief is succeeded by gently sloping bench land to San Pedro Valley......... None of the arroyos draining to San Pedro Valley contain permanent streams, but near the manganese deposit a spring issues from the quartzite and flows for a short distance down the arroyo.

"The Hardshell mine is in a gulch at an altitude of 5,150 feet. The hills in the immediate vicinity of the mine rise from 300 to 400 feet above it, but a mile to the south American Peak stands at an altitude of about 6,200 feet. Manganese minerals crop out in several places on the claim group between the mine and the summit of a hill half a mile south of the mine.

"Hardshell Gulch contains no permanent stream, although at its mouth water stands ten feet below the surface. No records of the rainfall are available, but it is probably not less than ten inches a year, and it is sufficient to support a good growth of oak, juniper, and walnut trees and several varieties of grasses.

"The mine is accessible by a good wagon road nine miles long, which leads to Patagonia, on the El Paso & Southwestern (now Southern Pacific) Railroad.

"The geology and ore deposits of the Santa Rita and Patagonia mountains have been described by Schrader and Hill. [63] The rocks which underlie the Hardshell group of claims are limestone, quartzite, conglomerate, and intrusive rhyolite and felsite.

"The boundaries of the diffreent types of rock are most irregular, owing to faulting and the manner in which felsite and rhyolite are intruded in the beds of quartzite and limestone. In the Hardshell mine rhyolite and felsite are the dominant rocks, but there are also beds of quartzite and limestone. In the field it is difficult to distinguish quartzite from felsite. On the hill south of the mine a body of massive blue limestone is sharply delimited on two sides by masses of quartzite, conglomerate and rhyolite. The limestone is of Devonian age, and the quartzite is probably of Paleozoic age but can not be definitely assigned to any period. The rhyolite and felsites are Tertiary.

"The Hardshell mine explores a shear zone which strikes northeast and dips northwest at angles varying from a few degrees to 35°. The developments consist of an inclined shaft 600 feet deep on the dip of the ore body anad drifts on several levels which extend about 200 feet east of the incline and about 75 feet west of it. The workings attain a vertical depth of 250 feet. Water now stands in the shaft to the 325-foot level, or 160 feet from the surface, and most of the workings were inaccessible at the time of visit.

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[63] Schrader, F. C., and Hill, J. M., Mineral deposits of the Santa Rita and Patagonia mountains, Ariz.: U. S. Geol. Survey Bull. 582, 1915.

"The shear zone ranges from a few feet to 60 feet or more in width, and the ore deposits occur rather irregularly in it but with a persistent vein along its footwall. The material of the shear zone is greatly crushed quartzite, rhyolite, felsite, a persistent band of kaolinized material, and the ore, consisting of lead carbonate and subordinate galena associated with iron and manganese oxides. The iron and manganese oxides are generally separate. In some places the manganiferous ore is six feet wide and is fairly persistent, but elsewhere it occurs in irregular bunches and stringers and in nodular masses disseminated in kaolinized material. Oxidized lead ore is intimately associated with the manganese deposits, near the surface some pyromorphite occurs also. The manganese oxides are pyrolusite, psilomelane, and braunite. Most of the ore is hard, and it can be separated, though rather imperfectly, from the gangue minerals by mechanical means. An analysis of the manganese concentrates is said to yield about 42 percent of manganese, fifteen percent of silica, and a little iron and phosphorus, but the ore contains also about fifteen ounces of silver to the ton, from ten to fifteen percent of lead, and about two percent of copper. The silver and lead are lost when the ore is smelted for its manganese content.

"Manganese oxides occur as the cementing substance of quartzite and felsite breccias in several places in Hardshell Gulch south of the Hardshell mine. In places the solid ore is six inches wide, but most of it is in narrow seams in the fractured rock. Braunite and psilomelane are the most prominent oxides. A few shallow holes have been driven on these outcrops.

"The manganese deposit on the crest of a small hill half a mile south of the mine is developed by four shafts from six to fifty feet deep. These shafts roughly mark the outline of a brecciated zone in limestone 300 feet long and from 50 to 100 feet wide. The rocks are greatly brecciated and contain numerous seams of manganese oxides where pits have been sunk, but it is not known how generally the mineralization extends across the brecciated zone. Samples from these shafts are said to have yielded from 22 to 38 percent of manganese and eight ounces of silver to the ton. Most of this material would have to be concentrated in order to make a shipping product.

