REPORT OF INVESTIGATIONS

GEOPHYSICAL INVESTIGATION OF MANGANIFEROUS IRON DEPOSITS, BOSTON HILL, GRANT COUNTY, N. MEX.

BY

H. R. Joesting, L. O. Bacon, and J. H. Getz
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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 4175."

2/ Supervising geophysicist, Bureau of Mines.


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INTRODUCTION

For a number of years manganiferous iron ore has been mined on a small scale at Boston Hill, in Grant County, N. Mex. Total production up to 1943 is estimated to be over 793,000 long tons, containing 8 to 35 percent manganese and 26 to 46 percent iron. During 1941 to 1943 production was estimated to be 206,000 long tons, containing about 13 percent manganese and 37 percent iron. During 1944 daily production was several hundred tons, mostly from a single open pit. Several moderately large deposits have been mined, and many smaller ones have been found.

From February to April 1945 geophysical surveys were carried out on Boston Hill by the Division of Geophysical Exploration, in cooperation with District 5, Central Region, Bureau of Mines, to determine if hitherto undiscovered manganiferous iron deposits exist. Field work was interrupted for a total of about 1 month during this period by work on other projects in nearby areas. Previous to the geophysical surveys, a preliminary examination was made by H. R. Joesting to determine if geophysical methods could be utilized in exploring the area.

Field measurements were made by L. O. Bacon and J. H. Getz, project geophysicists of the Bureau of Mines, under the general supervision of H. R. Joesting. A grid survey of the area, to locate geophysical stations, was made by Paul Russell, Bureau of Mines engineer, who also collected specimens for laboratory tests. Most of the computations and the preliminary magnetic and resistivity maps were made by L. O. Bacon.

4/ Entwistle, L. P., Manganiferous Iron-Ore Deposits near Silver City,
   N. Mex.: New Mexico School of Mines, Bull. 19, 1944, p. 36.
5/ Joesting, H. R., The Application of Geophysical Methods to Exploration
   of Certain Mineral Deposits in the Central Mining District, New
FIGURE I.- GEOLOGIC MAP OF BOSTON HILL, NEW MEXICO, SHOWING GRID FOR GEOPHYSICAL SURVEYS.
LOCATION AND PHYSICAL FEATURES

The Boston Hill area adjoins the southwest limits of Silver City, the county seat of Grant County and the principal town in the district, as seen in figure 1. It covers about 2 square miles and is roughly triangular in outline.

The area is one of low hills with moderate slopes. The maximum relief is about 300 feet and the maximum elevation about 6,300 feet. Most of the area is covered by a thin residual soil derived from dolomite.

Mean temperatures vary between 72.6° F. in July and 39.1° F. in January. Mean annual precipitation is about 17.5 inches, the heaviest rains falling during July, August and September. During the winter there are occasional light snows. Ground water stands 40 to 60 feet beneath the surface at lower elevations. At higher elevations the depth to water is unknown, but is considerably greater.

GEOLoGY AND ORE DEpOSITS7/

A nearly complete section of the local Paleozoic formations is exposed in the Boston Hill and surrounding areas (fig. 1). Cretaceous and Quaternary sediments overlie the Paleozoic rocks northwest and south of Boston Hill, respectively. Pre-Cambrian granite underlies the sedimentary rocks.

The Paleozoic rocks have been cut by several hornblende diorite porphyry dikes, which occupy preexisting north-striking faults; and by the Silver City intrusive, a roughly circular mass of quartz monzonite porphyry. The dikes are older than the main intrusive. Both are tentatively regarded as of Laramide age.

Boston Hill lies within a larger region of Laramide deformation which is reflected locally mainly in steeply dipping normal faults. The earliest faults are premineral and strike north to northeast. Some of these are cut by later faults, which strike northwest to west. All of the pre-Quaternary sedimentary rocks dip about 15° south southeast.

