

UNITED STATES DEPARTMENT OF THE INTERIOR

Harold L. Ickes, Secretary

GEOLOGICAL SURVEY

W. E. Wrather, Director

Bulletin 936-R

**MANGANESE DEPOSITS IN THE
ARTILLERY MOUNTAINS REGION
MOHAVE COUNTY, ARIZONA**

BY

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**Strategic Minerals Investigations, 1942
(Pages 417-448)**



**UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1944**

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MANGANESE DEPOSITS IN THE ARTILLERY MOUNTAINS REGION, MOHAVE COUNTY, ARIZONA

By S. G. Lasky and B. N. Webber

ABSTRACT

The manganese deposits of the Artillery Mountains region lie within an area of about 25 square miles between the Artillery and Rawhide Mountains, on the west side of the Bill Williams River in west-central Arizona. The richest croppings are on the northeast side of this area, among the foothills of the Artillery Mountains. They are 6 to 10 miles from Alamo. The nearest shipping points are Congress, about 50 miles to the east, and Aguila, about 50 miles to the southeast.

The principal manganese deposits are part of a sequence of alluvial fan and plays material, probably of early Pliocene age, which were laid down in a fault basin. They are overlain by later Pliocene (?) basalt flows and sediments and by Quaternary basalt and alluvium. The Pliocene (?) rocks are folded into a shallow composite syncline that occupies the valley between the Artillery and Rawhide Mountains, and the folded rocks along either side of the valley, together with the overlying Quaternary basalt, are broken by faults that have produced a group of horsts, grabens, and step-fault blocks.

The mangiferous beds lie at two zones, 750 to 1,000 feet apart stratigraphically, each of which is locally as much as 300 to 400 feet thick. The main, or upper, zone contains three kinds of ore—sandstone ore, clay ore, and "hard" ore. The sandstone and clay ores differ from the associated barren sandstone and clay, with which they are interlayered and into which they grade, primarily in containing a variable proportion of amorphous manganese oxides, besides iron oxides and clayey material such as are present in the barren beds. The "hard" ore is sandstone ore that has been impregnated with opal and calcite and in which the original amorphous manganese oxides have been largely converted to psilomelane and manganite. The average manganese content of the sandstone and clay ores is between 3 and 4 percent and that of the "hard" ore is between 6 and 7 percent. The ore contains an average of 3 percent of iron, 0.08 percent of phosphorus, 1.1 percent of barium, and minute quantities of copper, lead, and zinc. Although the manganese content of the sandstone and clay ore may change abruptly from bed to bed, the content within any individual bed changes gradually, and for any large volume of ore both the manganese and iron content are remarkably uniform.

Explorations to June 1941 consisted chiefly of 43 holes diamond-drilled in the upper zone on the Artillery Mountains side of the area.

The district is estimated to contain an assured minimum of 200,000,000 tons of material having an average manganese content of 3 to 4 percent. About 20,000,000 tons of this total contains 5 percent or more of manganese, and 2,000,000 to 3,000,000 tons contains 10 percent or more. To what extent these deposits can be utilized is a metallurgical and economic problem. Although the clay and sandstone ores, as well as the "hard" ore, are present in large tonnages, the "hard" ore is the only kind that combines minable tonnage with promising grade. About 15,000,000 tons of "hard" ore is present; about 500,000 tons of this contains 15 percent or more of manganese and averages 17 percent, and somewhat over 2,000,000 tons contains 10 percent or more and averages nearly 13 percent.

Except for closer drilling to determine such things as the tonnage, grade, spacing, and form of the richer shoots with greater accuracy before beginning to mine them, further explorations are not recommended, for any new ore found is likely to be similar, both in grade and kind, to that already discovered.

INTRODUCTION

Since 1929, investigations of manganiferous sediments in the Artillery Mountains in western Arizona have proved the presence of very large low-grade reserves. Private engineers are quoted^{1/} as having estimated that there is about 14,000,000 tons containing an average of 13 percent of manganese in one block alone; other private engineers have estimated that the main part of the district contains over 60,000,000 tons of somewhat lower grade. The Bureau of Mines, United States Department of the Interior, tested some of the ore in 1934, and although they reported^{2/} that its concentration by present methods of ore-dressing appeared hopeless, they listed^{3/} the deposit as the second largest of the low-grade manganese deposits in the United States that might prove amenable to some form of hydrometallurgical treatment.

In the Spring of 1938, S. G. Lasky and R. J. Roberts of the Geological Survey, United States Department of the Interior, made a geologic survey of the area and also sampled the deposits

^{1/} Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 81, 1936.

^{2/} Dean, R. S., and others: Manganese: Its occurrence, milling, and metallurgy, pt. 1: U. S. Bur. Mines Inf. Circ. 6768, pp. 39-41, 1934.

^{3/} Idem, pt. 3: U. S. Bur. Mines Inf. Circ. 6770, pp. 168-169, 1934.

for an independent appraisal of reserves. The opportunity was particularly timely, because at that time the M. A. Hanna Co., which controlled the principal holdings, was establishing in the Artillery Mountains a diamond-drilling camp, in charge of B. N. Webber, who had been associated with the development of the area since 1929. Webber already had prepared various maps, charts, drill-logs, and reports in his capacity as geologist for the M. A. Hanna Co., and most of these records were placed at Lasky's disposal. Webber contributed also what knowledge he had of the country outside the company holdings, and he participated in some field conferences.

As a result of these investigations, it was concluded that although the region contains a large reserve of low-grade material, the amount of rock containing enough manganese to constitute possible ore for current exploitation is much less than originally estimated. In 1941, therefore, the Bureau of Mines explored the blocks north and south of Maggie Canyon for more complete information on the grade and distribution of such material. This work formed a part of the joint investigation that is being made by the Geological Survey and the Bureau of Mines of the strategic-mineral resources of the nation. The Bureau of Mines at this time mined several thousand tons of ore from the Maggie tunnel, for the double purpose of testing mining methods and of obtaining ore for metallurgical tests in its plant at Boulder City, Nev.

The surface sampling upon which the estimates of ore reserves given in this report are partly based was done by Lasky and R. J. Roberts. The text was written by Lasky, who is responsible for all descriptions, comments, and conclusions concerning the area beyond the limits of the Hanna holdings, as well as for the recommendations for future prospecting.

For the parts of the Maggie block explored by the Bureau of Mines, estimates of reserves containing 10 percent or more of

manganese were made jointly by R. J. Sanford of the Bureau of Mines and S. G. Lasky and Vard Johnson of the Geological Survey. Estimates for the lower grades of material in that part of the Maggie block, and all estimates for the rest of the Maggie block and for the several other blocks, were made by Lasky.

Acknowledgments

The officials of the M. A. Hanna Co. cooperated in this investigation by placing the facilities of their camp in the Artillery Mountains at the disposal of Lasky and Roberts of the Geological Survey and by generously permitting study and publication of company records. D. W. Woodbridge of the Arizona Manganese Corporation supplied confidential information. The authors wish to thank the residents of Alamo, particularly Mr. and Mrs. George Lewis, the Rogers brothers, and Mr. Kimmel, for many favors.

GEOGRAPHY

The Artillery Mountains are in west-central Arizona, about 30 miles east of the Colorado River (see fig. 48). Except for two or three minor isolated exposures, the manganese deposits lie within an area about $3\frac{1}{2}$ miles wide by $7\frac{1}{2}$ miles long on the west side of the Bill Williams River, between Alamo crossing and the point where the Big Sandy and Santa Maria Rivers join to become the Bill Williams. Except for the isolated croppings mentioned, which lie in Yuma County, the deposits are at the south edge of Mohave County. The manganiferous croppings are partly in the valley between the Artillery and Rawhide Mountains and partly among the foothills on either side. The richest croppings, and the only ones that have been prospected, are on the northeast side of the valley, among the hills on the southeastern flank of the Artillery Mountains. They are 6 to 10 miles by road from Alamo.

The district is isolated and undeveloped. Even its one settlement, Alamo, is at times abandoned. The nearest other settlement is Signal, about 16 miles north on the Big Sandy River. The nearest supply points are Congress (or Congress Junction),

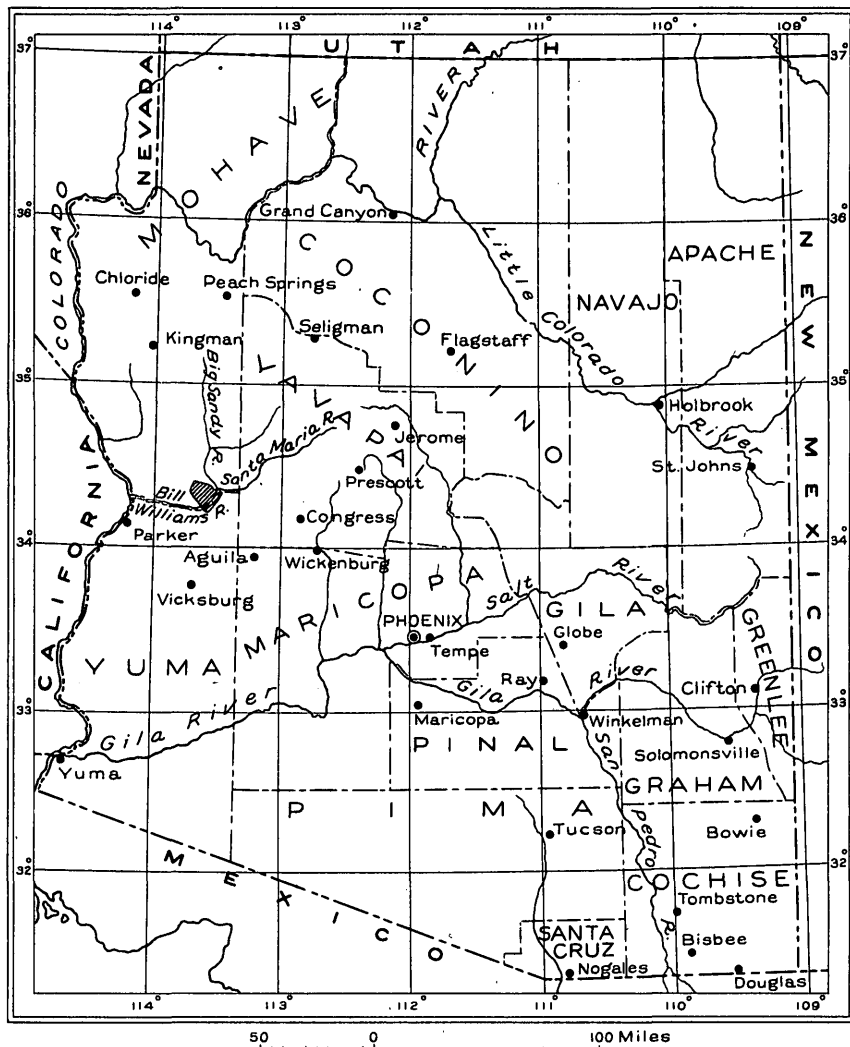


Figure 48.--Index map of Arizona showing location of the Artillery Mountains region (shaded).