"The depth to which manganese oxides extend is not known, but they have been reported in the deepest workings of the Hardshell mine, which are 250 feet below the surface. Water now stands at a vertical depth of 165 feet, so the manganese oxides extend a considerable distance below the water level. It is believed that the manganese oxides do not extend as deep below the numerous outcrops on the Hardshell group as in the Hardshell mine, because they are in poorly defined shear zones that do not offer a medium for circulating waters like the Hardshell fissure.

"The total reserves of manganiferous material indicated in the Hardshell fissure and in deposits that crop out at several points on the claim group aggregate many thousand tons, but the utilization of this material will be dependent on the continuity of the high prices for manganese ores that prevailed during the summer of 1918 and its adaptability to some form of concentration or other process of beneficiation."

Mowry Mine: According to Mr. C. A. Pierce, [64] the Mowry deposit during the World War produced 206 tons of ore that averaged 33. 6 percent in manganese content.

The Mowry Mine is in the eastern part of the Patagonia Mountains, at an elevation of about 5,500 feet above sea level. It is accessible from the railway at Patagonia by fourteen miles of good highway.

This remarkable lead-silver deposit has been known since the advent of the early Padres, and, particularly during the past century, has been a long, but intermittent, producer. [65]

According to Schrader, [66] the deposit is on the north, or hanging wall, side of an east-west fault contact between Paleozoic limestone and quartz monzonite. Gabbro intrudes the limestone along this fault. He continues: "The croppings, consisting mainly of oxides of manganese and iron, kaolin, and some argentiferous galena, extend interruptedly along the contact fissure for half a mile or more and continuously along the 600-foot stretch now occupied by the mine openings, being especially prominent over the ore bodies. From the surface........ the vein extends downward (500 feet) to the bottom of the mine in a continuous tabular sheet and was ore-bearing almost throughout.........

"Most of the ore bodies, however, occur apparently as replacements of the adjoining limestone........ back from the fissure.........

"The ore consists mainly of the argentiferous ore minerals, cerussite, coarse galena, anglesite, and bindhemite, all contained

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[64] Written communication.

[65] See Schrader, F. C., Mineral deposits of the Santa Rita and Patagonia mountains, Arizona: U. S. Geol. Survey Bull. 582, pp. 296-297.

[66] Work cited, pp. 299-305.

in a manganiferous and ferruginous gangue consisting principally of psilomelane and massive pyrolusite and hematite. The manganese and iron together are said to form about one-fifth of the ore body in volume. There is but little if any quartz, and a remarkable feature is the absence of zinc. The ore is mostly oxidized down to or below the 300-foot level, and scarcely any sulphide other than galena, not even pyrite, was found above this level. Copper and iron sulphides first began to appear on the 400-foot level. Much of the ore is a friable argillaceous mixture of silver-bearing cerussite and anglesite, with calcium carbonate, hematite, psilomelane, and pyrolusite......... The ore is said to become less manganiferous and more siliceous with increasing distance from the gabbro dike.

"The galena is in the main coarsely crystalline. It occurs in lenses and masses of considerable size embedded in the manganiferous gangue, and when associated mainly with pyrolusite, as in the lower workings, it is said to form the richest ore, averaging several thousand ounces in silver to the ton.........

"At a depth of about 235 feet the limestone gives way to gabbro......... The vein or ore body in general narrows downward from this depth and seemingly deteriorates in value.

"........ The manganese of the gangue........ continues from the surface to the bottom of the mine......... The 400-foot level in general is characterized by an abundance of calcite and kaolin, in addition to the usual manganese and iron minerals.

"At about the 150-foot level occur several veins or sheets of manganese, which in one place unite and form a large ore body with a corresponding increase in the amount of good ore.

"........ The abundance and purity of the pyrolusite in gangue suggest that this mineral may prove a useful by-product."

