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Titaniferous Magnetite Deposits of the
Laramie Range, Wyoming

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Titaniferous Magnetite Deposits of the Laramie Range, Wyoming*

BY R. A. DIEMER

INTRODUCTION

Titaniferous iron ore deposits in the Laramie Range were first reported in 1850 by Stansbury (22: 266)†. They have since been found at a number of localities in the form of dike-like bodies in an area of 250 square miles of massive anorthosite along the eastern edge of Albany County between South Chugwater Creek and North Sybille Creek (Fig. 1). Considerable interest has been shown at various times as to the possibilities of use of these deposits, particularly the two largest. None of the previous investigators (1: 206-212) (5: 395) (7: 14-16) (8: 14) (11: 420) (12: 352, 355) (13: 64) (14: 13-14) (15: 177) (16: 984-985) (21: 111-125) (23: 429-430) (24: 107-109) provide detailed maps or estimates of tonnage of ore.

The purpose of the writer's investigation was to determine the areal distribution and make estimates of the tonnages in the various deposits. Detailed geologic and topographic maps of the Iron Mountain and Shanton localities were prepared for the purpose of making estimates of the quantity of easily mineable ore. The Iron Mountain deposit was mapped on a scale of one inch to 400 feet, and the Shanton deposit on a scale of 1 inch to 100 feet. Several smaller deposits that had not been described were visited. No detailed petrographic or structural studies were undertaken. Relations of the ore bodies to their host rock were noted, however, so that some conclusions could be drawn as to genesis of the deposits. Six chemical analyses were made, the results of which are presented later in this report.

Field work was carried on for five weeks during the summer of 1939 under the direction of Dr. S. H. Knight, State Geologist‡, and field expenses were furnished by the Geological Survey of Wyoming.

The writer is indebted to Dr. S. H. Knight and Dr. Horace D. Thomas for making possible the preparation and publication of this report, and to Dr. R. H. Beckwith for invaluable aid rendered the writer in every phase of the work. Thanks are also due the Research Chemistry Department of the University of Wyoming for analyses of samples, Dr. A. F. Hagner for aid in thin section work, and Robert J. Farthing for his assistance in the field.

*Thesis submitted to the Department of Geology and the Committee on Graduate Study at the University of Wyoming in partial fulfillment of the requirements for the degree of Master of Arts.

†Numbers in parentheses refer to the list of references on pages 22 and 23. The number following the colon in parentheses gives the page in the reference cited.

‡Resigned, September 1, 1940.

TOPOGRAPHY

The Laramie Range is, in general, an unsymmetric anticlinal mountain range trending southward from central Wyoming across the eastern part of the state and joining the Colorado Front Range. The mountains rise 1,500 feet above the adjoining Laramie Basin to the west to an average elevation of about 8,000 feet. The core of the range is truncated by a gently rolling surface sloping to the east and is cut by many canyons. A large part of the upland is covered by coarse angular residual material many feet thick produced by mechanical weathering of the underlying plutonic igneous rocks. In the surface of the weathered material are wind-excavated hollows, some of which are occupied by small lakes. Rounded bosses of bare rock project prominently above the surface of the residual mantle.

GENERAL GEOLOGY

The core of the eroded arch composed of pre-Cambrian crystalline rocks varies in width from 15 to 30 miles and is flanked on the east and west by Paleozoic and Mesozoic beds forming prominent hogbacks. On the west side these beds have a westward dip of a few degrees; on the east side dips are to the east and much steeper. At numerous places on the east side the beds are overturned, dip to the west, and are cut by westward-dipping thrust faults. In several localities on both sides of the Laramie Range nearly horizontal Tertiary sediments lap onto the pre-Cambrian core.

The oldest rocks in the core are a complex series of gneisses, schists, quartzites, and marbles formed by intense folding and metamorphism of sediments, intercalated sills, and extrusive lava flows. The complex of metamorphic rocks is invaded by a large anorthosite mass with gabbroic differentiates and titaniferous magnetite dikes. The anorthosite forms the center of the crystalline core. Metamorphics are found within the anorthosite along its outer border and between the anorthosite and the Paleozoic sediments. The gabbroic differentiate of the anorthosite is distributed in small patches within the anorthosite or in scattered areas along the border. The gabbro is later than the anorthosite and in one locality cuts through and carries small xenoliths of anorthosite. The titaniferous magnetite cuts both the gabbro and anorthosite. The Sherman granite batholith surrounds the anorthosite area, and Sherman granite in the form of dikes cuts all of the pre-Cambrian rocks of the region, indicating that it is the youngest of the group. Several facies of the granite, from typical Sherman granite to the extreme end-stage differentiates of pegmatites, graphic granite, and pure quartz, are present. Quartz veins cut the anorthosite at several places.