46 miles by desert road east of Alamo, and Aguila, about the same distance by road southeast. Congress is on U. S. Highway No. 89, 15 miles north of Wickenburg, and Aguila is on U. S. Highway No. 70, 27 miles west of Wickenburg. Both towns are

stations on the Santa Fe Railway and both are used as shipping points, but Wickenburg is generally used as the trading center, though Yucca, 63 miles north of Alamo, is occasionally so used in the rainy season.

The Bill Williams River, though at times almost dry, is a permanent stream, and at flood stage it sometimes carries an enormous volume of water. In flood season the river may be impassable at Alamo for several weeks, but at such times the manganese area can be reached by way of Kingman and Yucca. Except during floods, which may come only once or twice, or not at all, in a year but which may last for some time, the normal discharge at Planet, 28 miles below Alamo, seems to range between 10 and 20 second-feet.^{4/}

A tremendous amount of water is probably contained in the gravel and sand of the flood plain of the Bill Williams River, and probably some of it could be pumped out and used in exploitation of the manganese deposits, provided that such pumping did not seriously lessen the surface flow preempted by users farther down the river.

The hot, dry climate and scanty vegetation of the area are typical of the desert regions of western and southern Arizona.

GEOLOGY

The distribution of the various rocks in and around the Artillery Mountains manganese area is shown on the geologic maps, plates 62 and 63. In order of age they include (a) a basement complex, consisting mainly of granite, gneiss, and subordinate schist that are probably of pre-Cambrian age, but including some igneous rocks that may be younger; (b) metamorphosed limestone, shale, and quartzite possibly of Paleozoic

^{4/} U. S. Geol. Survey Water Supply Papers 689, 704, 719, 734, 749, 764, 789, 809, 1929-36.

age; (c) sediments of lower Eocene (?) age, apparently thousands of feet thick and consisting of clay, conglomerate, arkose, sandstone, shale, and some limestone and tuff, with a widespread basalt member; (d) Miocene (?) volcanic rocks; (e) the principal manganese-bearing formation, which consists of alluvial fan and playa deposits of early Pliocene (?) age; (f) basalt lying conformably on these deposits; (g) conglomerate, locally including a basalt member, of late Pliocene (?) age; (h) basalt flows that cap some of the extensive mesas and that may be early Pleistocene; and (i) alluvium. The thicknesses, for most of which only minimum or uncertain figures can be obtained, are given in the table on the following page.

The oldest structural feature well displayed in the area is a thrust fault along which the pre-Cambrian and Paleozoic (?) sedimentary rocks are brought on top of the Eocene (?) rocks. This fault is overlapped by the Miocene (?) volcanics, but it may be contemporaneous with the Eocene (?) rocks, which were deposited in a northwestward-trending basin that may have been of fault origin. The lower Pliocene (?) sediments and overlying basalt also were deposited in a minor fault basin, or graben, that lay within the limits of the earlier basin and had the same trend. The upper Pliocene (?) conglomerate was deposited in the same basin at a later time, apparently after the basin had been captured by through drainage. The chief effect of this capture, so far as the manganese deposits are concerned, was to erode some of the manganese-bearing beds, many pebbles of which are now distributed through the upper Pliocene (?) conglomerate.

The Pliocene (?) rocks are folded into a shallow composite syncline that parallels the northwestward trend of the basin and that now occupies the valley between the Artillery and Rawhide Mountains (see pl. 64). The folded rocks along either side of the valley, together with the overlying Pleistocene (?) basalt,

Rock units of the Artillery Mountains manganese area

Recent:

Talus deposits, and gravel and sand along the present drainage Feet
(Erosional unconformity.)

Later Pleistocene:

Pediment gravel and valley fill.
(Angular unconformity.)

Earlier Pleistocene (?):

Massive fine-grained to vesicular glassy basalt.. 0-350+
(Angular unconformity.)

Upper Pliocene (?):

Largely light- to dark-red, poorly sorted conglomerate with discontinuous bedding. Includes a prominent basalt member in the northwestern part of the area..... 0-2,000+
(Erosional unconformity.)

Lower Pliocene (?):

Massive aphanitic vesicular basalt..... 0-250+
Alluvial fan and playa deposits--conglomerate, conglomerate, sandstone, siltstone, mudstone, clay, and limestone; in part gypsiferous. The principal manganese-bearing formation..... 0-1,500+
(Angular unconformity.)

Miocene (?):

Tuffs, breccias, and flows, rhyolitic to andesitic..... 1,800+
(Angular unconformity.)

Lower Eocene (?):

Conglomerate, arkose, sandstone, shale, limestone, and a little clay, with some tuff and a widespread basalt member; in large part highly indurated..... 2,500+
(Angular unconformity.)

Paleozoic (?):

Limestone with minor quantities of shale and quartzite, in part metamorphosed.
(Angular unconformity.)

Pre-Cambrian:

Granite, gneiss, micro-breccia, and subordinate schist, including some monzonitic rock in the Rawhide and Buckskin Mountains that may be of post-Cambrian age.

are broken by northwestward-trending faults, which presumably are the effect of renewed movement along older fault zones. The faults along the northeast side of the valley, at the border of the Artillery Mountains, are particularly extensive and are fairly well exposed. From west to east the more significant ones are the Rudy fault, the Manganese Mesa fault, the Common Corner-Plancha Mountain fault zone, and the Price fault zone (pls. 62 and 63). The Rudy fault, whose maximum throw is about 300 feet, marks the western limit of the exposures of the manganese-bearing beds on the Artillery Mountains side of the valley. The Manganese Mesa fault partly follows the axis of one of the major synclines. Its throw is about 250 feet in the area where the fault displaces the mangiferous beds. The Plancha Mountain fault has a throw of 500 to 600 feet where measured near the south end of Plancha Mountain, and the Price fault has throws ranging from 400 to over 1,500 feet where measured at different places along the strike. These faults produce a group of horsts, grabens, and step-fault blocks which convert what originally was a fairly continuous body of mangiferous sediments into what, from the standpoint of the miner, must be considered as several separate ore bodies. These are known locally as the Maggie (or Manganese Mesa) block, between the Rudy and Manganese Mesa faults; the upper Chapin block, between the Manganese Mesa fault and the Common Corner-Plancha Mountain zone; the lower Chapin block, between the Plancha Mountain and Price faults; and the Price block, northeast of the Price fault.

Manganese-bearing formation

The beds containing the principal manganese deposits crop out roughly in the form of an elongate U, 6 to 7 miles long and 3 to 5 miles wide, around the shallow syncline which occupies the valley between the Rawhide and Artillery Mountains, and

presumably are continuous below the surface across the trough of the syncline within the arms of the U.

The exposures near the Rawhide mine, in the Rawhide Mountains, reveal that the deposits pinch out between the basement rocks and the overlying conglomerate, and they evidently mark the westernmost limit of the formation in that area. In the Artillery Mountains, on the other hand, the westernmost exposures, in Maggie Canyon and near the head of Chapin Wash, are so thick as to suggest that the beds extend much farther westward or northwestward under the basalt of Manganese Mesa.

The manganese-bearing formation rests with angular unconformity upon the smoothly eroded surface of the older rocks. Along the 8 miles or more of contact exposed in the Artillery Mountains and along the 2 miles of contact well exposed in the Rawhide Mountains, the formation was deposited on a surface cut indiscriminately across all varieties of older rocks and across strong structural features, and its base is essentially parallel with its bedding. The formation is in part overlain conformably by basalt, and in part unconformably by the upper Pliocene (?) conglomerate and younger rocks.

The beds are composed mainly of pink to red and brown clay, mudstone, siltstone, and sandstone, each of which grades into the others and contains partings of the others (see pl. 65). The manganiferous beds are blackened with a pigment of manganese oxides, instead of being reddened, like most of the nonmanganiferous beds, with a pigment of iron oxides. Most beds contain thin conglomeratic lenses, and several of these are fairly extensive. Cross-bedding, ripple-marks, drying-cracks, mud flakes, intraformational conglomerates, and scour-and-fill surfaces are present here and there. An angular conglomerate, composed of the material upon which it rests, commonly lies at the base of the formation. The dominant sands, silts, and clays merge and intertongue laterally with alluvial fan material or

into conglomerate. All the beds, from clay to conglomerate, are composed of the same kinds of material and differ from one another only in texture and in the proportion of clay to rock fragments.

The clastic beds are generally cemented only with the clay and with the iron and manganese oxides of the red and black layers respectively; but in Maggie Canyon and locally in Chapin Wash west of the Plancha Mountain fault, the upper part of the manganiferous beds is cemented with supergene manganese oxides, opal, chalcedony, and analcite. Crystals of "sand-calcite" also constitute a cement in many of the manganiferous beds. The cementation is more fully discussed under the heading "Manganese deposits."