Black Eagle Mine: During the World War, the Black Eagle Mine in the Harshaw district produced, according to Mr. C. A. Pierce, [67] 66 tons of ore that contained 44.8 percent of manganese. This ore, Mr. Pierce states, was obtained from a replaced limestone bed that was followed down by the main inclined shaft. It continued from the surface to the 28-foot level, where it became more siliceous but yielded, according to Mr. Pierce, approximately 3,200 tons of ore which in general averaged 28.2 ounces per ton in silver, 0.9 percent in lead, 0.18 percent in copper, 18.2 percent in silver, 8.7 percent in iron, 22.6 percent in lime, and 19.9 percent in manganese.

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[67] Written communication.

YAVAPAI COUNTY

Three deposits of manganese ore in southern Yavapai County were described by Jones [68] as follows:

"*Bunker & Burmeister Claims*: The manganese claims owned by Bunker & Burmeister are near the junction of Sycamore Creek with Agua Fria River, twelve miles southeast of Mayer, the nearest shipping point, on a branch line of the Atchison, Topeka & Santa Fe Railway. The claims are readily accessible by wagon road. In 1917, thirty tons of ore was shipped, the returns of which were as follows: Manganese, 44.56 percent; iron, 0.92 percent; silica, 6.77 percent; phosphorus, 1.23 percent. Work was being done in a number of shallow holes on the claims at the time of examination in September, 1917, and several tons of ore was stacked on the dumps. The nature of the deposit makes any estimate of ore reserves uncertain, but the quantity is believed not to exceed a few hundred tons.

"The deposits lie in a bench that rises 75 feet above the river, whose altitude at this point is 3,500 feet above sea level. The dominant rocks of the region are schists and intrusive igneous rocks, but the low-lying country through which Agua Fria River flows is largely covered with basalt. The deposits occur as nodules in sand associated with magnesian travertine in which there are bands and nodules of a waxy white and yellow chert. The travertine [69] is said to merge horizontally into a volcanic agglomerate with calcareous cement, which is overlain by the basalt. The nodules and small masses of manganese ore so far extracted have come from depths of not more than six feet. There are few surface indications of the occurrence of ore except for an occasional piece of float, and the ore bodies are found by digging shallow holes indiscriminately in the sand and chert formation. Some of ore is attached to the travertine or occurs as nodules in weathered cavities of the travertine. The ore is psilomelane in vesicular or botryoidal form. It generally lies in horizontal lenses, the largest of which was reported to be two feet thick. One body six feet long and one foot thick was exposed in a pit at the time of examination, and leading into it above and below were several stringers or feeders of manganese

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[68] Work cited, pp. 177-181.

[69] Jaggar, T. A., Jr., and Palache, Charles, U. S. Geol. Survey Geol. Atlas, Bradshaw Mountains folio (No. 126), p. 3, 1905.

ore, some of which were vertical and some slightly inclined. The manganese oxides are not associated with iron oxides, and the ore is readily sorted to a high-grade product.

"The source of the manganese is not known, although its association with the travertine suggests that it was deposited by the same agencies, namely, from springs. The only other source of the ore that appears probable is water which percolated through overlying rocks and collected manganese from the decomposition of manganese-bearing minerals which they may have contained. The basalt may contain minerals carrying small quantities of manganese to fulfill these conditions, but no analyses of it are available.

"About a mile west of the Bunker & Burmeister claims, on the opposite side of Agua Fria River, two claims owned by E. V. Bunker and E. S. Rogers are situated similarly to those above described, on the bench land overlooking the river and associated with travertine in sand and clay beds. No ore had been shipped from the property to the time of visit, but several tons were on the dumps of the several shallow holes. Assays of the ore are said to have yielded 55 percent of manganese with little or no impurities.

Castle Creek Deposit: The Castle Creek manganese deposit, owned by J. B. Girand and R. A. Craig, of Phoenix, Ariz., and C. E. Champie, is about 23 miles northeast of Morristown, a station on the Atchison, Topeka & Santa Fe Railway. Development work........ consists of a few open cuts and short tunnels. No ore had been shipped from the deposit to the time of visit, September 13, 1917, but there was about forty tons of high-grade ore on the dumps and loading platform. A wagon road .... goes from Morristown to Castle Hot Springs, on Castle Creek, a short distance southeast of the deposit. From the road a trail one mile long leads to the manganese deposit, which is at an altitude of 2,800 feet, or 600 feet above the road at the point where the trail begins.

