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Silver in Veins of Hypogene Manganese Oxides

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By D. F. Hewett

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ABSTRACT

During the First and Second World Wars, a great shortage of manganese ore in the United States led to an intensive search for deposits. One result of this search was the discovery in the Southwestern United States of numerous veins of high-grade manganese oxides whose mode of origin was the subject of much speculation. Studies of these veins during recent years indicate that the manganese in the oxide minerals was derived from great depth, that the explored veins were formed near the original surface, and that, if explored in depth, they might be succeeded by deposits of barite, fluorite, and sulfide minerals of zinc, lead, and copper that are generally mined for their content of silver and gold and that make up a group commonly known as epithermal.

Recent explorations of a manganese-bearing vein of barite in Nova Scotia fortify these speculations. In order to test this speculation, it will be necessary to drill holes that would cut the vein-zones 500 to 1,000 feet below the present level of explorations.

INTRODUCTION

Since the theory announced by Lindgren about 60 years ago, it is now widely believed that ore deposits with hydrothermal affiliations may be classified into five zonal groups: (1) epithermal deposits formed within the temperature range of 50° to 200°C at moderate pressures, (2) mesothermal deposits formed within the temperature range of 200° to 300°C at high pressure, (3) hypothermal deposits formed within the temperature range 300° to 500°C at very high pressure, (4) pyrometasomatic deposits formed within the temperature range 500° to 800°C at very high pressure, and (5) magmatic deposits proper formed within the temperature range 700° to 1,500°C at very high pressures. Other geologists have recognized several other groups such as leptothermal, telethermal, and xenothermal. Recent work has indicated modifications of the temperatures and pressures stated by Lindgren for some of the groups, but the concepts presented here would not be materially affected.

As one result of recent studies of hydrothermal deposits that contain manganese minerals, it seems possible to recognize five mineral groups (Hewett, 1964). Of these, the deepest has been called the base-metal group (Burbank, 1933), to which many veins in the San Juan Mountains, Colo., and elsewhere in the Southwest are assigned. The mined shoots of ore con-

tain 10 to 35 percent of base-metal sulfides and noteworthy amounts of silver and gold. Characteristic gangue minerals include quartz, barite, fluorite, rhodonite, rhodochrosite, and huebnerite. The next higher group, precious metal (gold-silver) (Nolan, 1933), is characterized by the same assemblage of base-metal sulfides, but these occur in lesser amounts than in the base-metal group. This group also contains the same assortment of gangue minerals, but chalcedony is the abundant form of silica, and rhodochrosite is more abundant than rhodonite.

Overlying these two groups are two other groups with abundant fluorite and barite whose limits are only rarely sharp and distinct. Of the veins with abundant fluorite, only a few wholly lack barite, and other veins exploited for barite rarely lack some fluorite. Some veins explored for either fluorite or barite have local shoots of base-metal sulfide minerals large enough to warrant mining. Rhodochrosite is rare in these veins, but some contain veins of black calcite, which is calcite containing several percent of dispersed black manganese oxides. Some of these black calcites contain noteworthy amounts of silver (Hewett, Fleischer, and Conklin, 1963; Hewett, 1964).

In the United States, most of the explored epithermal veins contain the mineral assemblages characteristic of one of the five groups; a few show the mineral characteristics of two groups, and only a few are known that show elements of three groups. It is obviously a speculative venture to explore any vein to depths as great as several thousand feet in order to determine whether it contains three or more of the mineral groups.

HYPOGENE VEINS OF MANGANESE OXIDES IN THE SOUTHWESTERN UNITED STATES

Recent work on numerous veins of manganese oxide minerals in the Southwestern States indicates that they may be regarded as having formed near the original surface in the epithermal environment (Hewett, 1964). Several mineral associations as well as chemical composition indicate an affiliation with the veins of fluorite and barite. The most abundant manganese oxide

minerals are the barium manganates, psilomelane and hollandite, but small amounts of barite and fluorite are also present in many of the veins. The common form of silica is chalcedony, and the wallrocks show alteration to adularia, which is also common in the deeper sulfide mineral zones. Spectrographic analyses of more than 125 samples from many veins show that the manganese oxide minerals commonly contain noteworthy zinc, copper, and especially lead; tungsten and arsenic are also commonly present in amounts that range as high as 1.5 percent. Table 1 shows spectrographic analyses of seven samples from four veins in New Mexico and California.