Mineralization is confined in the area to Ordovician and Silurian dolomite. Primary mineralization was formed by the replacement of favorable dolomite beds by hydrothermal solutions which ascended along the earlier faults.

According to petrographic studies by the Rella laboratory of the Bureau of Mines the principal hypogene mineral, and the principal source of the manganese and iron, is a carbonate of the rhodochrosite-siderite-magnesite series. Entwistle8/ has identified the mineral as mesitite, a manganese-bearing iron-magnesium carbonate. Minor primary minerals are magnetite, specularite, and

6/ Entwistle, L. F., work cited in footnote 4, p. 11.
7/ Condensed partly from work cited in footnote 4.
sulfides of iron, copper, lead and zinc. Primary gangue minerals are quartz, calcite, dolomite and barite.

Through supergene processes the primary deposits were oxidized and enriched in iron and manganese by removal of valueless carbonates. The supergene ore minerals are iron and manganese oxides and hydrated oxides. Calcite and small amounts of quartz occur in the ore.

Oxidation and enrichment is apparently limited to the zone above ground water, consequently the economic deposits are confined to shallow depths. Like many replacement deposits, the ore bodies are extremely irregular in shape and grade. Even when careful selective mining is practiced, a considerable proportion of the ore is left in small, irregular offshoots or is lost in waste rock.

GEOPHYSICAL EXPLORATION METHODS

An examination of several deposits on Boston Hill showed that appreciable amounts of magnetite and specularite, apparently derived unaltered from the primary deposits, remain in the supergene ore. It was considered likely, therefore, that magnetic methods could be utilized for exploration, especially since the enclosing dolomites are essentially nonmagnetic.

Magnetic minerals are likewise found in the primary deposits, which are not economically important, at least for their iron and manganese content. However, since these deposits occur at greater depths and usually directly beneath the supergene deposits, their effect on the magnetic field at the surface would be generally small and would act chiefly to increase somewhat the intensity of the anomaly.

In connection with the magnetic survey, determinations of magnetic susceptibility and of iron and manganese content were made on specimens collected from most of the known ore deposits in the area. These tests were made to determine if any relation exists between magnetization and tenor of the ore, and whether any of the deposits are likely to be too feebly magnetic to be detected by a magnetic survey.

It was further found that consistent differences in porosity and hardness exist between the ore and the adjoining dolomite. In general, the ore is porous and soft, while the dolomite is dense and hard. These differences, which are accompanied by differences in moisture content, made it apparent that resistivity surveys also could be used to indicate the presence and extent of the oxidized deposits.

MAGNETIC SURVEY

Field Procedure

A temperature-compensated Askania vertical magnetometer, with a sensitivity of 25 gammas per scale division, was used for the magnetic survey. Standard auxiliary magnets were used with the magnetometer to measure variations in the magnetic field beyond the normal scale of the instrument.
FIGURE 3.—SURFACE MAP OF ADONIS FAULT AREA, BOSTON HILL, NEW MEXICO.
FIGURE 4.—SURFACE MAP OF COMANCHE PIT AREA, BOSTON HILL, NEW MEXICO.
A roughly triangular area about 1 square mile in extent was covered by the magnetic survey, as shown in figure 1. Magnetic stations were spaced at 50- and 100-foot intervals on lines 200 feet apart. Detailed measurements were taken on 50-foot grids wherever anomalies greater than about 200 gammas were encountered. Locations of stations are shown on the magnetic maps of the area (fig. 2).

Stations were spaced so that a comparatively large area could be covered rapidly. The spacing used was considered to be sufficiently close to obtain indications of any deposits of possible economic importance, but not necessarily of the smaller ones.

**Results of Magnetic Survey**

As shown in figure 2, numerous deviations from the normal magnetic field intensity were found in the area. A number of these magnetic anomalies are high, but most of them are of small areal extent. They indicate the presence of magnetic bodies, irregular in outline and close to the surface.