"Granite and granite gneiss are the rocks that inclose the deposit. Pegmatite veins and masses in which large, well-developed hornblende crystals are conspicuous are abundant along the trail. Lava flows which overlie granitic and metamorphic rocks are prominent along Castle Creek.

"The manganese ore occurs in fissure veins in the granite and granite gneiss. Two veins are developed on the property. One strikes N. 70° W. and is vertical, and the other strikes N. 20° W. and dips 70° W. Each vein averages about one foot in width, and as exposed by the development the ore shoots are respectively 50 and 75 feet long. A short tunnel driven on one of the fissures below an open cut gains a depth of forty feet, but at the face the ore is a mere stringer inclosed in sheared granite.

"The ore consists of psilomelane, manganite, and pyrolusite deposited in nodular and botryoidal crusts and masses. Calcite is very abundant in the ore, and nodular masses composed of concentric layers of manganese oxides are commonly incrusted with sparkling calcite crystals. Along parts of the vein on the surface botryoidal crusts of psilomelane are on the walls of the fissure. A polished section of a part of the nodule of ore shows some very interesting structure. The nodule is apparently made up of many composite bands of the oxides about different nuclei. Bands from one nucleus may coalesce with bands from another, resulting in an extremely irregular pattern with deep indentations. Some concentric growths of manganese oxide appear to have been interrupted by fracturing and the deposition of calcite. The bands are irregular in thickness, and in the polished specimen a band composed mainly of psilomelane is from one-sixteenth to one-third inch in thickness. This band is bordered by bands of manganite in small fibers about one-eighth of an inch thick and in part of the specimen by finely granular material believed to be pyrolusite, which may result from the alteration of manganite. In the psilomelane band are discontinuous films of pyrolusite in microscopic grains. In the broader parts of the psilomelane band several minute fractures extend through the band but stop at the bordering bands of manganite and pyrolusite. These fractures have subsequently been filled with calcite, and calcite has also been deposited in the interstitial spaces between concentric growths about different nuclei. The fractures in the psilomelane bands are believed to have been produced by contraction of the bands of psilomelane possibly before the succeeding deposition of manganite. Other fractures extend through thin bands of psilomelane into bordering bands of manganite, but the fracture in the crystalline material is sharply deflected from its course in the psilomelane and indeed may extend nearly parallel with the manganite band, but not go through to the opposite wall of the next psilomelane band. The chemical and physical conditions which caused the deposition in alternating bands of manganite, pyrolusite,........ and psilomelane are not known,......... The original source of the manganese oxides is not apparent in the veins as far as the workings extend, but the abundance of calcite deposited in and about nodules of ore indicates that manganese oxides were derived from manganiferous calcite or were deposited with calcite.

"Probably not more than 500 tons of ore could be produced from the two ore shoots thus far discovered on this property. The ore is, however, of high grade, containing about fifty percent of manganese and very little iron.

"*Hatton Group*: The Hatton group of manganese claims, nine miles northwest of Aguila, is in the Aguila district (see pages 65-70), though it lies in Yavapai County, whereas the other manganese deposits of the district are in Maricopa County. The principal workings of the Hatton claims are near the base of a small outlying hill of the Harcuvar Mountains, at an altitude of 2,500 feet above sea level. The hill is composedd of red sandstone which strikes northwest and dips about 30° SW. The deposit occurs in a well-defined fault fissure which strikes N. 60° W. and is generally vertical. The fissure is explored through a distance of 400 feet by a number of open cuts and at one point by a shaft forty feet deep, from which at a depth of twenty feet are short drifts. The largest ore body thus far exposed is fifty feet long and three feet wide. The ore is for the most part composed of soft amorphous manganese oxides inclosing small bunches of short prismatic crystals of manganite. Small cavities in the ore are lined with minute filaments of a soft black lustrous manganese oxide which may also be manganite. The ore is apparently a decomposition product of black calcite with its contained manganese oxides. In parts of the vein black calcite and barite show banded structure. Barite predominates in the vein near the bottom of the shaft. A few stains of copper salts were noted in the vein material. The best ore was obtained near the surface, and the limit of commercial ore in depth as shown in the shaft is about 35 feet. The ore is screened and hand sorted in order to obtain a product said to contain 38 percent of manganese. Between August, 1917, when production began, and April, 1918, when operations ceased, the mine produced about 600 tons of ore. It was reported that the greater part of the ore has been mined from the deposit."