The available record at four localities—Manganese Valley, Luna, and Black Canyon mines, New Mexico, and Terrenates, Chihuahua, Mexico—shows that veins containing shoots of manganese oxide minerals, ranging in manganese content from 20 to 30 percent near the surface, become progressively smaller and lower in grade at 450 to 500 feet below the existing surface. Recently, at the Tower mine, near Socorro, N. Mex., a drill hole 1,425 feet long cut the vein zone

1,000 feet below the surface. At the surface the vein contained only abundant manganese oxides with some fluorite and barite, but 1,000 feet lower it contained only fragments of rhodochrosite in a wide zone in which the country rock was altered to chalcedony, clay, and adularia. Sparse barite veinlets were found from place to place through the entire length of the drill hole. The minerals in the vein indicate that it may be regarded as representing the precious-metal group.

None of the manganese-bearing veins in the Southwestern United States has been explored more than a few hundred feet below the outcrop; the deepest exploration, at the Luna mine in the Little Florida Mountains of southwestern New Mexico, is only 510 feet; but a drill hole, at the previously mentioned Tower mine, reaches a depth of 1,000 feet. Thus, in this region the possibility that such veins may be succeeded downward by one or more of the mineral groups discussed above has not been adequately tested. Such a test has, however, been made recently in Nova Scotia, and the results are believed to be significant enough to warrant careful attention.

Table 1.--Spectrographic analyses of hypogene manganese oxides, in percent, from New Mexico and California [M indicates major constituent]

Mine-----	New Mexico			California			Tolbard
	Tower		Manganese Valley	Black Jack			
Field No.	-----	-----	207	297	298	-----	-----
Lab.No.--	63M-24	63M-25	64M-2006	M103811	M103812	280288	271064
Mineral--	Psilomelane	Coronadite	Pyrolusite	Psilomelane	Pyrolusite	Psilomelane	Psilomelane
Collector	Hewett	Hewett	Unknown	Hewett	Hewett	Hewett	Hadley
Si-----	0.07	0.1	0.5	0.1	0.5	---	---
Al-----	.5	.5	.15	.05	.3	.15	-1
Fe-----	.03	.03	.03	.003	.07	.07	.015
Mg-----	.02	.005	.02	.01	.03	.07	.03
Ca-----	.2	.07	.1	.7	.3	.3	.3
Na-----	.1	.03	.02	.1	.07	---	---
K-----	.7	0	0	0	0	0	0
Ti-----	.01	.007	.007	0	.005	.007	0
Mn-----	M	M	M	M	M	M	M
Ag-----	.0002	0	0	0	0	0	0
As-----	.5	.7	0	.7	.7	.3	0
Ba-----	15.0	7.0	.7	M(20.)	7.0	7.0	M
Be-----	.0015	.003	.003	0	.001	0	.003
Co-----	.03	.01	.0015	.001	.001	.005	.0015
Cr-----	.003	.007	.0007	0	0	.0007	.0007
Cu-----	.07	.02	.07	.02	.07	.02	.007
Ga-----	.007	.005	.001	0	0	0	0
Ge-----	0	0	---	0	0	0	.015
Mo-----	.07	.03	.05	.15	.07	.15	.003
Nb-----	.003	.003	.003	0	0	0	.003
Ni-----	.003	.003	.02	0	.0007	0	0
Pb-----	3.0	15.0	0	0	.03	.007	-.01
Sb-----	.2	.3	0	0	0	0	0
Sc-----	.0015	.002	.001	0	0	0	---
Sr-----	.7	.15	.1	.7	.3	1.50	.7
Tl-----	.2	.1	.05	.015	.02	.03	0
V-----	.03	.02	.01	.003	.003	.007	.07
W-----	.05	.15	0	.03	.15	0	.3
Y-----	.002	.002	.007	0	0	0	0
Yb-----	.0003	.0002	.0005	0	0	0	0
Zn-----	.7	.7	.05	0	.07	0	0
Zr-----	.0007	.0005	0	0	0	0	0

RECENT DEVELOPMENT OF MANGANESE DEPOSITS IN NOVA SCOTIA AND NEW BRUNSWICK

Manganese deposits have been known and explored in Nova Scotia since 1865 (Hanson, 1932; Johnston and McCartney, 1965). The most productive epoch extended from 1870 to 1890, but since then periods of activity have been only intermittent and brief until recent years. The greatest production of ore from one deposit (23,000 tons) was derived from that at Markhamville, New Brunswick, between 1868 and 1891, but the most extensive and deepest workings are at the New Ross mine, Lunenburg County, Nova Scotia; here one shaft is 265 feet deep and another 196 feet deep (Kramm, 1912; Fearing, 1923; Weeks, 1945). Numerous deposits have been explored in a belt along the northwest coast, adjacent to the Bay of Fundy. Since 1941 there has been a spectacular record of development at the Magnet Cove mine near Walton in this belt.