Since no similar anomalies are known to be associated with the dolomite country rock or with the few dikes in the area, these magnetic bodies may be manganiferous iron deposits. Many deposits are exposed in mine openings and prospect pits; and direct correlation with their associated anomalies is therefore possible. Others are not exposed, and their possible presence is indicated only by magnetic anomalies.

One comparatively large group of deposits is indicated by an irregular anomalous area extending southeast and south for about 1,000 feet from 111N., 119W. (fig. 2). This area lies southeast of the Comanche pit (fig. 4), where a large oxidized deposit has been mined. According to the magnetic data, these newly indicated deposits are irregular in shape and tenor.

Also shown on the magnetic map are about 25 additional anomalies of small areal extent, but with intensity deviations greater than 1,000 gammas. Most of them lie between coordinates 100N. to 120N. and 84W. to 120W. Some of these anomalies are directly over known deposits exposed in pits; others indicate extensions of known deposits; while the remainder are apparently caused by shallow and for the most part small deposits not previously discovered by prospect workings.

Despite the great number of mine and prospect pits in the area east of the California pit, here called the Adonis-fault area and shown in figure 3, anomalies believed to indicate additional deposits were found in several localities by the magnetic survey. These are shown in figure 2 at 112N., 94W.; at 112W., 90 to 50W.; and in the area between 112N. to 114N. and 86W. to 88W. In the last named area the indicated deposit may be sufficiently large to mine, and all are believed to lie at shallow depths.

Between the Silver Spot fault and the intrusion bounding the Boston Hill area on the east (fig. 1), the ore-bearing dolomites are covered by shale up to several hundred feet thick. It follows that any manganiferous iron deposits that might occur in this area would give rise to comparatively small
anomalies, as measured on the surface. Surface obstructions, including two
cemeteries, prevented obtaining complete magnetic data in the area east of
the Silver Spot fault. The magnetic map nevertheless shows strikingly that
anomalies over the dolomite west of the fault are of near-surface origin,
while those over the shale east of the fault are of deeper origin.

Between the Silver Spot incline and the Silver Spot No. 2 shaft are a
series of low-gradient anomalies that may be caused by manganiferous iron
deposits beneath the shale. It is unlikely, however, that any deposits
which exist under the shale in this locality have been extensively oxidized
and enriched. It was not possible to learn anything of underground condi-
tions because the shafts are caved.

The anomaly at 108N., 81W. may arise either from a deep-lying ore deposit
or an extension of the large, south-striking dike, shown in figure 1. In-
sufficient data are available to determine whether the anomaly originates
close to the surface, or at a depth of 100 feet or more.

The comparatively intense anomaly near 99E., 88W. may be associated with
an ore body formerly worked from the Silver Spot incline. The indicated de-
posit lies close to the surface and on both sides of the fault. It may be
shallower than any of the underground workings, which apparently did not
cross the fault.

Comparatively small anomalies were found in the north and in the west
and southwest parts of Boston Hill. Little evidence of mineralization exists
in much of the west and southwest, hence large anomalies were not anticipated.
Magnetic indications of mineralization were anticipated, however, near the
Fierro No. 1, Second Value, and Apex shafts in the west, and near the shafts
and numerous pits in the north. Even though most of the ore bodies worked
from these openings may be exhausted, it is likely that some material re-
 mains as lean ore and in inaccessible offshoots from the main deposits.

Possible reasons for the absence of large anomalies in these areas are:
(1) the remaining deposits are small or low-grade, (2) they are comparatively
deep, and (3) they are comparatively nonmagnetic.