YUMA COUNTY

Yuma County has a few manganese deposits in its northeastern portion. Jones [70] has described the principal ones as follows:

"*Iron King Group*: The Iron King group of four manganese claims is in Yuma County about 26 miles north of Bouse and four

[70] Work cited, pp. 181-184.

miles from the Planet mine. The nearest shipping point is Midway, twelve miles to the southeast, on the Arizona and Swansea Railroad, which is accesible by a good wagon road......... One carload of ore is said to have been shipped in 1916, but none has been shipped since that time, and the property was idle at the time of visit, May 19, 1918.

"The deposit occurs in an area of moderate relief marked by ridges and isolated peaks that rise a few hundred feet above the plain sloping to the south and the detritus-filled washes........ between the hills. The principal shaft is at an altitude of 1,350 feet, on the slope of a hill whose summit is about 200 feet higher. The mountainous area is drained by washes which flow to Williams River, about four miles to the north, and to Cactus Plain, on the south. None of the washes contain water except after heavy rains, and the nearest source of supply is Williams River. The rainfall is probably not more than five inches a year in this region, and the vegetation is very scanty except along Williams River, where cottonwood trees and abundant mesquite grow.

"The rocks in the vicinity consist of an older series of granite gneiss overlain by bands of limestone and amphibolite, massive limestone, quartzite, and metamorphosed shales; and a younger series of sandstone, calcareous sandstone, and detritus and wash material. The older rocks are probably pre-Cambrian; the younger rocks range from late Tertiary to Pleistocene. The manganese deposit is contained in sheared rocks along a fault zone, which strikes N. 45° W. and apparently dips southwest. The fault marks the contact between conglomerate and wash material on the northeast or footwall side and silicified and serpentinized limestone and quartzite breccia on the hanging wall, in which the manganese minerals occur. Overlying these rocks on the hanging-wall side a short distance to the southwest is red sandstone, in part calcareous, which strikes N. 60° W. and dips 30° SW. It is much younger than the underlying rocks and is very similar to rocks noted along the bench or mesa lands north of Williams River in the vicinity of Alamo. The zone of brecciation along this fault is 100 feet wide in places, and for a distance of 1,000 feet the rocks are generally iron stained, but the occurrence of manganese minerals is limited to a few so-called 'blowouts,' the largest of which is about fifty feet long and twenty feet wide. The deposits have been explored by short tunnels and a shallow shaft, in all about 125 feet of development work. The mineralized material of the 'blow-outs' or chimneys is silicified limestone and quartzite, impregnated with iron and manganese oxides and cut by seams an inch or less in width of long fibrous manganite crystals. In some of these seams barite crystals are developed about projecting needles of manganite. Barite veins several inches wide are numerous, and hematite, calcite, and quartz are other accompanying minerals of the deposit. The deposit as a whole probably contains fifteen percent of manganese, fifteen percent of iron, and at least forty percent of silica. It was stated that a carload of sorted ore shipped in 1916 contained about thirty percent of manganese and was high in silica. The material is not amenable to mechanical concentration except as it might be possible to separate the manganite crystals. The depth to which oxidation extended in this deposit has not been determined, and none of the original manganese minerals that gave rise to the manganese oxides were observed. The deposit has no value under present conditions.

"*Dobbins Claims*: Two claims owned by J. M. Dobbins are in the Granite Wash Hills six miles east of Bouse. A poorly defined road follows an arroyo to a point within half a mile of the deposit and could be made serviceable with little expenditure. The claims were located in April, 1918, and at the time of visit (May 19) the deposit was being worked and about thirty tons of ore was stacked on the dump.

"The deposit lies in low hills at an altitude of 1,350 feet above sea level, and the local relief is not more than 100 feet. There are no streams or springs in the vicinity. The region is drained to Bouse Wash by arroyos that carry off the infrequent flood waters following heavy storms.........