According to Boyle (1963), in the Walton-Cheverie map area (about 9 by 12 miles), 14 manganese-bearing deposits have been recorded, as well as others in the adjoining area northeast as far as Tennycape. From this area, there had been modest development and production during the period 1875-1900. In 1941 an outcropping body of manganese-bearing barite attracted attention, and later development revealed at

the Magnet Cove mine the most productive barite deposit known in Canada; to 1960, about 2,700,000 tons of barite had been shipped. About 1956, when the barite deposit had been developed by an opencut to a depth of about 300 feet and by underground workings to about 600 feet, a program of diamond drilling was begun. Soon thereafter, drilling revealed a lenticular body of silver-bearing sulfide minerals underlying the vein of barite. Recently, this and other similar bodies of sulfide minerals, as well as the barite body, have been developed to a vertical depth of 1,200 feet below the surface. Later exploration on the vein of sulfide minerals showed that it extended upward but pinched out about 250 feet below the surface.

In addition to the study of the mine and the local area, a detailed study of minerals present in the sulfide assemblage has been made by Boyle and Jambor (1966). The ore contains at least 10 sulfide minerals of base metals and silver which are considered to have been deposited by low-temperature solutions (epithermal?). Curiously, unless some manganese is present in the siderite, no manganese minerals have been observed in the sulfide body. Specimens from the upper part of the barite body now exposed in the opencut submitted to the writer show hausmannite in process of replacement by pyrolusite. Information available to this writer concerning the minerals at the Magnet Cove deposit

Table 2.--Spectrographic analyses of manganese oxides, in percent, from the Maritime Provinces of Canada [M indicates major constituent]

Mine-----	Stephens		Macumber		New Ross				Markhamville	
	1	2	1	2	291	293	295	296	285	294
Field No.	286	287	288	289	291	293	295	296	285	294
Lab. No.--	M103778	M103779	M103780	M103781	M103783	M103784	M103809	M103810		M103808
Mineral--	Manganite	Manganite	Manganite	Manganite	Pyrolusite	Manganite	Manganite	Manganite	Manganite	Braunite
Collector	Boyle	Boyle	Boyle	Boyle	Eakins	Eakins	Nowlan	Nowlan	U.S. Museum	Eakins
Si-----	0.15	0.1	0.1	0.15	0.05	0.07	0.2	0.15	0.1	2.0
Al-----	.5	.15	.5	.5	.15	.15	.3	.15	.2	.3
Fe-----	.15	.1	.02	.1	.01	.2	.15	.05	.007	.2
Mg-----	.015	.01	.01	.02	.007	.02	.03	.03	.007	.02
Ca-----	.3	.3	.07	.7	.15	.05	.15	.05	.5	2.0
Na-----	0	0	0	0	.2	0	0	0	0	0
K-----	0	0	0	0	1.5	0	0	0	0	0
Ti-----	.02	.003	.002	<.001	0	0	.005	<.001	0	.007
Mn-----	M	M	M	M	M	M	M	M	M	M
Ag-----	0	0	0	0	0	0	0	0	.0007	0
B-----	0	0	0	0	0	0	0	0	.1	.03
Ba-----	.03	1.5	.2	.2	3.0	.05	.02	.015	.1	.03
Be-----	.0007	.0015	.001	.001	.005	.007	.007	.005	0	.0003
Bi-----	0	0	0	0	0	.001	0	0	0	0
Co-----	.02	.015	.015	.03	0	0	0	0	.007	.02
Cr-----	.005	.002	.002	.001	.0002	.0007	.0007	.0005	0	.001
Cu-----	.07	.07	.07	.05	.05	.15	.15	.15	.1	.1
Mo-----	.003	.01	.002	.005	.003	.002	.003	.003	.01	.0015
Ni-----	.015	.015	.01	.015	0	.001	.0007	.001	.002	.0007
Pb-----	0	0	0	0	1.0	.03	.03	.03	.05	.07
Sr-----	.005	.05	.01	.01	.5	.01	.01	.007	.007	.002
Tl-----	.007	.007	.01	.007	.15	.007	.01	.01	.015	.005
V-----	.005	.015	.005	.007	.01	.003	.005	.005	.03	.01
W-----	0	0	0	0	.007	0	.005	.003	0	0
Y-----	0	0	0	0	.003	.003	.005	.003	0	0
Yb-----	0	0	0	0	.0002	.0001	.00015	.0001	0	0
Zn-----	.1	.07	.1	.15	0	.03	.02	.03	.03	.7
Zr-----	0	.001	0	0	0	0	0	0	0	0

indicates that hausmannite and probably some of the pyrolusite are hypogene; some pyrolusite may be supergene.