MAGNETIC SUSCEPTIBILITY DETERMINATIONS

As demonstrated by field tests and by the magnetic survey, many, and
perhaps a majority, of the supergene deposits on Boston Hill are strongly
magnetic compared with the barren country rock. Considerable variations in
magnetization are inevitable, however, because of variations in the intensity
of both primary and secondary mineralization. Accordingly, an attempt was
made to determine the extent to which the magnetization of the ore varies and
particularly if any of the deposits are insufficiently magnetic to be detected
by a magnetic survey. This was done by comparing the magnetic susceptibility
of ore specimens from a number of deposits with their iron and manganese
content.
About 300 specimens, in all, were collected from 42 localities. All of the larger deposits were sampled, as well as many of the smaller ones. Specimens from each locality were approximately representative of the various ore types in that locality, but not necessarily of the average tenor of the deposit. Likewise, no special effort was made to collect specimens on the basis of uniform areal distribution; in fact, proportionately more were collected from areas where magnetic anomalies were small. Three to 10 specimens weighing 1 to 2 pounds each were collected from each of the 42 localities.

Relative susceptibility determinations were made using an astatic magnetometer devised by F. C. Farnham,2/ in which the scale deflection was proportional to the magnetization of the specimen. Using specimens of approximately equal dimensions and a standardized procedure, qualitative susceptibility values were assigned, ranging from 0 to 10 on an arbitrary scale, depending on the deflection produced. Quantitative values could not be determined because of severe disturbances produced by rapidly varying stray magnetic fields caused by street railway operations.

One of the specimens tested was assigned a susceptibility value of zero and yet contained traces of magnetite. It gave a relative reaction too small on the arbitrary scale to be assigned a value higher than zero. Though the value assigned for the specimen was zero, the actual susceptibility was higher than that of the dolomite country rock, which contained no magnetic material. Specimens with a maximum susceptibility of 10 were sufficiently magnetic to deflect a Brunton compass several degrees. A few specimens deflected the astatic magnetometer off scale, but the purpose of this investigation was satisfactorily served by assigning them a value of 10 also.

The assigned susceptibility scale values bear an approximately linear relation to each other, but precise results were not required nor possible to attain. For the same reasons, no attempt was made to distinguish between induced and residual magnetization of the ore specimens.

Specimens from each locality were grouped according to their susceptibility and to their estimated iron and manganese content. Iron and manganese determinations were then made by the Rolla laboratory of the Bureau of Mines.

In the following table are shown the location, iron and manganese content, and relative susceptibility of each group of specimens.

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Location (1/)</th>
<th>Percent (Fe)</th>
<th>Percent (Mn)</th>
<th>Relative susceptibility</th>
<th>Remarks</th>
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**Remarks:**

Iron Spike dump.

Do.

Do.

See footnote at end of table.

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<td>47.5</td>
<td>12.9</td>
<td>3.682</td>
</tr>
<tr>
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<td>1.621</td>
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<td>124N, 102W</td>
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</tr>
</tbody>
</table>

See footnote at end of table.

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According to the susceptibility tests, measurable magnetic anomalies may well exist over all near-surface deposits of commercial size and grade but will vary considerably because of variations within individual deposits as well as between deposits.

The relation between the iron and manganese contents and the susceptibilities of all of the specimens of oxidized ore from Boston Hill is shown in figure 5. In plotting the curves, grouped averages of susceptibility were used because of wide variations in individual specimens.

The increase in mean susceptibility with increased iron, and with increased manganese up to 14 percent, possibly signifies that primary deposition of magnetic minerals was proportional to that of the primary carbonates which were the main source of iron and manganese. The decrease in the manganese curve from a maximum at 14 percent signifies a corresponding decrease in magnetic mineral content in the higher-grade ore, either through dilution of these minerals during deposition of secondary manganese or by their partial alteration.

The decrease in slope of the iron curve for iron contents above 40 percent can probably be attributed to the same secondary enrichment processes. That the slope did not actually become negative as did that of the manganese curve indicates either that there was less secondary enrichment in iron, or that the magnetic minerals were little altered during deposition of secondary iron. It is also possible that some of the secondary iron minerals are magnetic.

Further inspection of the table shows that the magnetization of the ore varies according to locality as well as according to grade. Thus, ore from the Apex, Fierro No. 1, and Second Value shafts and from the Comanche, Raven and North pits has a low susceptibility compared with its iron and manganese.
contents. These mines are all in the western part of the area, where magnetic anomalies are for the most part likewise small. Most of the specimens from the remainder of the area, on the other hand, have a comparatively high susceptibility.