The variations in the lithologic character of these beds from place to place can be broadly correlated with lithologic differences in the older rocks from which the formation was derived. Where the bedrock is granite, the formation thus contains much granitic material; or, where the bedrock consists of Miocene (?) volcanic rocks, as among the manganiferous beds of Maggie Canyon, it contains much tuffaceous and pumiceous material. Elsewhere the formation contains boulder beds derived from similar boulder beds in the Eocene (?) conglomerate.

The thickness of the manganese-bearing formation differs from place to place because of the unconformities at the top and bottom. The formation pinches out between older and younger rocks at the edges of the basin, and reaches a maximum thickness of possibly 1,500 feet or more near the center of the basin.

MANGANESE DEPOSITS

The only manganese deposits that have been commercially investigated in the Artillery Mountains area, and that seem likely to be worth mining, are the bedded oxide in the playa deposits of lower Pliocene (?) age. Manganese oxides occur also

(1) in stratified deposits in the Eocene (?) rocks; (2) in stratified deposits in the upper Pliocene (?) conglomerate; (3) in faults and fissure- and breccia-zones in the Eocene (?) rocks cemented with manganese oxides; and (4) in supergene vein deposits, together with some related replacement bodies, along the latest faults and along fissure zones of similar age. In the aggregate, these other deposits may contain much manganese, but the available tonnage in them is insignificant as compared with the tonnage of prospective ore in the lower Pliocene (?) bedded deposits.

Under present metallurgical practice none of this bedded material constitutes ore in the accepted sense, but as a matter of convenience the word "ore" is used in the following pages for material that to the unaided eye appears to be uniformly manganeseiferous. The tabulation of reserves indicates the quantity of material of various grades that is present, and, with figure 49, it forms a basis for estimating how much of this material may become ore according to strict economic definition as practice improves.

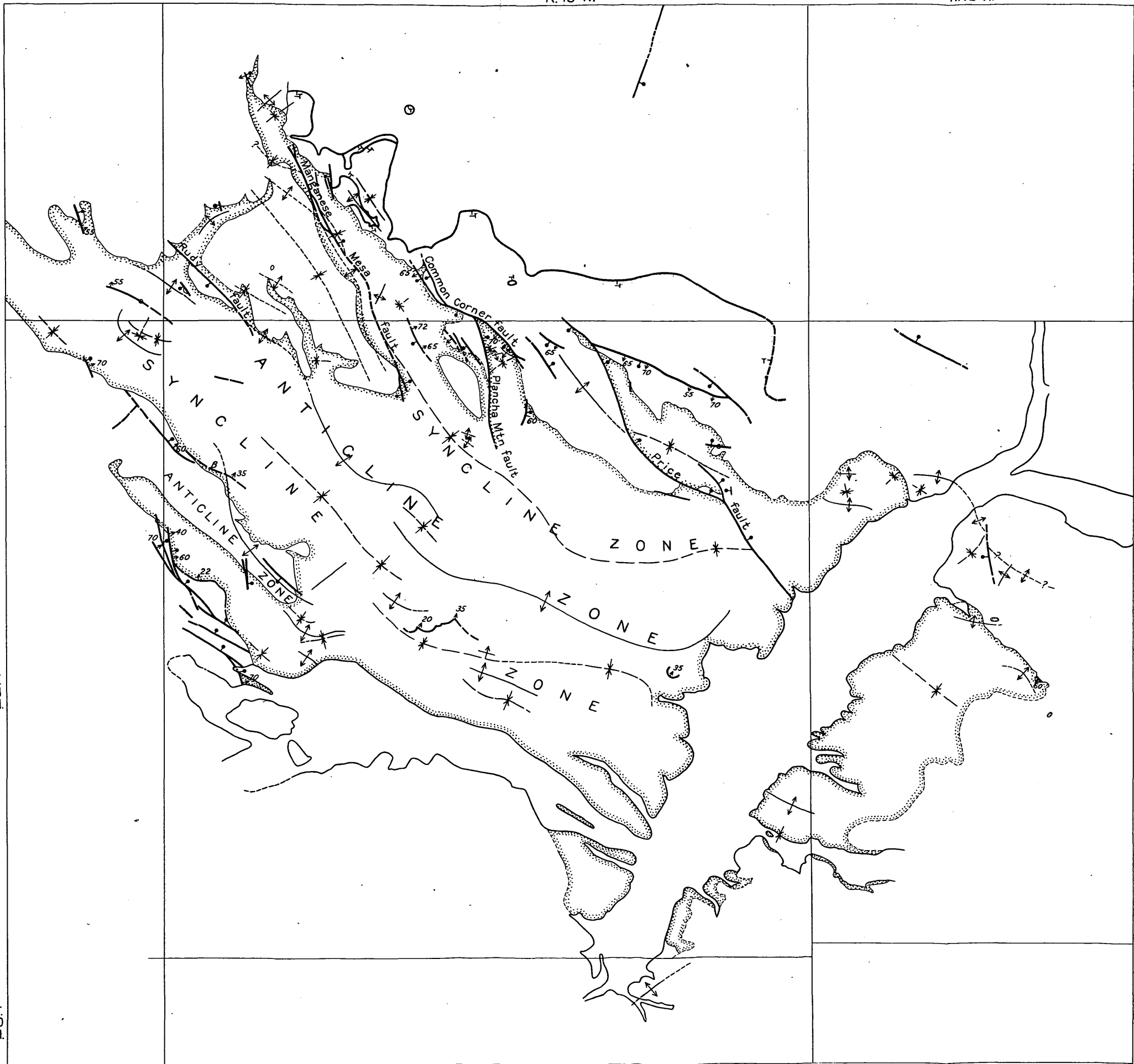
General character

The manganeseiferous beds contain, in addition to the iron oxides or hydroxides that accompany the clay cement of the associated barren beds, manganese oxides intimately associated with these iron oxides. Some beds are uniformly manganeseiferous throughout; others that are mainly barren contain minute knots of manganese oxides distributed along the partings. The manganeseiferous beds are present at various horizons and include every kind of rock in the formation. The manganeseiferous beds are in part interlensed with barren beds, and in part they merge into barren rock through diminution of manganese oxides in the matrix. The manganeseiferous beds range from gray to brown or black, but assays prove that the color is only a rough indication of the manganese content.

T. 12 N.

T. 11 N.

T. 10 N.



EXPLANATION

Thrust fault, showing
overthrust side, T

Fault, showing dip and
downthrown side

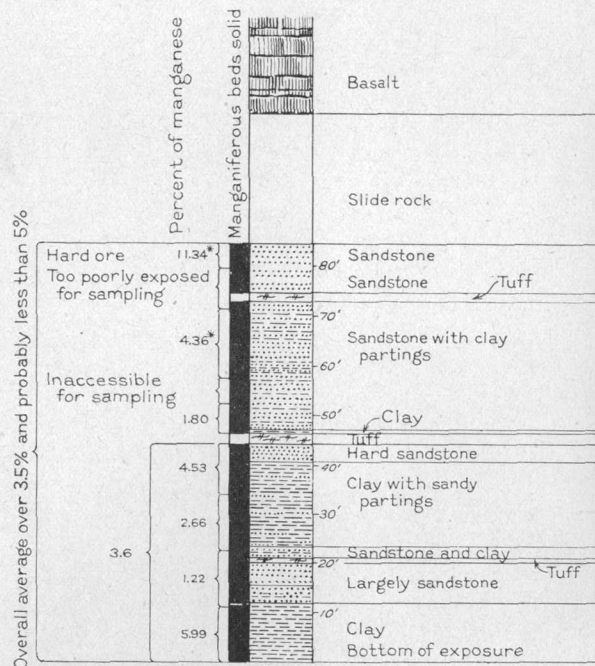
Axis of anticline
(Dashed where hypothetical or
covered by later deposits)

Axis of syncline

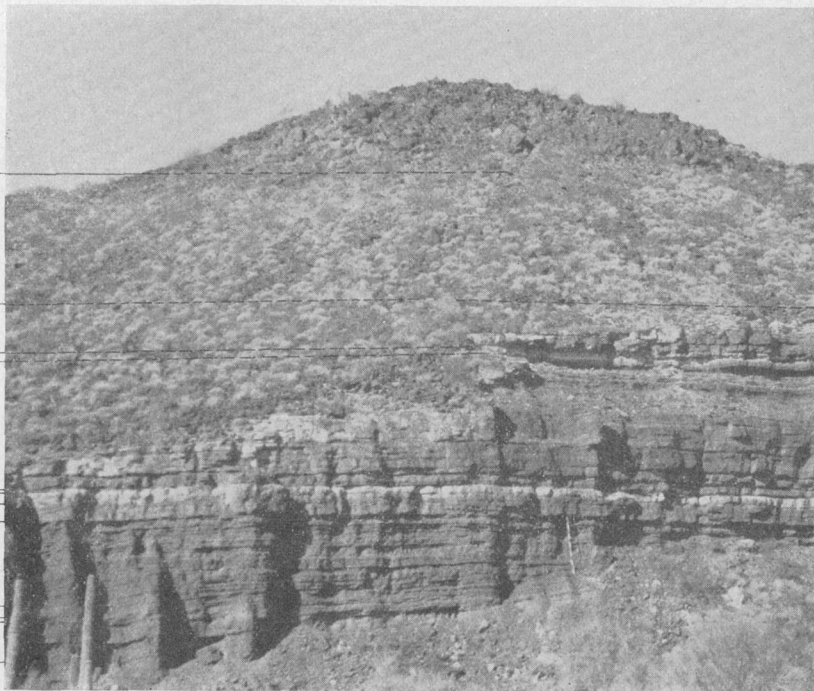
Limits of outcrops of the manganese-
bearing formation and other Plio-
cene (?) rocks
(Shaded side, Pliocene (?) rocks; unshaded
side, younger and older rocks)

STRUCTURE MAP OF THE ARTILLERY MOUNTAINS MANGANESE REGION, ARIZONA





* Sampled at north end of hill beyond the limits of the photograph



MANGANIFEROUS SEDIMENTS IN CHAPIN WASH AT COBWEBB HILL.