The Magnet Cove deposit reveals characteristic minerals of three groups that are considered to belong to the epithermal zone (Hewett, 1964). The hausmannite and pyrolusite represent the uppermost group; the barite, the next group downward; and the shoot of silver-bearing sulfide minerals represents the precious-metal (gold-silver) group defined by Nolan (1933). The fluorite group, which might be expected to lie between the barite and precious-metal groups, is not reported.

Through the kindness of R. W. Boyle of the Geological Survey of Canada, Don LeHeup of the Magnet Cove Barium Co., and J. P. Nowlan of the Department of Mines of Nova Scotia, the writer has been able to examine specimens of the minerals from the Macumber, Magnet Cove, Stephens, and New Ross mines in Nova Scotia, and the Markhamville mine in New Brunswick (Sidwell, 1952). In table 2, there appear spectrographic analyses of manganese oxides from 10 of these specimens. In these specimens, manganite is the most widely dispersed and abundant mineral; hausmannite is common in the Magnet Cove deposit; braunite and manganite are present in the Markhamville deposit. To the writer, familiar with the modes of occurrence of these

minerals in the United States and Cuba, the manganite, hausmannite, and braunite in the specimens from Nova Scotia and New Brunswick are definitely hypogene; the pyrolusite is in part hypogene and in part supergene (Smitheringale, 1929).

COMPARISON OF THE VEINS OF THE MARITIME PROVINCES OF CANADA WITH THOSE OF THE SOUTHWESTERN UNITED STATES

The deposits in the Southwestern States resemble those in the Maritime Provinces in Canada, but there are some differences. The manganese minerals in both regions are oxides, but abundant species in the ores from Nova Scotia are absent in the veins in the Southwestern United States. The characteristic oxides in the Maritime Provinces include manganite, hausmannite, and braunite, with some pyrolusite; in the Southwestern States, the most widespread and abundant oxides are psilomelane, hollandite, and cryptomelane, with some pyrolusite and coronadite. Barite is a persistent gangue mineral in both regions but is apparently more abundant in the Canadian districts than in the United States. Quartz is present in some Canadian deposits, whereas chalcedony, which is widespread in the United States, is not recorded. In Canada, most of the deposits are

Table 3.--Spectrographic analyses of hollandite specimens, in percent, from the Black Canyon (Gianera) shaft, Luis Lopez district, New Mexico [M indicates major constituent]

Veins-----	210	211	212	213	262	263	264	265	266	267
Depth (ft)----	Surface	150	250	400	150	250	300	350	400	450
Collector-----	Radtke	Radtke	Radtke	Radtke	Bluege	Bluege	Bluege	Bluege	Bluege	Bluege
Si-----	0.7	0.2	0.15	0.15	0.1	0.05	0.1	0.07	0.05	0.15
Al-----	.7	.3	.15	.2	.5	.5	.2	.3	.2	.3
Fe-----	.1	.015	.005	.007	.015	.003	.003	.005	.003	.03
Mg-----	.02	.02	.01	.015	.01	.005	.007	.007	.01	.015
Ca-----	.3	.1	.15	.15	.2	.1	.15	.15	.1	.2
Na-----	.02	.15	.07	.07	.15	.07	.15	.1	.1	.07
K-----	0	1.0	1.0	.7	1.0	.7	.7	1.0	1.0	.5
Ti-----	.01	.0005	.0005	.0003	.0007	.003	.0005	.0007	.0003	.005
Mn-----	M	M	M	M	M	M	M	M	M	M
As-----	.15	.15	.3	.3	.5	.5	.3	.3	.2	.5
Ba-----	M	M	M	M	M	M	M	M	M	M
Be-----	.0015	.001	.002	.003	.002	.001	.0015	.0015	.001	.005
Co-----	.01	.02	.01	.03	.015	.015	.007	.02	.015	.03
Cr-----	.01	.002	.003	.01	.002	.002	.001	.002	.005	.015
Cu-----	.02	.03	.03	.1	.03	.1	.05	.1	.07	.15
Ga-----	.0015	.0015	.0015	.0015	---	---	---	---	---	---
Ge-----	0	0	0	0	.002	.003	.003	.003	.003	.003
Mo-----	.02	.05	.05	.07	.02	.1	.05	.07	.07	.07
Nb-----	.003	.002	.002	.003	.0015	.0015	.0015	.0015	.0015	.0015
Ni-----	.0015	.003	.002	.007	.003	.002	.003	.005	.003	.007
Pb-----	2.0	0	.2	2.0	.7	1.5	1.5	.3	.15	2.0
Sb-----	.2	.15	.15	.1	.15	.15	.15	.1	.07	.15
Sc-----	.0015	.007	.0005	.0007	.001	.002	.001	.0015	.001	.0015
Sr-----	.2	.5	.5	.5	.5	.15	.2	.3	.2	.3
Tl-----	.15	.2	.3	.5	.1	.03	.1	.15	.2	.05
V-----	.07	.1	.05	.2	.05	.2	.07	.2	.3	.15
W-----	.2	.07	.03	.15	.15	.15	.15	.1	.07	.2
Y-----	0	0	0	0	0	0	0	0	0	.002
Yb-----	.00015	.00015	.0001	.0003	0	0	0	0	0	.0002
Zn-----	.15	.3	.5	.7	.2	.15	.2	.1	.15	.5