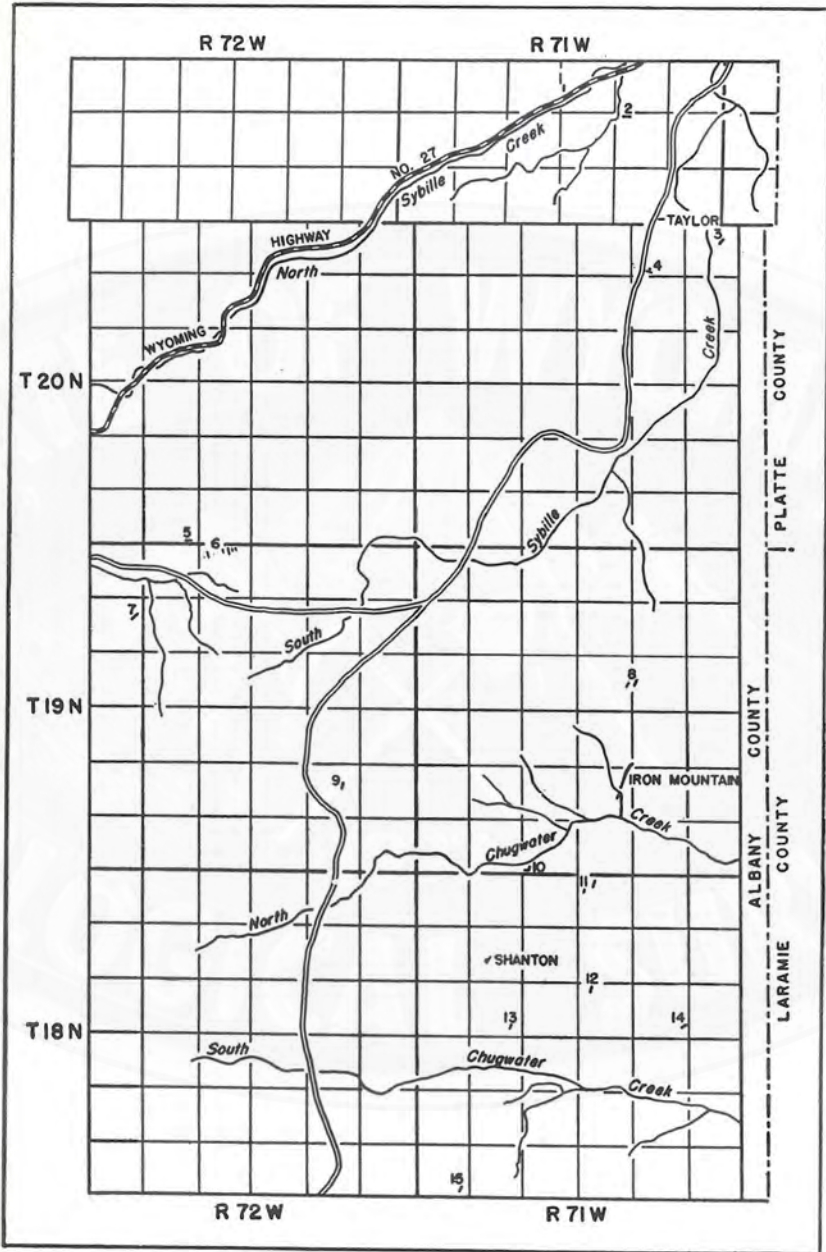


Fig. 1. Index map showing location of the deposits.

DESCRIPTION OF DEPOSITS

IRON MOUNTAIN

Iron Mountain (Fig. 1) is located on the eastern border of the anorthosite area in secs. 22, 23, 26, and 27, T. 19 N., R. 71 W., one-half mile west of the Paleozoic sediments along the east flank of the Laramie Range. It lies 40 miles northeast of Laramie by road and approximately 9 miles northwest of Farthing Station on the C. B. & Q. Railroad. In 1872 a wagon road was built to Iron Mountain from the east, but the road is no longer passable. In 1873 Iron Mountain postoffice was established at the base of the ridge and was abandoned the following year. In 1897 and 1898 the Colorado Fuel and Iron Company shipped several tons of ore to their smelters at Pueblo, and to the writer's knowledge this is the only commercial shipment of ore.

Because of the absence of any points of known elevation in the vicinity, the map (Fig. 2) was begun from a point whose elevation was established at the dike by aneroid barometer. Undoubtedly this elevation was not true elevation above sea level, and consequently contour lines do not show true elevations. Relief is shown to an accuracy of several tenths of a foot, as the mapping was done with plane table and telescopic alidade. A number of small dikes occur, but, because of their relatively small size, they are not shown on the map.

Iron Mountain is a northward-trending ridge rising 600 feet above North Chugwater Creek, which flows south along the west side of the ridge, turns east, and cuts through the ridge in a precipitous gorge. The ridge stands out sharply above the surrounding terrain and is covered with rounded blocks of titaniferous magnetite.