Though there are gradations from one kind of manganiferous material to another, as from clay to sandstone or from sandstone to conglomerate, and though in part the different kinds are

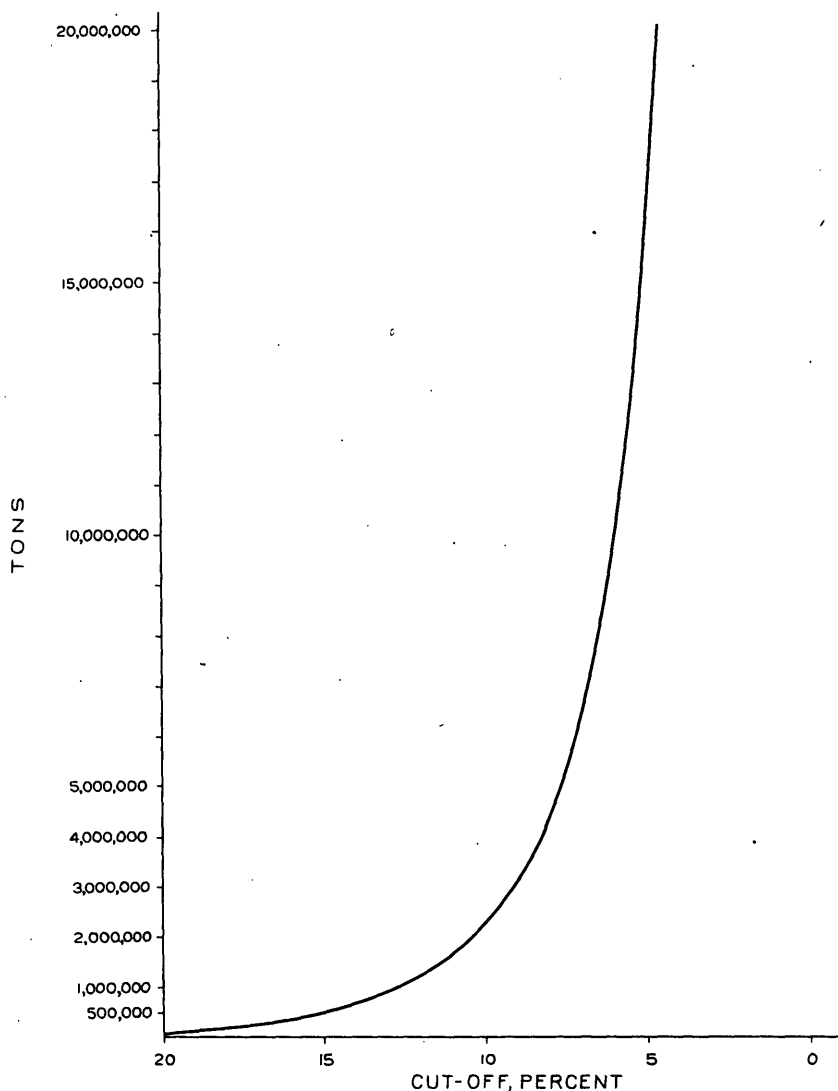


Figure 49.--Graph showing reserves of manganese ore in the Artillery Mountains for various cut-off values.

intimately interbedded, the ore may be classified from the point of view of the miner and metallurgist as (1) sandstone ore, which includes friable to compact siltstone, sandstone, and conglomerate; (2) clay ore, which includes clay and mudstone;

and (3) hard cemented ore that is a supergene modification of the sandstone ore. Each of the three kinds is present in large tonnages, but the hard ore, because parts of it have been enriched, is the only kind that offers any hope for commercial exploitation in the near future.

The manganese content in the three main kinds of ore ranges from less than 1 percent to as much as 30 percent, but very little of it contains more than 20 percent, and by far the greatest part contains less than 5 percent. The average grade of the sandstone and clay ores is 3 to 4 percent, and the average grade of the hard ore is 6 to 7 percent. The ore contains, on the average, 3 percent of iron, 0.08 percent of phosphorus, 1.1 percent of barium, and minute quantities of copper, lead, and zinc. Although the manganese content may change abruptly from bed to bed, the results of sampling and of geologic observation indicate that for the unaltered ore the content within individual beds changes gradually and that on a large scale both the iron and the manganese content are remarkably uniform.

Sandstone ore

The sandstone ore includes friable siltstone, sandstone, grit, conglomerate, and similar rocks that are well compacted but not hard and that have no cement other than clay and the oxides of manganese and iron. These ores consist of sand grains in a matrix that ranges from a reddish clay to a brown and black manganese-bearing opaque material. As seen in thin section, the opaque matter consists in some places of partly red or brown iron hydroxide and partly of black manganese oxides; in other places the iron and manganese oxides are intimately mixed; and in still other places only one or the other is present. There is no recognizable replacement of the sand grains by the oxides. The ores show the same textures and the same relations between sand grains and cement as the equivalent barren beds.

The manganiferous part of the cement is almost wholly amorphous. Most of the ore soils the fingers and has a brown streak, and the ore itself is somewhat brownish. The cementing material of such ore may properly be called wad. Some ore is sooty black to blue-black, and presumably the manganese oxide in it is largely pyrolusite.

Some of the manganiferous tuff beds are classified with the sandstone ore, the manganiferous layers being delicately to coarsely interlaminated with nonmanganiferous layers and differing from the barren tuff only in the presence of manganese oxides.

The sandstone ore constitutes about half the reserves in the area. Its manganese content ranges from a trace to as much as 24 percent, but this high figure was obtained in only one sample. A little contains about 10 percent of manganese. The average grade of the parts of the manganiferous beds that are thick enough and extensive enough to be minable ranges from 1.5 to 4 percent in the various blocks and is between 3 and 3.5 percent for the district as a whole.

Clay ore

The clay ore has the same sort of conchoidal fracture as the barren red and brown clay and mudstone; like these, also, it is plastic when wet and slacks on weathering. Under the microscope the ore looks like the sandstone ore except that it contains a smaller proportion of coarse clastic grains.

The ore ranges from massive black clay to brown manganiferous clay and silt interlaminated with barren clay and silt. The laminated material as a whole contains blebs and bedding streaks, some of them brown and some sooty black, of essentially pure oxides. Some ore that is mostly black or brown has fine laminae of ordinary red and pink clay and silt, and the red clayey members of the laminated ores have fine manganiferous

laminae. In some laminated ore the sooty blue-black material forms persistent layers as much as 4 inches thick, and some groups of laminae that consist mostly of such material are as much as 2 feet thick.

Most of the clay ore is near the bottom of the mangiferous zone (see pl. 69), and in the area represented by plate 63 this material constitutes a reserve almost as great as that of the sandstone ore. The manganese content for any one bed and for the clay ore as a whole seems remarkably uniform.

Hard or supergene ore

The hard ore consists of mangiferous siltstone, sandstone, and conglomerate that has been impregnated with opal, "sand calcite," and a little analcite, and in which the original wad has been converted to psilomelane and manganite. The processes of alteration included leaching of clay and iron oxide from the original cement, as a result of which the ore is highly porous. Though most of the hard ore contains both "sand calcite" and opal, much contains only one or the other, and some contains neither, the sand grains being held together by psilomelane and manganite. Usually, however, these various phases occur together and are intimately associated.

As compared to unaltered ore, the hard ore is relatively resistant to weathering. It is somewhat blacker than sandstone ore of equal grade and comparable grain size, though not so black as sandstone ore containing much pyrolusite. Some of it reacts vigorously, some of it faintly, to hydrogen peroxide, the vigor of the reaction being apparently in inverse proportion to the degree of insulation of the manganese oxides by opal or "sand calcite." This fact would have to be taken account of in any process designed to recover the manganese by chemical methods.

Almost the only bodies of ore in the region that combine minable size with promising grade consist of hard ore. Although perhaps a third of the hard ore has about the same average manganese content as the unaltered sandstone ore—less than 5 percent of manganese—the remainder of it contains 10 percent or more of manganese, and some contains more than 20 percent. (See also drill hole No. 3, pl. 66.)

Extent and thickness

The manganiferous beds crop out in two bands, one along the Artillery Mountains side of the valley and the other along the Rawhide Mountains side (see pl. 62), which represent two distinct zones in the lower Pliocene (?) formation 750 to 1,000 feet apart stratigraphically. The relations between the two zones are interpreted in geologic sections C-C', D-D', and E-E' of plate 62.

Upper zone

The upper zone includes all the manganiferous croppings on the Artillery Mountains side of the valley except the small ones at the base of the lower Pliocene (?) formation near the east edge of sec. 11, T. 11 N., R. 13 W. (See pl. 62 and sec. D-D'.) The lens in secs. 23 and 26, T. 11 N., R. 13 W., on the Rawhide side of the valley, and possibly also some small outcrops in the northeast corner of sec. 19 in the same township, belong to the upper zone (see sec. C-C', pl. 62). The geologic maps, plates 62 and 63, show the general outline of the zone, and plates 66 and 67 show stratigraphic details and some variations in thickness and continuity.

The zone is continuously manganiferous for a stratigraphic thickness of as much as 165 feet, and at some places manganiferous beds, separated by more numerous barren layers, form a zone as much as 350 or 400 feet thick. Zones that are manganiferous throughout are traceable for as much as 3 miles along the

strike, and outcrops and diamond-drill holes in the Maggie and upper Chapin blocks indicate that some individual manganiferous beds are continuous for at least a mile down the dip.