in Paleozoic carbonate host rocks, but one important deposit (New Ross) is in granite. In the United States, most of the veins are in layered volcanic rocks that are widely altered to adularia, but some are in Precambrian crystalline rocks.

Minor elements in the manganese oxides of the two regions show similarities as well as some distinct differences (tables 1, 2, and 3). Noteworthy amounts of lead, arsenic, copper, and tungsten are persistently present in the manganese oxides in the veins of the Southwest: lead, 0.5 to 4 percent; arsenic, 0.2 to 1.5 percent; copper, 0.1 to 0.5 percent; and tungsten, 0.1 to 1.5 percent (Hewett, 1964). In the Canadian manganese oxides, zinc and copper are persistently low, rarely in excess of 0.15 percent; small amounts of tungsten are sporadic, and arsenic has not been found. Small amounts of thallium, generally 0.01 to 0.1 percent, are persistently present in the manganese oxides of both regions. Alteration of the host rocks to adularia is common in the United States but is not recorded in Canada.

Most of those who have studied the Canadian deposits have concluded that the manganese oxide vein minerals are supergene, whereas those who have studied the vein deposits in the United States in recent years conclude that most of the oxides are hypogene.

AREAS IN THE UNITED STATES ATTRACTIVE FOR EXPLORATION

As the result of widespread search for manganese deposits during the two World Wars, many veins of manganese oxides were found in the Southwestern United States. Most of the explored deposits lie in a broad arc that extends from southern Colorado and southwestern New Mexico across southern Arizona into southeastern California. Only a few are known in Utah and Nevada, and only one is known in Oregon. About 250 veins are known in the Southwest; the location of the principal districts is shown in figure 1.

There follow brief descriptions of five veins in three districts in New Mexico and California and a description of a fourth district in Arizona that are worthy of attention as sites for exploration in depth to test the vertical distribution of the mineral groups considered to belong to the epithermal zone.

Little Florida Mountains, Luna County, New Mexico

Within an area of about 1 square mile at the south end of the Little Florida Mountains, Luna County, N. Mex., there are the deepest shaft on a vein of manganese oxides (Luna mine, 510 ft) and the greatest explored length of a vein (Manganese Valley, about 2,700 ft) in the entire Southwest. The production of crude ore and concentrate shipped is 32,704 long tons, exceeded only by the Black Jack mine in the McCoy Mountains, Calif., (about 71,000 tons). Within the area of the Little Florida Mountains, numerous other veins have been less extensively explored—Manganese Valley No. 13 and Killion, for example.

The mines were first examined by the writer in 1924 and were reexamined several times in the following

6 years. In 1938 Lasky and Thayer mapped the geology of the Little Florida district and examined the mines (Lasky, 1940); in 1941-42 the U.S. Bureau of Mines drilled 13 holes below the existing workings (Evans, 1949) and thoroughly sampled the accessible workings. About 1960, in connection with a review of the manganese deposits of the State, the workings were reexamined (Farnham, 1961). As part of a review of veins of manganese oxides in the Southwest, the writer has recently made spectrographic and X-ray-diffraction analyses of several specimens.

The Little Florida Mountains are carved from a block of layered fragmental volcanic rocks separable into two units; the lower unit is interbedded flows, tuffs, and breccias about 3,000 feet thick; and the upper, also layered fragmental volcanic rock about 1,000 feet thick, is considered a fanglomerate. Both are well indurated; the layering dips eastward at a low angle. The veins form an echeloned system that lies along the eastern slope of the Little Florida Mountains. As regional geologic mapping shows that there are only slight changes in the rocks for several thousand feet below the mine workings, the veins should persist downward at least that distance. The manganese minerals consist of several oxides in veins that have a strike length of 500 to 3,000 feet; underground workings prove that several extend more than 500 feet below the local surface (Manganese Valley, Luna).