In an attempt to determine whether any relation exists between the magnetization of the ore and its geographic and geologic distribution, susceptibility curves were plotted for specimens from various localities and various formations in the area.

Figure 6 shows that the magnetization of the ore in the west part of Boston Hill is comparatively low and that it decreases in the higher grades. It follows that shallow deposits with no associated large anomalies could exist in this part of the area.

Figures 7 and 8 show that the magnetization of the ore from the remainder of the area is comparatively high and further that it is proportional to the iron content. It follows that correspondingly large magnetic anomalies will probably exist over any large or near surface deposits of commercial ore. The absence of large anomalies in the north part of the area, therefore, indicates that probably no shallow deposits of any consequence remain. Conversely, the existence of many large anomalies in the central part of the area, south of 124N, and between 84 and 112W, indicates the probability that some high-grade deposits remain. Most of them are small, however, according to the small areal extent of the anomalies.

Susceptibility curves for specimens grouped according to geologic formations in which they occur are shown in figures 9 to 12. High-grade ore from the Fusselman dolomite and from the Raven member of the Montoya dolomite was found to have a correspondingly high susceptibility, while that from the El Paso dolomite and from the Par Value member of the Montoya dolomite had a much lower susceptibility. No specimens were collected from the Second Value member of the Montoya formation because few deposits are found in that member.

The curves show that comparatively large anomalies, proportional to the grade of the ore, may exist over deposits in the Fusselman and Raven dolomites and that comparatively small ones, not necessarily proportional to the grade of the ore, may exist over deposits in the El Paso and Par Value dolomites.

The Raven and El Paso curves are based on scant data, consequently they are probably only roughly indicative of actual relations. The lack of sufficient information on ore from the El Paso formation is unfortunate in view of the large anomaly southeast of the Comanche pit. This anomaly is apparently caused by material that is more magnetic than is found in the known deposits in the El Paso formation.

It should be stressed that the curves show generalized or average conditions in various parts or in various formations in the Boston Hill area. Exceptions to these average conditions certainly exist, as witnessed by several high-intensity anomalies in the west part of the area. Likewise, exceptional deposits of low-susceptibility ore may exist in the Fusselman dolomite, although the majority are highly magnetic.
FIGURE 5—RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF BOSTON HILL ORE.

FIGURE 6—RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM WESTERN PART OF BOSTON HILL.
FIGURE 7—RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM CENTRAL AND EASTERN PARTS OF BOSTON HILL.

FIGURE 8—RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM NORTH PART OF BOSTON HILL.
FIGURE 9—RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM FUSSELMAN DOLOMITE.

FIGURE 10—RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM RAVEN MEMBER OF MONTOYA DOLOMITE.
FIGURE 11-RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM EL PASO DOLOMITE.

FIGURE 12-RELATION BETWEEN IRON AND MANGANESE CONTENTS AND MAGNETIC SUSCEPTIBILITY OF ORE FROM PAR VALUE MEMBER OF MONTOYA DOLOMITE.
FIGURE 13. ISORESISTIVITY MAP OF ADONIS FAULT AREA, BOSTON HILL, NEW MEXICO.
FIGURE 14. - ISORESISTIVITY MAP OF COMANCHE PIT AREA.
A detailed geologic and petrographic study would be required to determine the significance of the observed differences in magnetization of the ore in different parts of the area.

RESISTIVITY SURVEY

Field Procedure

Resistivity surveys had little practical value in the Boston Hill area, because the cheaper and faster magnetic survey was in the main successful in locating possible ore deposits. Furthermore, the shallow occurrence of these deposits makes it possible to obtain additional information better by direct prospecting than by additional geophysical exploration. Resistivity surveys were therefore run for experimental purposes only, in selected parts of the area. These surveys consisted of horizontal traverses in the Adonis-fault area and in the Comanche-pit area. Electrodes were spaced to measure earth resistivity to an apparent depth of 80 feet, which is the approximate maximum economic depth for small-scale open-pit mining in the Boston Hill area. In parts of the area 80 feet is also the probable maximum depth of complete oxidation of the ore.