"Tertiary lava flows composed principally of a red biotite andesite are the dominant rocks in the vicinity of the manganese deposit. They are flanked or more or less covered by angular debris. A shear zone in andesite which trends S. 65° W. and dips steeply northwest contains the manganese deposit. This zone can be traced for 1,000 feet or more, but the manganese deposits in it are apparently local, and only one ore body of importance has been discovered. A hole ten feet deep was dug at a point where manganese float was abundant, and an ore body 25 feet long and two feet wide was disclosed. The manganese oxides are psilomelane and pyrolusite, which occur as the cementing material of breccia and which replace in part the andesite fragments. Psilomelane is more abundant at the surface, but at depths of a few feet pyrolusite predominates. There is much secondary calcite in the ore, but no quartz except that contained in included fragments of country rock. The limit of the ore is apparently reached at a depth of six feet, where there are small quantities of soft pyrolusite in abundant calcite, some of which is dark colored from the inclusion of manganese oxides.

"*Kaiserdoom Claims*: The Kaiserdoom claims, which were located May 2, 1918, by W. M. Whipple and L. M. Watson, are in the NW¼ Sec. 21, T. 11N., R. 11W., in the bench land on the south side of Santa Maria River. Congress Junction on the Atchison, Topeka & Santa Fe Railway, 33 miles to the east, is the nearest shipping point.........

"The bench land on the south side of Santa Maria River rises from 100 to 250 feet above the bottom lands. It is composed at the base of greenish and yellow shale, which may grade horizontally and vertically into red and reddish-brown sandstone, red clay, grit, and conglomerate. Above this series are white volcanic ash beds, a basalt flow, and then loose gravel and conglomerate beds to the top. At the top of the lower series a spring issues and a considerable stream of water flows in a waterfall fifteen feet high over the grit capping of the underlying clay beds. In the lower series the members show remarkable variations within short distances on their strike; in places the clay and shale beds grade into sandstone and arenaceous limestone. The formations strike in general northwest and dip about 10° SW.

"The manganese ore occurs at the top of the lower series, in the grit member and in the clay bed which underlies it. The grit member is from one to five feet thick and the clay bed about ten feet thick. The ore occurs for about 1,200 feet following the sinuosities of the outcrop of the grit.

"The ore replaces the cement of the sand or grit by psilomelane and occurs also in layers of pure psilomelane as much as six inches thick in the clay below the grit and in disseminated nodules and thin sheets in the clay beds. Where explored by a short tunnel near the waterfall, the clay beds contain these nodules and sheets through a distance of six feet. On the top and bottom surfaces of these flat tabular masses of ore are little ridges of psilomelane that probably represent little fissures or channels in the clay beds along which the manganese solutions flowed. Limonite also occurs in these clay beds in forms similar to the manganese oxides, but it is not mixed with the manganese oxides. How far back from the outcrop the ore extends is not known, as only two small tunnels each ten feet long have been driven in the clay bed. The source of the manganese has not been determined, but it is evident that the oxides were deposited from solutions percolating through the sandstone member into the underlying clay bed. These solutions replaced the sandstone in part, first attacking the cementing substance of the grains and then the quartz grains, but rarely was the replacement by manganese oxides complete.

"In the hard psilomelane are little nests of finely fibrous and prismatic crystals that are probably manganite.

"The grit that is partly replaced is much too siliceous to be smelted, but possibly a marketable product might be made by crushing and concentrating the material. The nodular and tabular ore masses in the clay are of good quality, and they contain about 45 percent of manganese. The quantity of ore that the deposit contains can not be estimated in advance of development, but there is probably 200 tons of float ore on the property."

PRACTICAL DEDUCTIONS

The foregoing descriptions give an idea of the known size, grade, and possible extent, together with mining, concentration, and transportation factors, etc. of the principal deposits of manganese ore in Arizona.

Obviously, the shape, grade, and probable size or extent of an ore body largely govern the cost of its mining, while the character and grade of ore are the main factors in costs of hand sorting or of beneficiation.

Trucking over average roads in Arizona is reported to cost from fifteen to twenty cents per ton mile. Freight rates existing in October, 1929, as shown on page 104, vary considerably but are lowest to Los Angeles.

If a large steel plant were established on the Pacific Coast, the demand for manganese ores in the Southwest should be apciably greater. According to press reports, the United States Steel Corporation has taken over the holdings of Columbia Steel in California, and plans to expand its steel production on the Pacific Coast.