Manganese Valley mine.—The stopes and sampling records of the Manganese Valley mine workings indicate that the manganese oxides are concentrated in at least three distinct shoots (Evans, 1949), the greatest lengths of which were found in the upper levels; also that the lengths as well as percent of contained manganese minerals in the veins decrease downward. Of the 13 drill holes, only one attained a depth of as much as 200 feet below the existing stopes (middle shoot). On the lower level, 19 samples in a distance of 100 feet showed the vein to have an average width of 5 feet and a manganese content of 25 percent; 240 feet lower the vein zone was 13 feet wide but contained only about 1.5 percent manganese as oxide.

The oxides from the Manganese Valley vein (No. 12) have not been thoroughly analyzed for minor elements. Mill concentrate of the oxides mined in 1924 from the northern shoot, upper level, contained 75 to 77 percent manganese oxide, 0.468 to 0.558 percent lead, 0.068 to 0.077 percent copper, and 0.028 to 0.032 percent arsenic. One spectrographic analysis of a specimen from the lower level of the middle shoot appears in table 1.

Luna mine.—About 2,500 feet northwest of the Manganese Valley mine, the Luna vein, trending northwest, crops out for 2,500 feet and is explored by a shaft to a depth of 510 feet; it is also explored by drifts at five levels whose aggregate length is about 1,700 feet. There is one major shoot of manganese oxides; the greatest horizontal length, about 200 feet, is on the upper three levels, whereas the proved length on the lower two levels is less than 100 feet and the manganese content is uniformly less than 5 percent. About 1941-42, the U.S. Bureau of Mines thoroughly sampled the vein zone