The electrode spacing used was considered suitable for indicating comparatively large deposits, but not the smaller ones, which though numerous are of no commercial value. It also permitted covering the areas chosen more rapidly than if a smaller spacing had been used.

Results of Resistivity Surveys

Iso-resistivity maps of the Adonis-fault and Comanche-pit areas are shown in figures 13 and 14. These areas were chosen for experimental surveys to determine the effects of changes of formation, of faults and dikes, and of a number of ore deposits indicated by magnetic anomalies and by pits.

In the Adonis-fault area the shale, the large dike, and the mineralized areas shown in figure 7 are characterized by low to medium resistivity, while the areas of barren dolomite are characterized by high resistivity. The resistivity of the shale was found to vary between about 8,000 and 30,000 ohm-centimeters; of the dike between 20,000 and 40,000 ohm-centimeters; of the mineralized areas between 25,000 and 100,000 ohm-centimeters; and of the barren dolomite between 100,000 and 150,000 ohm-centimeters. In many cases the resistivity lows found over ore deposits are flanked by pronounced resistivity highs.

Of particular interest is the low-resistivity area between coordinates 113W. to 1141/2W. and 86W. to 88W. This area is also one of intense magnetic anomalies. The coincidence of resistivity and magnetic anomalies indicates the possibility of a higherto unsuspected deposit of economic size.

In the Comanche-pit area the earth resistivity is affected by waste dumps around the large pits and by alluvial deposits in two small valleys in the south part of the area. Despite these disturbing factors, it was possible to distinguish a number of subsurface features and correlate them with geologic features. Of the five lithologic units in the area, the Bliss sandstone was found to have the lowest resistivity, while the Par Value number of the Monteoya dolomite was found to have the highest. Intermediate is resistivity were
the El Paso dolomite and the Raven and Second Value members of the Montoya formation, in increasing order as listed. The lower resistivity of the Bliss sandstone is probably caused by a greater thickness of residuum.

The known ore bodies along the Fierro fault, both southwest and northeast of the Comanche pit, are characterized by low resistivity, as is the ore body at the Raven pit.

A low-resistivity area was also found extending about 1,500 feet south from 111N., 115W. The low resistivity at the south end of this area are caused by a small, alluvium-filled valley which heads at about 101N., 115W. Between 101N. and 115N., however, they are apparently related to subsurface features, and coincide with the zone of maximum intensity of the magnetic anomaly already discussed. The extent of the ore is probably indicated more closely by the resistivity anomaly than by the magnetic, because it is not possible to resolve the combined magnetic effects of near-surface and deeper deposits.

Two additional resistivity lows were found south of the Comanche pit, where there are neither surface nor magnetic indications of ore. Two faults, and possibly others, cross this area, as shown in figure 1. It is doubtful if the faults themselves reduce resistivity values, but they could have served as channels for mineralizing solutions. The absence of large magnetic anomalies cannot be regarded as definite evidence of the absence of mineralization, because the ore from the nearby Apex shaft is comparatively nonmagnetic. These two resistivity lows might therefore be considered as possible indications of ore deposits.

CONCLUSIONS

Both magnetic and electrical resistivity surveys were successful in locating oxidized manganeseiferous iron deposits of possible economic value in the Boston Hill area.

Large magnetic anomalies probably exist over nearly all of the large or shallow deposits, except in the western part of the area. In the west no significant anomalies were found over several shafts, and pits, where some ore presumably remains. Because the ore in the west is slightly magnetic, it is possible that small anomalies at least, would be revealed by detailed measurements over shallow deposits of any considerable size.
FIGURE 2—MAGNETIC MAP OF BOSTON HILL, GRANT COUNTY, NEW MEXICO.