Maggie block.--The Maggie block lies between the Rudy and Manganese Mesa faults. The richest and most continuous exposures in this block are those of hard ore in the walls of Maggie Canyon. As exposed through the slide rock, the manganiferous zone seems to be from 75 to 100 feet thick in the main part of the canyon and to have a maximum thickness of about 200 feet. Diamond-drill holes indicate that the manganiferous beds under the basalt may underlie 400 or 500 acres south of Maggie Canyon and 150 or 200 acres north of it (see pls. 67 and 68). Some of the richest ore in the district, of the hard type, was cut in these drill holes, as well as some of the thickest and most continuous sections. Hole No. 9, for example, cut 164 feet of manganiferous rock, of which only 16 feet is barren material, and in which the thickest barren interval is 7 feet; and hole No. 3 cut a total of 180 feet of manganiferous beds in a zone 285 feet thick. As interpreted from drill logs and from surface exposures, the manganiferous zone frays out southward and to the northwest in the Maggie block into barren sediments roughly along the line indicated on plate 68. The zone passes beneath the surface toward the east, reappearing on the east side of Manganese Mesa opposite the head of Maggie Canyon (see pl. 63) where 3 feet of manganiferous conglomerate crops out below some high alluvium. From that point the manganiferous zone can be traced northward about a mile to where it pinches out against Miocene (?) volcanics. The manganiferous zone along the segment of its outcrop has a maximum thickness of only 17 feet, and where it begins to thin out against the Miocene (?) rocks it consists of only a few dark streaks in a zone not over 10 feet thick.

Upper Chapin block.--The upper Chapin block constitutes the part of the upper manganese zone that lies between the Manganese Mesa fault and the Plancha Mountain-Common Corner fault zone. The manganiferous beds crop out extensively along the walls of Chapin Wash and on the side slopes, and the most extensive and striking exposures in the district are in this block (pl. 65). The upper Chapin block occupies the east flank and part of the trough of the syncline whose faulted west flank is in the Maggie block (see pls. 63 and 64, plan and sections).

One diamond-drill hole in the upper Chapin block cut as much as 200 feet of manganiferous beds, only 34 feet of which is barren; and one outcrop exposes 110 feet of manganiferous beds, less than 30 feet of which is barren. Plate 65 shows an exposure of 85 feet that is manganiferous almost throughout.

Measured sections illustrate some of the variations in the continuity and thickness of the beds. The manganiferous zone begins to feather out northward at a point, covered by debris, somewhat southeast of the position of measured section No. 3, and it frays out southward in the general area of the tunnel on Chapin No. 2 claim in Chapin Wash (see pls. 63 and 68), where it splits into three very narrow members. Diamond-drill holes (see pl. 68) indicate that the manganese zone here, at the south edge of the upper Chapin block, frays out at about the same rate down the dip as along the strike. This frayed edge is the extension of the southeastern limit of the manganiferous zone in the Maggie block.

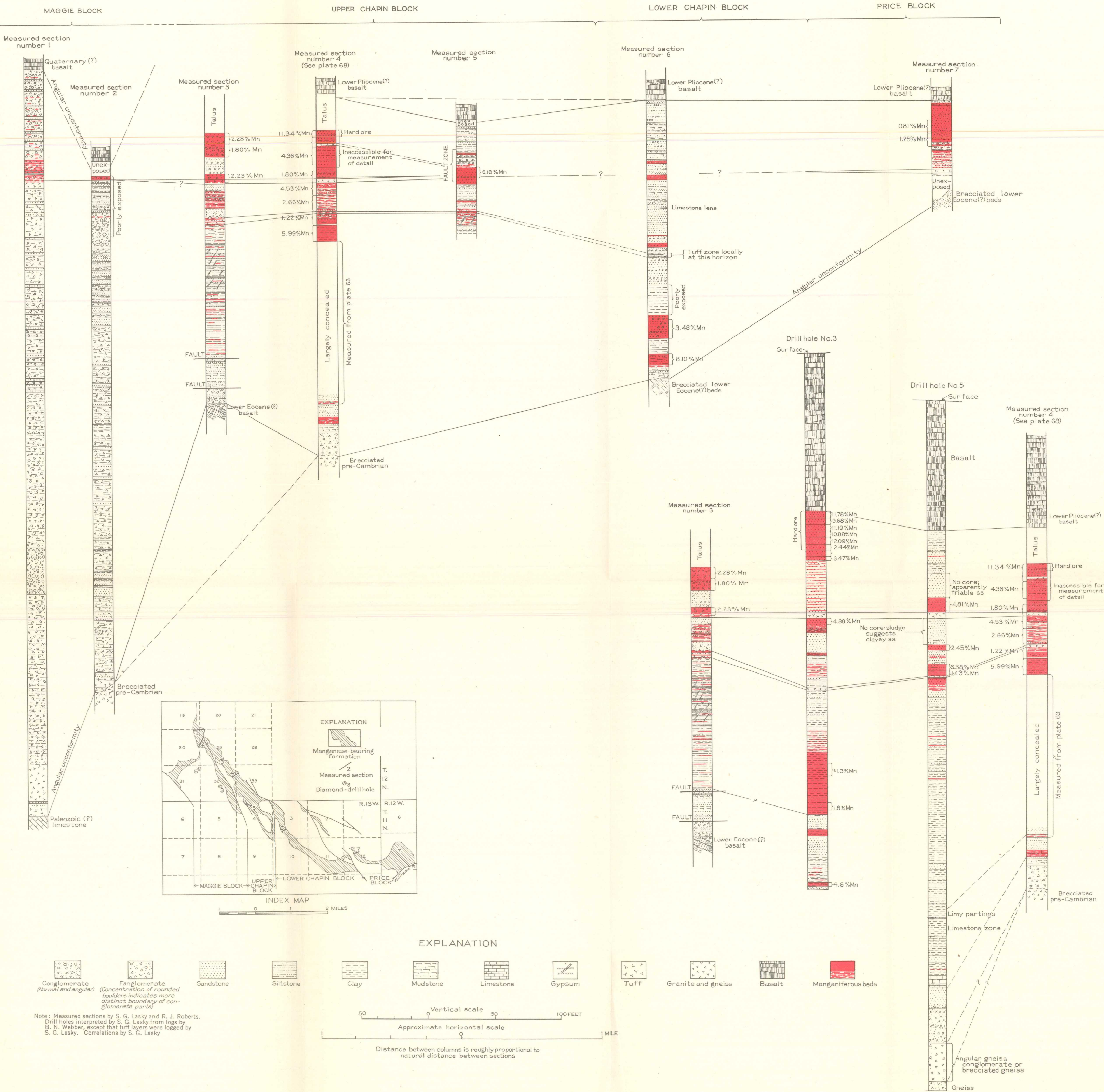
Isolated exposures amid the talus on the slopes of Plancha Mountain show that manganiferous beds underlie the talus and the basalt, but the thickness and extent of these beds is unknown.

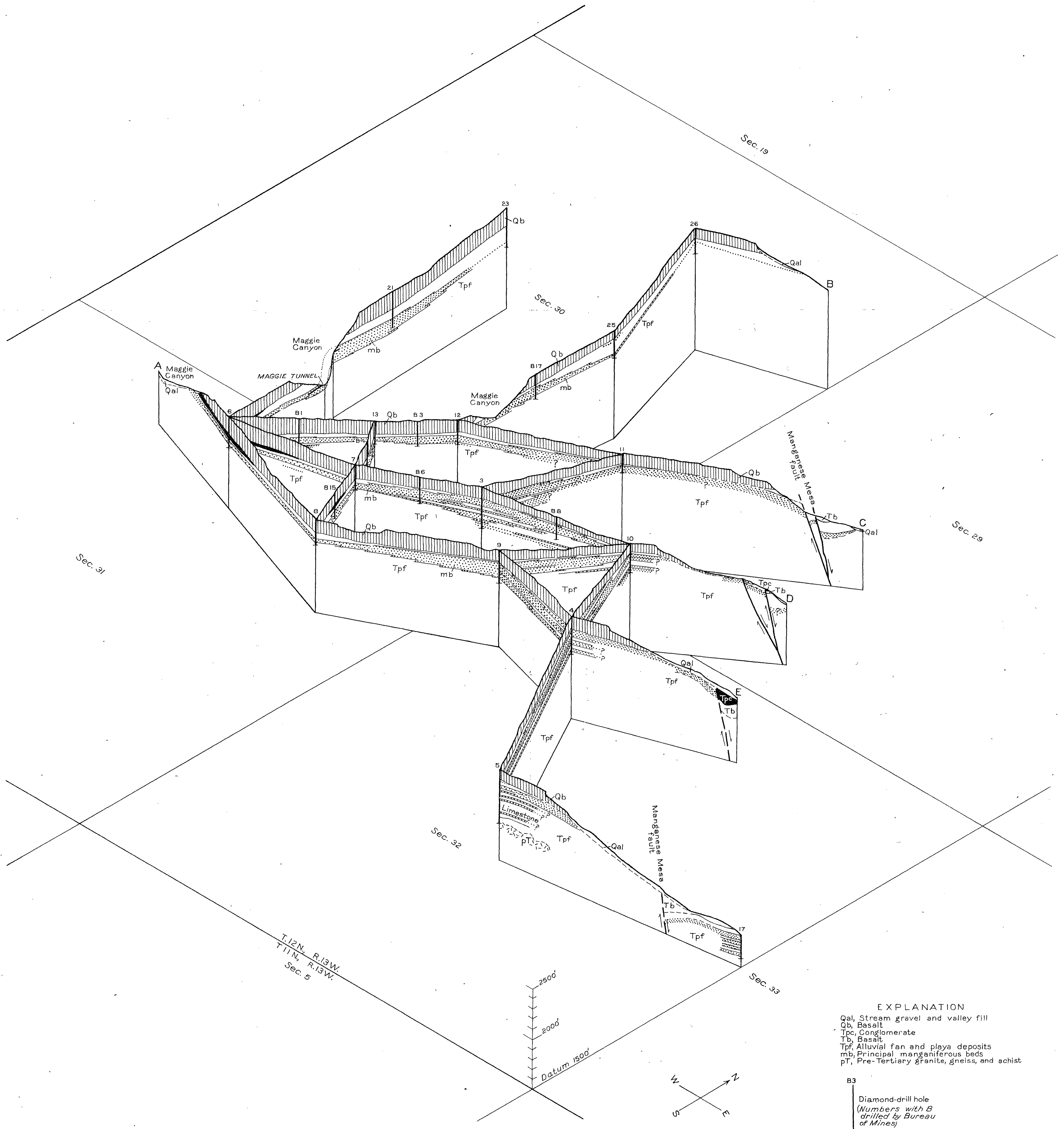
Lower Chapin block.--The principal exposures in the lower Chapin block, which is between the Plancha Mountain and Price faults, are along Chapin Wash east of Plancha Mountain (see pls. 62 and 63). The thickest exposures are at the tunnel in Chapin