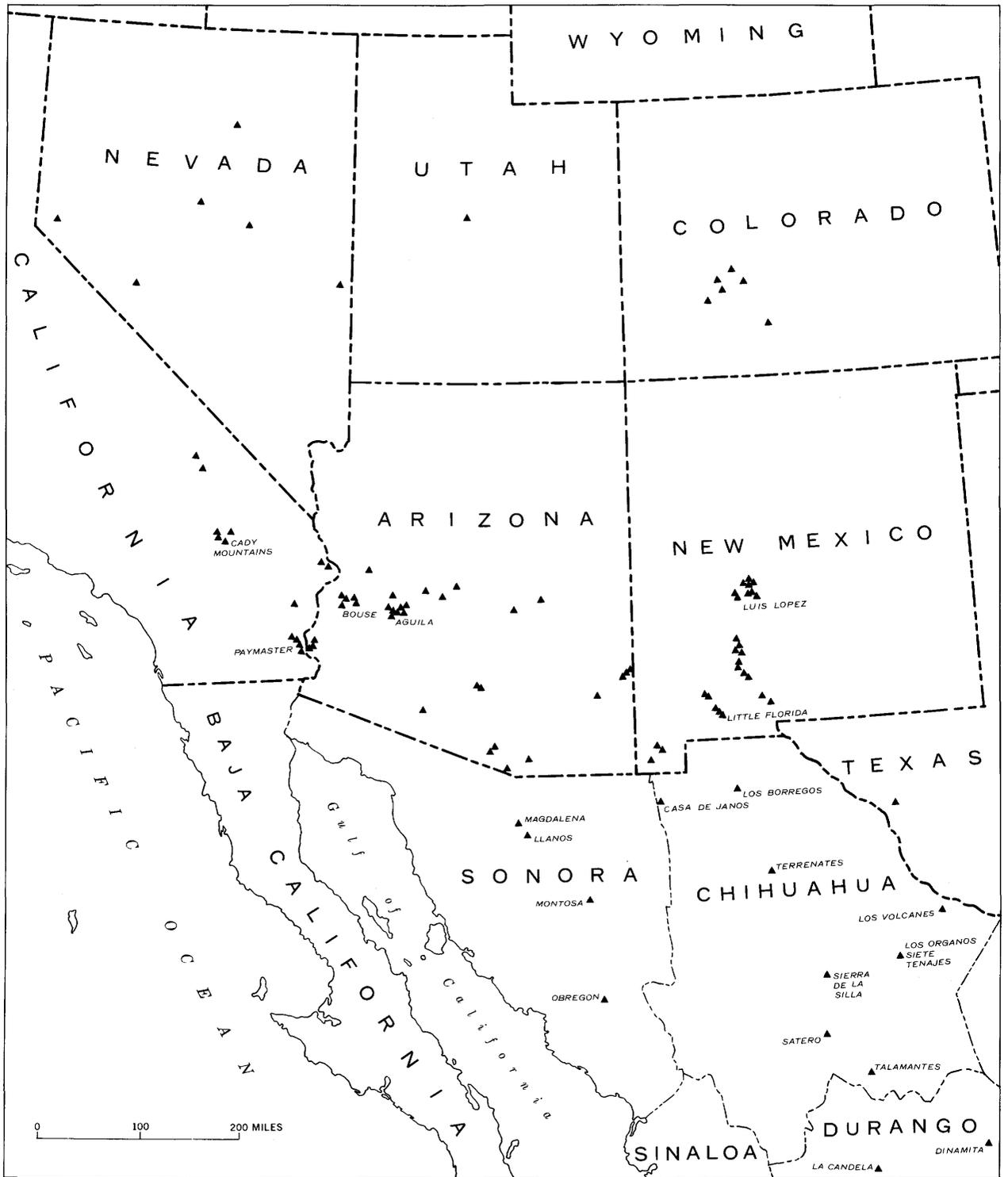


Figure 1.—Map showing distribution of explored veins of hypogene oxides of manganese in the Southwestern United States and northern Mexico.

to the lowest level of the shaft, 500 feet, and drilled four holes, of which the deepest, 540 feet, cut the vein zone (Evans, 1949). Near the bottom, one hole cut veinlets of manganese oxides over a distance of 33 feet; the central part of the zone, 18 feet thick, contained 5 to 7 percent of manganese as oxides. As the vein on the second level largely ranged from 3 to 6 feet in width and, sampled over a distance of about 275 feet, contained 10 to 35 percent manganese, it is clear that the manganese content decreased considerably in the explored depth of 500 feet. No samples of manganese oxides from the Luna vein have been examined by X-ray diffraction or spectrographic analysis; so the minerals and content of minor elements have not been determined. Chemical analyses of a specimen of oxides from the Killion vein, halfway between the Luna shaft and the Manganese Valley adit, appear in Hewett and Fleischer, table 6 (1960) and Hewett, Fleischer, and Conklin, table 3 (1963).

Luis Lopez district, Socorro County, New Mexico

More manganese oxide veins have been explored and the production of high-grade oxides has been greater in the Luis Lopez district, Socorro County, N. Mex., than in any other in the Southwest. Most of the explored veins lie within an area about 15 miles in diameter, 5 to 10 miles southwest of Socorro. The production of high-grade concentrate to 1957 was about 77,000 tons, of which about 26,295 tons was derived from the Red Hill group, 10,613 tons from the Tower (Lucky Strike No. 2), and 16,060 tons from the Black Canyon (Gianera); the remainder was derived from numerous other mines (Jicha, 1956; Miesch, 1956; Farnham, 1961).

Tower (Lucky Strike No. 2) mine.—At this mine an opencut 1,600 feet long and about 30 to 40 feet wide explores a zone of oxide veins to a depth that ranges from 80 to about 150 feet. As this is one of the most persistent veins known in New Mexico, the vein and its minerals have been closely studied by the writer.

Here and at most of the other productive veins of this district, the host rock is rhyolite, but near the veins the feldspars are widely altered to adularia. At this mine, most of the veins of manganese oxide minerals are confined to zones 5 feet or more thick adjacent to the walls. The veins are made up of layers of manganese oxides as much as several inches thick that cement angular fragments of altered host rock; probably psilomelane is the most abundant oxide, but hollandite and coronadite are persistently present. Coronadite is so abundant that most shipments of concentrate contained 2 to 4 percent lead. Two spectrographic analyses are shown in table 1. Among the non-metallic minerals, crystals of fluorite are present in the early and late layers of manganese oxides, and small amounts of barite and chalcedony are present.

At the Optimo prospect, 2,000 feet north of the Tower opencut, the principal mineral in the vein (4 ft wide) is coronadite.

Black Canyon (Gianera) mine.—At the Black Canyon mine, about 1,500 feet southwest of the Tower mine, the shaft explores to a depth of 450 feet a vein that is parallel to that at the Tower mine; there are drifts on the vein at six levels. Unlike the Tower vein zone, manganese oxides form crusts several inches thick on fractures in the vein zone several feet wide. On the levels, the shoot is only 200 feet long, but minable ore persists to the lowest level.

Table 3 presents spectrographic analyses of two suites of samples collected from the surface downward on the separate levels to the bottom of the shaft. The analyses of the suite of four samples indicate an almost regular increase downward of the contents of copper, lead, zinc, molybdenum, arsenic, and thallium. Analyses of the second suite of six samples show less consistent trends.