Important advances in processes of beneficiation, particularly flotation of manganese ores have been made during the past years, and it seems highly probable that others will be developed. New uses, such as in agriculture, may stimulate local demand. Considering these factors, the lower grade manganese deposits of Arizona should, aside from any war needs, be of considerable economic importance at some future time. As to how distant this future will be, no one can foretell.

The American Manganese Producers Association, which was formed in 1927, has attempted to encourage research upon beneficiation and utilization problems, and has worked for higher tariff on manganese ores.

APPENDIX

FREIGHT RATES

The following freight rates per ton of 2,000 pounds of manganese ore, from certain Arizona points to places of consumption, existed in October, 1929, but are subject to change without notice.

From	Birmingham, Ala.	Chicago, Ill.	Los Angeles, Cal.	Pittsburg, Pa.	Pueblo, Colo.	New York, N. Y.	Cincinnati, Ohio	Denver, Colo.	Provo, Utah	Jersey City, N. J.
Globe, Arizona	$10.80	$10.80	$12.60	$12.60	$9.56½	$13.80	$12.60	$9.56½	$19.56	$13.80
Winkelman, Arizona	10.80	10.80	9.80	12.60	9.56½	13.80	12.60	9.56½	16.96	13.80
Duncan, Arizona	10.80	10.80	12.00	12.60	9.56½	13.80	12.60	9.56½	19.16	13.80
Bisbee, Arizona	9.10	10.80	8.40	12.60	9.56½	13.80	12.60	9.56½	16.16	13.80
Tombstone, Arizona	10.80	10.80	10.20	12.60	9.56½	13.80	12.60	9.56½	17.16	13.80
Nogales, Arizona	10.80	10.80	10.20	12.60	9.56½	13.80	12.60	9.56½	17.16	13.80
Yucca, Arizona	10.80	10.80	7.00	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80
Parker, Arizona	10.80	10.80	7.00	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80
Powell, Arizona	10.80	10.80	7.00	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80
Wenden, Arizona	10.80	10.80	7.80	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80
Congress, Arizona	10.80	10.80	8.00	12.60	9.56½	13.8	12.60	9.56½	14.96	13.80
Mayer, Arizona	10.80	10.80	7.00	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80
Winslow, Arizona	10.80	10.80	7.00	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80
Flagstaff, Arizona	10.80	10.80	7.00	12.60	9.56½	13.80	12.60	9.56½	14.76	13.80

GENERAL INDEX

MAPS OF ARIZONA

The Arizona Bureau of Mines now has available for distribution four different maps of the State, as follows:

1. Base map of Arizona in two sheets on a scale of about eight miles to the inch. This map is strictly geographic, with the positions of all towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, etc., indicated in black, and the location of mountains and other topographic features shown in brown. It also indicates where the various mining districts are situated, and is accompanied by a complete index. It was issued in 1919 and is sold, unmounted, for 35c, or mounted on cloth with rollers at top and bottom for $2.50.

2. A topographic map of Arizona in one sheet, on the same scale as the base map. It shows 100-meter contours, and there is a meter-foot conversion table on the map. It was issued in 1923, and is sold, unmounted, for 50c, or mounted on cloth with rollers at top and bottom for $2.50.

3. A geologic map of Arizona on the same scale as the base map, printed in many colors. It was issued in 1925, and is sold both mounted and unmounted for the same price as the topographic map.

4. A relief map of Arizona on the same scale as the base map, printed in various shades of brown, black, and blue. It was issued in 1925, and looks like a photograph of a relief model of the State. This map was prepared by the U. S. Geological Survey, and is sold by the Survey for $1.00. Unmounted copies may be obtained from the Arizona Bureau of Mines at the same price. The same map mounted on cloth with rollers at the top and bottom is sold by the Bureau for $3.00.

POSTAGE IS PREPAID ON ALL MAPS.

SERVICE OFFERED BY THE BUREAU

The Arizona Bureau of Mines will classify free of charge all rocks and minerals submitted to it, provided it can do so without making elaborate chemical tests. Assaying and analytical work is done at rates fixed by law, which may be secured on application.

The Bureau is always glad to answer to the best of its ability inquiries on mining, metallurgical, and geological subjects; and takes pride in the fact that its replies are always as complete and authoritative as it is possible to make them.

All communications should be addressed and remittances made payable to "The Arizona Bureau of Mines, University Station, Tucson, Arizona."