Wash at the northwest corner of the Minnesota No. 10 claim. Two black beds, the upper one 18 feet and the lower one 8 feet thick, separated by 12 feet of barren material, crop out there along the bottom and walls of an arroyo tributary to Chapin Wash, and several thinner layers are exposed at higher horizons. In general stratigraphic position the main beds correspond to the deep manganese beds cut by diamond-drill hole No. 3 in the upper Chapin block.

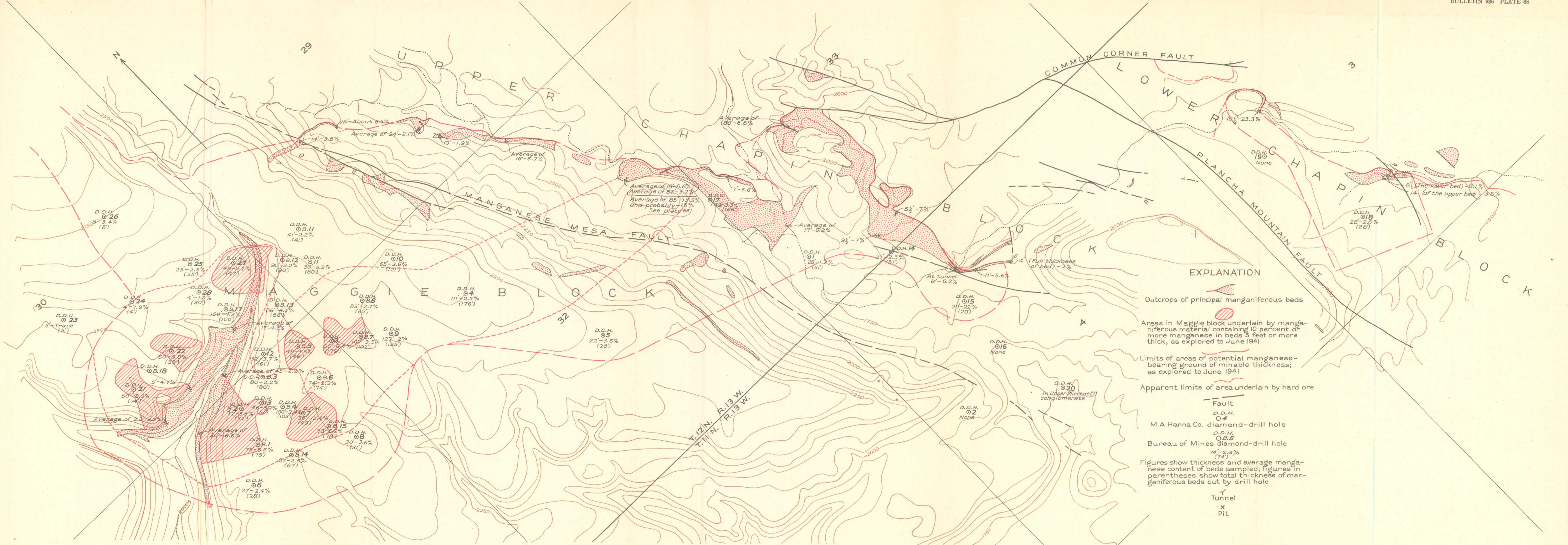
The main part of the zone, composed of the two thicker beds and the barren interval between, extends northwestward along the arroyo as shown on plates 63 and 68. The two main beds thin out southeastward from the tunnel, and the lower one eventually pinches out against the lower Eocene (?) beds. The upper one has thinned down to 3 feet or less at the line between secs. 3 and 10, and at that place the next higher manganese bed, which is 3 feet thick near the tunnel, has thinned down to 1 foot. Manganiferous beds crop out for a mile or more further along the walls of Chapin Wash, and on the south bank where they are not covered by pediment gravels, but they are thin and generally lean. Other minor showings crop out east of Chapin Wash in the southwest corner of sec. 12, where the manganese-bearing formation is cut off by the Price fault.

The down-dip extent of the manganiferous beds in the lower Chapin block has been explored by the adit on the Minnesota No. 10 claim, which is 50 feet deep, and by two diamond-drill holes. Hole No. 18 (see pl. 68) cut the manganese zone about 600 feet down dip from the tunnel exposures and crossed three manganiferous beds, 6 feet, 12 feet, and 10 feet thick respectively from the top down, that correspond to the two beds at the tunnel and the first subordinate layer above. The other drill hole, No. 19, was drilled through to the lower Eocene (?) beds and was barren throughout.





ISOMETRIC DRAWING OF GEOLOGIC SECTIONS THROUGH MANGANESE MESA, SHOWING VARIATIONS IN THICKNESS AND CONTINUITY OF THE MANGANIFEROUS ZONE AS INTERPRETED FROM DRILL HOLES



MAP SHOWING DISTRIBUTION OF ORE IN THE MAIN PART OF THE ARTILLERY MOUNTAINS MANGANESE REGION, AS EXPLORED TO JUNE 1941

1000 0 3000 Feet

Price block.--The principal exposures in the Price block are along the part of Burro Wash where the manganiferous zone occupies the full thickness of the lower Pliocene (?) formation (see pl. 62). The main manganiferous beds are there exposed along the perpendicular walls of the wash for over 2,000 feet. A measured section at the thickest part of the zone shows an overall thickness of 50 feet. Throughout the block the richest and most uniform part of the zone is in the upper beds, but parts of some streaks in the lower beds are fairly black and as much as 2 or 3 feet thick. A 50-foot tunnel in the west bank of Burro Wash, where the section was measured, prospects the bottom of the main manganiferous part of the zone, which fades out just downstream from the point where the uppermost beds cross the wash.

Two manganiferous layers crop out to the northwest, in the angle between the two main spurs of the Price fault. The lower one, which is at or close to the base, is mostly less than a foot thick; the upper one has a maximum thickness of 3 feet.

Secs. 23 and 26, T. 11 N., R. 13 W.--The manganiferous zone as exposed in sec. 23 south of the road, is about 350 feet thick and includes 20 to 30 separate manganiferous beds ranging in thickness from an inch to a foot.

The manganiferous zone extends southward toward the river, to a point where it is overlapped by alluvium. Nothing more than faint showings were found in the isolated exposures in the alluvium or in the bluffs along the river. Toward the northwest the manganese zone seems to have almost faded out where a broad area of high alluvium begins to obscure the bedrock.

Lower zone

The lower zone includes all the manganiferous exposures along the Rawhide Mountains side of the valley except the one in secs. 23 and 26. It may include also the manganiferous beds

near the east edge of sec. 11, on the Artillery Mountains side of the valley.

The lower zone is traceable along its strike for a little less than 4 miles. It has its greatest observed thickness, about 350 feet, in sec. 21. To the southeast it is partly hidden by alluvium, but northwest it thins out abruptly, being only a little over 100 feet thick in the western part of sec. 17. There a part of the lower zone—perhaps all of it at one place—is cut out by conglomerate.

Most of the manganiferous beds of the lower zone are widely separated lenses ranging in thickness from less than an inch to a foot—though the maximum is rarely attained—and in length from a few feet to a few hundred feet. In the western part of sec. 17, however, some of the manganiferous beds are 2 to 3 feet thick, and in the eastern part of sec. 18 a prominent manganiferous bed attains a thickness of about 15 feet and extends for 1,000 feet along the strike.

In 1941 no effort had yet been made to prospect the lower zone.

Origin

Although the scope of this preliminary report precludes a detailed discussion of origin, it can be said that the deposits were undoubtedly formed at the same time as the containing rocks. Hewett^{5/} included the Artillery deposits in the small group that "convincingly display that the manganese oxides were laid down as part of the sedimentary rocks that contain them," and Hewett's conclusion is corroborated by the following evidence noted in the present examination:

(a) The stratigraphic persistence not only of the manganiferous zones themselves, but also of individual layers.

^{5/} Hewett, D. F., Sedimentary manganese deposits, in Ore deposits of the Western States (Lindgren volume), pp. 488-489, Am. Inst. Min. Met. Eng., 1933.

(b) Interstratification of barren and manganiferous beds, ranging from large-scale interbedding to minute interlamination, and the interlensing of manganiferous and barren beds.

(c) The fact that the manganiferous beds include every kind of rock, however diverse in strength, permeability, and degree of compaction, that the formation contains.

(d) Significant details of sedimentation shown by the manganiferous beds, such as "mud flakes" and coarse intraformational conglomerates, drying-cracks filled with silt from overlying layer, and scour-and-fill surfaces.

(e) A general uniformity in the distribution of manganese in the various beds, as well as throughout the unaltered part of the deposit as a whole.