Arlington district, Riverside County, California

In the northwest part of the McCoy Mountains, eastern Riverside County, Calif., several groups of veins of manganese oxides have been extensively explored (Trask, 1950). The Black Jack group, not named in figure 1 but lying about 25 miles north of the Paymaster district, shipped ore as early as 1916, but the greatest development took place after the war of 1941-45, and there was further exploration under a loan from the Government in 1958. The total length of underground tunnels and drifts exceeds 6,000 feet, and more than 70,000 tons of ore has been shipped to date. The early work explored one vein for about 600 feet, but later work discovered several other parallel veins; they trend generally north and dip about 55°W. The greatest depth of workings below the surface is about 250 feet. The most abundant manganese oxide is psilomelane, but there is some pyrolusite; three spectrographic analyses appear in table 1. The contents of copper, lead, and zinc are less than 0.10 percent, but arsenic is as much as 0.7 percent and tungsten as much as 0.15 percent.

The principal vein crops out along the ridge which forms the north end of the McCoy Mountains; west of this ridge, there is a small valley from which holes could readily be drilled to explore the veins in depth. Probably a drill hole could be drilled west of the vein that would cut the main vein 500 feet below the main level within a distance of 800 feet.

Aguila district, Maricopa County, Arizona

The Aguila district includes an area about 15 miles long and 4 miles wide in west-central Arizona. The first discoveries were made during the first World War when six properties were explored and about 4,000 tons of ore was shipped. During the second World War, there was little activity, but by 1958 the total number of explored deposits was about 25, and considerable

low-grade ore had been shipped. During the postwar period, the greatest production came from the open-cut of the Black Rock mine. Most of the explored deposits are simple veins of manganese oxides, and the latest record indicates that no explorations exceeded 100 feet in depth.

During a brief examination of the district in 1963, F. S. Simons, of the Geological Survey, collected numerous samples of the vein oxides, and spectrographic analyses have been made of 17 samples of the crude oxides and three samples of the manganese oxide residues (insoluble in dilute HCl) from associated black calcites. Measurable amounts of copper are present in every sample of crude oxides, largely ranging from 0.05 to 2 percent and in excess of 0.15 percent in five samples. Measurable amounts of lead are present in every sample and more than 0.2 percent in three samples; measurable zinc is present in every sample and in excess of 0.1 percent in seven samples. Measurable tungsten is present in 16 samples, attaining 1.5 percent in one sample and in excess of 0.1 percent in seven samples. Measurable thallium is present in every sample, and more than 0.1 percent in six samples. Small fractions of an ounce of silver to the ton are present in two samples, but 1.5 ounces to the ton is present in the residues from two samples of black calcite.

For several reasons, it is concluded that the veins of manganese oxide in this district are hypogene (Hewett and Fleischer, 1960; Hewett, Fleischer, and Conklin, 1963; Hewett, 1964).

From the samples collected by Simons, 13 were selected for assay for silver. A black calcite sample from the Hatton mine, Yavapai County, contained about 5 percent dispersed manganese oxide and contained 0.10 ounce of silver to the ton. Of the other samples, eight showed traces of silver and four showed no silver.

CONCLUSIONS

In the modern era, with the increasing need for numerous minerals, many types of inquiry are being used in the search for new sources. In a broad way, the greater the number of types of data, the greater the chances of success in discovery. Unfortunately, however, even after exhaustive study of areas by all the methods available, the element of luck still plays a great part in discovery.

The theory of downward changes in epithermal deposits is based largely upon the kind, abundance, and paragenetic relations of the minerals, the chemical elements present in the minerals and their abundance, and the nature of the alterations of the wallrocks.

The theory seems to be fortified by the recent explorations at the Magnet Cove mine, Nova Scotia. These explorations to the depth of 1,200 feet reveal three of the five groups of the epithermal zone, but one group, that with abundant fluorite, present in the Southwestern United States, is missing in the Magnet Cove mine.

In the Southwestern United States in the vein deposits which have been explored to the greatest depths (Manganese Valley, 500 ft; Luna, 510 ft; Black Canyon, 450 ft), the oxides lie in well-defined shoots, which are 200 to 500 feet long on the upper levels but narrower in the lowest levels. Explorations in depth should be so placed as to cut the downward extensions of the known shoots, not less than 500 feet and probably as much as 1,000 feet below the lowest explorations. There is general agreement that the deposits of the epithermal zone were formed at depths of from 3,000 to 5,000 feet below the original surfaces; so the upper parts of the precious-metal group would probably lie 1,000 to 2,000 feet below those original surfaces.

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