(f) The fact that the ores have the same textures as the equivalent barren rocks, and that the manganese and iron oxides have the same relations to the sand grains and clay in the ore beds that the iron oxide has in the barren beds.

The manganese oxides in the deposits were transported and deposited, largely by mechanical means, in a playa basin. The source of the bulk of the manganese is uncertain, but, as other conceivable sources seem quantitatively inadequate, it is assumed that the manganese was contributed primarily by hot springs.

RESERVES

Extent of exploration

In June 1941, only the upper manganese zone on the Artillery Mountains side of the valley had been explored. The exploring had been done by means of surface cuts, shallow underground workings, and diamond-drill holes. A total of 43 vertical holes, 15 of them by the Bureau of Mines, United States Department of the Interior, had been drilled. Their locations are shown on plates 63 and 68. They range in depth from 180 feet to

805 feet and aggregate about 13,400 feet. Of the holes that cut manganiferous beds, only one, No. 5 in the Maggie block, was drilled completely through the manganese-bearing formation; thus the reserves in the area drilled are greater than has actually been demonstrated (see pl. 69, particularly at holes 11, 12 and 3). For some of the earlier holes, moreover, drilled before it was recognized that color is not a good indication of grade, only the richer-appearing beds that were cut were sampled, so that grade can be computed for only part of the known reserves.

Basis of estimates

Estimates of reserves are based on the diamond-drill data supplemented by analyses of 51 samples collected for this purpose by Lasky, and on measurements of areal extent and thickness beyond the limits of the diamond-drilling, all interpreted on the basis of the geologic observations. Positions at which 48 of Lasky's 51 samples were taken are shown on plate 68; the other three were taken from the exposures of the Price block in Burro Wash. Analyses of these samples were made in the laboratories of the Geological Survey. Tonnages were estimated by averaging bulk specific gravity determinations made on 32 samples of typical ore collected during the investigation.

It has been assumed that no bed less than 5 feet thick would be mined, unless it were of extraordinary richness. It has also been assumed that any barren layer less than 5 feet thick and lying between minable manganiferous beds would have to be taken out with the ore. For the beds of minable thickness, all material has been included that is obviously manganiferous. This is equivalent to taking a cut-off value of about 1.5 percent of manganese, but some material containing as little as 1 percent of manganese is included.

Because of the general uniformity in the distribution of the manganese, the estimates of tonnage and average grade are based

on the assumption that the manganese content varies at a uniform rate between the points where samples were taken. Though this assumption is not quite so valid for the supergene, or hard, ore as it is for the unaltered material, it appears fairly safe, since earlier estimates made on the same assumption agree well with the results that the Bureau of Mines obtained later by diamond-drilling.

Lower Zone

For lack of exploration no worth-while estimate of reserves in the lower zone can be made. Although this zone contains many tens of thousands and may contain millions of tons of metallic manganese, it is impossible to predict in advance of exploration whether any of the zone would prove rich enough to constitute a reserve.

Upper Zone

Maggie block.--The probable limits of potential ore-bearing ground in the Maggie block, in so far as they could be drawn in the spring of 1941, are indicated on plate 68. The average aggregate thickness of the manganese-bearing layers as indicated by the drill holes is 68 feet, and the average for the whole area, as estimated by extrapolating beyond the drill holes, is about 65 feet.

The Maggie block is estimated to contain 80,000,000 tons of ore with an average manganese content of 3.75 percent. Table 19 lists the grade and tonnage of the three kinds of ore that make up this total, and the boundaries between them are indicated on plate 69. The boundary between the sandstone ore and clay ore in large part follows bedding planes, although no attempt was made to show this fact in the illustration. The apparent horizontal extent of the hard ore, which is the principal source of the higher grades of material, is indicated in plate 68. The thickness of this hard ore as cut in the drill holes ranges from 4 to 56 feet, and the average for the block is about 20 feet.

In addition to this 80,000,000 tons, there is estimated to be about 40,000,000 tons in the part of the manganiferous beds cut in some drill holes but not sampled, or too poorly exposed in Maggie Canyon to be sampled by the writer. This 40,000,000 tons is assumed to have a grade approximating the combined average of sandstone and clay ores and thus to contain an average of about 3 percent of manganese.

Table 20 shows the apparent tonnages of various grades of ore, by 5-percent increments. The breakdown of the gross tonnage into the various grades in the Maggie block is based primarily on the drill-hole samples, each of which represents an interval of 5 feet or less (see pl. 69); in this breakdown a scrupulous effort was made not to "dilute" higher grades of ore with underlying or overlying material of lower grade. The tonnages given for the various grades above 5 percent could be increased three to perhaps six times by including lower-grade material.

The data for the block north of Maggie Canyon are not so good as for the block south of the canyon, and the figures given, particularly for the higher grades of material, may have to be revised downward when and if that part of the block is more closely explored.

Upper Chapin block.--The horizontal extent of the manganese-bearing zone in the upper Chapin block is indicated on plate 68. The average aggregate thickness of manganiferous beds in this block is estimated to be about 65 feet.

The upper Chapin block is estimated to contain about 35,000,000 tons that have been found by sampling to average about 4 percent of manganese, and 15,000,000 tons more of unsampled material. The grade and tonnage of the various classes of ore are shown in tables 19 and 20. The unsampled material is largely sandstone ore. Because the ore below the outcrops has

not been well prospected, the basic data for the upper Chapin block, particularly for grade of ore, are not quite so complete as for the Maggie block, but the figures given are thought to be of the right order of magnitude.

Lower Chapin block.--The lower Chapin block has been too little explored to permit of more than a tentative estimate of its minimum reserves. No attempt has been made by the owners of the property to investigate the continuity of the ore between the two principal outcrops, and the only evidence as to the extent of the deposit down the dip is supplied by two diamond-drill holes, one of them directly down dip from each outcrop, and a 50-foot tunnel.

The average thickness of manganiferous material exposed in drill-hole No. 18 and at the outcrops is about 20 feet, and the average manganese content of the samples collected is about 7 percent. As each acre underlain by ore 20 feet thick would be equivalent to about 50,000 tons, it is estimated that the block contains a probable minimum of 2,000,000 tons of ore. All this is probably sandstone ore, and most of it, like that in the other blocks, probably contains less than 5 percent of manganese (see tables 19 and 20).

Price block.--The most continuous part of the manganiferous zone in the Price block ranges from 8 to about 35 feet in thickness and crops out for 2,000 feet. All of it is sandstone ore. Inasmuch as the croppings of the same beds to the southwest beyond the Price fault zone are but slightly manganiferous, the ore body cannot safely be assumed to extend down dip any farther than the nearest fork of the fault, and its tonnage would thus be about 1,500,000.

Two groups of samples were taken, one representing 30 feet of beds at the 50-foot adit in Burro Wash near the northern end of the exposure and the other representing 15 feet of beds 750 feet downstream. The average manganese content of these

samples is 1.6 percent, but some samples taken by others have shown as much as 12 percent of manganese.^{6/}

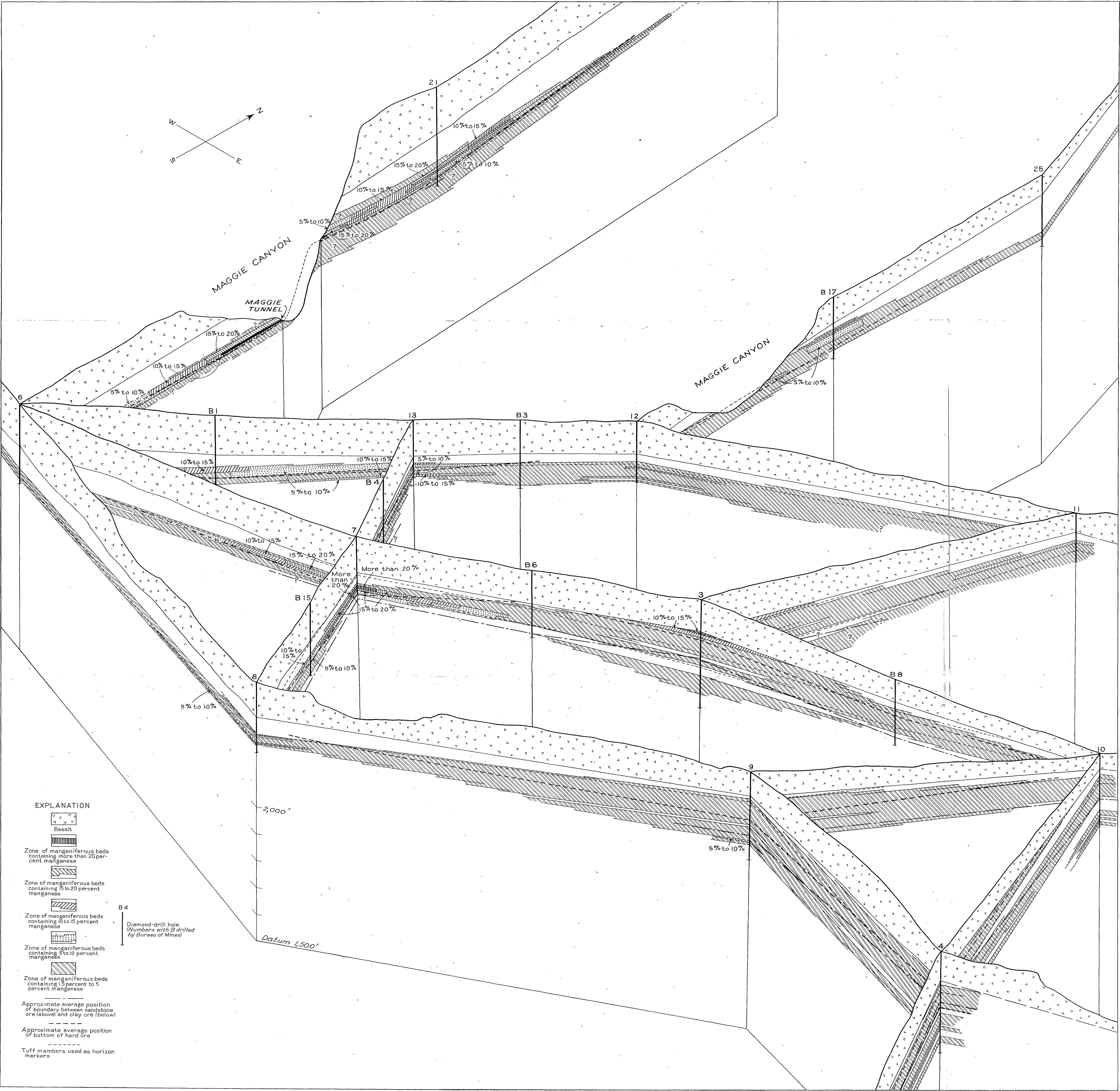
Total reserves

Tables 19 and 20 summarize the reserves in the bedded manganese ores of the Artillery area as explored prior to June 1941. There appears to be a minimum of about 175,000,000 tons, including about 125,000,000 tons containing an average of 3.5 to 4 percent of manganese and 50,000,000 tons unsampled but probably of similar grade. Of this total about 15,000,000 to 20,000,000 tons is estimated to contain 5 percent or more of manganese, and somewhat over 2,000,000 tons is estimated to contain 10 percent or more.

Further drilling to delimit the ore body in the Lower Chapin block may reveal additional reserves, and many square miles of territory still remain unexplored. It is probably safe to say that the area contains an assured minimum of 200,000,000 tons that averages 3 to 4 percent manganese, of which about 20,000,000 tons contains 5 percent or more and 2,000,000 to 3,000,000 tons contains 10 percent or more.

To what extent these deposits constitute a resource that can be used either now or in some future emergency is a metallurgical and economic problem. Beneficiation by simple gravity methods seems out of the question here because of the physical nature of the ores. The M. A. Hanna Co. has been conducting laboratory research since 1938 on other methods; the Bureau of Mines has recovered metallic manganese from the Artillery ores on a laboratory scale;^{7/} and further work, both by the M. A. Hanna Co. and by the Bureau of Mines, aimed at making these processes adaptable commercially, was in progress in July 1941.

^{6/} Hewett, D. F., and others, op. cit., (Bull. 871), p. 83.
^{7/} Shelton, S. M., Royer, M. B., and Towne, A. P., Electrolytic manganese: U. S. Bur. Mines Rept. Inv. 3406, p. 13, 1938.



ISOMETRIC DRAWING SHOWING DISTRIBUTION OF MINABLE THICKNESSES OF VARIOUS GRADES AND KINDS OF ORE IN THE MAGGIE BLOCK AS INTERPRETED FROM DRILL-HOLE DATA

Table 19.--Reserves of manganese ore in the Artillery Mountains, Arizona,
classified according to kind of ore
[Estimates based on explorations to June 1941]

Kind of ore	Maggie block		Upper Chapin block*		Lower Chapin block		Price block		Totals	
	Tons	Mn (per-cent)	Tons	Mn (per-cent)	Tons	Mn (per-cent)	Tons	Mn (per-cent)	Tons	Mn (per-cent)
Hard ore.....	15,000,000	6.5	400,000	8.0	.....	.....	.....	.....	†15,000,000	6.5
Sandstone ore.....	40,000,000	3.0	20,000,000	4.0	2,000,000	.....	1,500,000	1.5	†65,000,000	3.5
Clay ore.....	25,000,000	3.5	15,000,000	4.0	.....	.....	.....	.....	40,000,000	3.5-4
Total sampled.....	80,000,000	3.75	†35,000,000	4.0	2,000,000	7	1,500,000	1.5	†120,000,000	3.5-4
Unsampled.....	40,000,000	†3	15,000,000	†4	.....	.....	.....	.....	55,000,000	3 -3.5
Grand total.....	120,000,000	3.5	50,000,000	4	2,000,000	7	1,500,000	1.5	†175,000,000	3.5-4

* Basic data not so good as for the Maggie Block, but figures given are believed to be of the right order of magnitude.

† Round numbers given, so totals are not precise.

‡ Estimated.

Table 20.--Reserves of manganese ore in the Artillery Mountains, Arizona,
classified according to grade
[Estimates based on explorations to June 1941]

Mn (percent)	Maggie block									
	South of Maggie Canyon					North of Maggie Canyon*				
	Tons		Cumulative totals		Tons	Cumulative totals		Tons	Cumulative totals	
			Tons**	Grade (percent)		Tons**	Grade (percent)		Tons**	Grade (percent)
Over 20.....	5,000	5,000	5,000	21.5	60,000	60,000	23.0	65,000	65,000	23.0
15-20.....	245,000	250,000	250,000	16.2	140,000	200,000	18.5	385,000	450,000	17.3
10-15.....	1,000,000	1,250,000	1,250,000	12.7	750,000	1,000,000	12.7	1,750,000	2,250,000	12.7
5-10.....	5,000,000	6,250,000	6,250,000	7.9	1,500,000	2,500,000	9.4	6,500,000	8,750,000	8.3
Under 5, sampled†.....	.....	.....	.....	.....	.....	.....	.....	70,000,000	80,000,000	3.75
Total under 5.	.....	.....	.....	.....	.....	.....	.....	110,000,000	120,000,000	3.5
Total Maggie block										
Mn (percent)	Upper Chapin block†					Lower Chapin block				
	Tons		Cumulative totals		Tons	Cumulative totals		Tons	Cumulative totals	
			Tons**	Grade (percent)		Tons	Grade (percent)		Tons**	Grade (percent)
			Tons**	Grade (percent)		Tons	Grade (percent)		Tons**	Grade (percent)
Over 20...	5,000	5,000	5,000	22	500,000	.....	.....	.....	70,000	70,000
15-20.....	5,000	10,000	10,000	20		.....	.....	.....	390,000	460,000
10-15.....	50,000	60,000	60,000	12		.....	.....	.....	1,800,000	2,250,000
5-10.....	7,500,000	7,500,000	7,500,000	7		.....	.....	.....	15,000,000	17,000,000
Under 5, sampled	27,500,000	35,000,000	35,000,000	4	1,500,000	2,000,000	1,500,000	1,500,000	100,000,000	120,000,000
Total	40,000,000	40,000,000	40,000,000	4	1,500,000	2,000,000	1,500,000	1,500,000	155,000,000	175,000,000
under 5.	to 45,000,000	50,000,000	50,000,000	4	1,500,000	2,000,000	1,500,000	1,500,000	155,000,000	175,000,000

* Basic data not so good as for block south of Maggie Canyon. See page 442.

** Round numbers given.

† The lower limit for this material is about 1.5 percent. See page 440.

‡ Basic data not as good as for Maggie block, but figures given are thought to be of the right order of magnitude.

RECOMMENDATIONS FOR FUTURE PROSPECTING

Further explorations in the Artillery area might be directed toward three objectives—obtaining more data on known ore bodies; investigating extensions of known ore bodies not yet fully delimited either in extent or in thickness; and seeking new ore.

The Maggie block should be more closely drilled in order to determine the continuity of some of the higher-grade parts of the hard ore (see pl. 68). The hard ore is the only material in this block that appears adaptable to beneficiation by known methods, and before mining could start it would seem desirable that the tonnage, grade, spacing, and form of the higher-grade shoots of such ore be determined more closely than has yet been done. South of Maggie Canyon, drilling by the Bureau of Mines has delimited the known higher-grade shoots closely enough to give a good idea of reserves and of the form of the deposits; north of the canyon, however, there has been only enough drilling to indicate the presence of discontinuous high-grade shoots.

Should mining be started on the Artillery deposits and a method be devised for treating the sandstone and clay ores, it would be worth while to seek more complete data on the deposits of sandstone and clay ore in the upper Chapin block. As only two holes have been drilled between the known shoots of hard ore in the Maggie Canyon area and the cropping of hard ore in the upper Chapin block, it is not known whether this ore extends continuously between the two localities. There is a good chance, however, that it does so and that minable bodies of hard ore may be found in this interval. The down-dip extension of the ore in the lower Chapin block will doubtless be further explored later, and, should the Artillery deposits ever be mined, ore would presumably be looked for in the Maggie block at horizons below those that have hitherto been reached by drilling.

The areas in which new ore could be sought include (a) Plancha Mountain, (b) the Price block, (c) the down-dip extension of the part of the upper zone that crops out in secs. 23 and 26, T. 11 N. R. 13 W., and (d) the area underlain by the lower zone.

The possibility that there is minable ore beneath the basalt of Plancha Mountain merits consideration, because of the scattered croppings of manganiferous beds through the slide-rock on the flanks of the mountain. In the Price block some of the manganiferous beds below the main zone are as much as 2 or 3 feet thick and very black. They pitch from view below the level of Burro Wash and conceivably may increase below the outcrop to minable size. The small exposure farther up Burro Wash may deserve at least one drill hole, for though the two manganiferous layers that crop out are thin and apparently of very low grade, there is room down-dip for a body of commercial size.

The lower zone and the upper zone where exposed in secs. 23 and 26 consist mainly of barren layers, but both zones are several hundred feet thick and may be more uniformly manganiferous at some other place. How great the chances are that this is so and that the material may be of good grade can be determined only by exploration. Both zones are within reasonable range of drilling from the surface (see geologic sections, pl. 62), and together they underlie many square miles of potential ore-bearing ground.

Any new ore that may be found is likely to be similar both in grade and kind to that found already. New exploration, therefore, however likely it may be to find new ore, can well wait until improved methods of beneficiation have been tried out in treating the great tonnages already known.

Pres. U.S. Bank

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