The main Iron Mountain dike varies in width from 50 to 250 feet and extends for nearly a mile along the crest of the ridge. The dike is a black granular holocrystalline rock, which generally weathers to smooth surfaces. Pitted surfaces are produced where olivine crystals weather out with production of limonite. A white crust of calcium carbonate coats the ore in many places, especially in crevices. At the highest point on the dike a fracture from 1 to 2 inches wide filled with angular ore fragments in a matrix of carbonate cuts across the dike. Limonite commonly occurs along fractures and joint surfaces. Strike and dip of joints in the dike at the north end differ greatly from those at the south end. There is no consistent relation between strike and dip of joints in the dike and those in the adjacent anorthosite. Polished surfaces of the dike rock show a granular aggregate of medium to coarse grains of magnetite, ilmenite, and intergrown magnetite-ilmenite. Small amounts of spinel, olivine, and limonite are present. The magnetite-ilmenite intergrowth is in the form of a fine interpenetrating network of ilmenite lamellae along octahedral parting in the magnetite. Many of the ilmenite grains are twinned and show strain effects.

The dike is intruded into massive anorthosite, a medium- to coarse-grained rock consisting almost entirely of labradorite. The only well exposed contact between the main dike and the anorthosite is on the east side 200 feet south of the creek. Here the surface of the dike

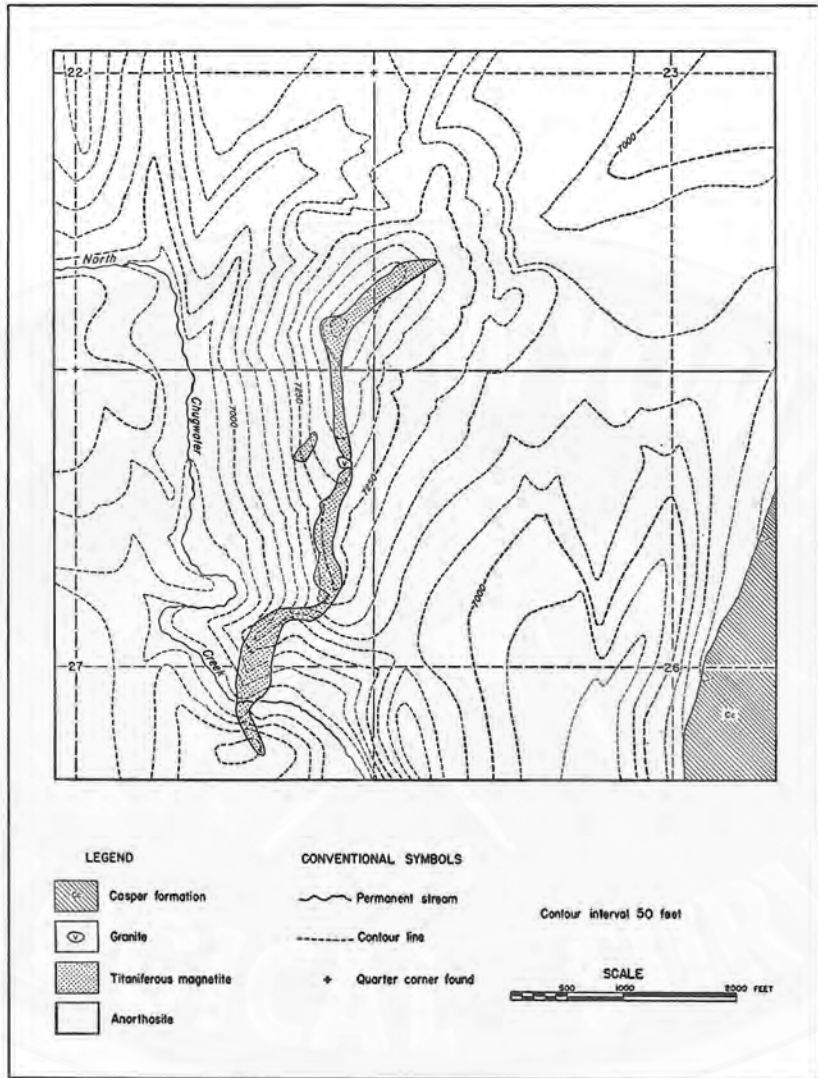


Fig. 2. Geologic and topographic map of Iron Mountain.

material is slickensided, and for a foot from the contact the adjacent anorthosite is fine breccia and gouge. These relations may have been caused by faulting long after solidification of both of the rocks in contact, but suggest faulting during dike intrusion.

An irregular mass of granite consisting of quartz, microcline, orthoclase, and biotite cuts the anorthosite and titaniferous magnetite near the center of the main dike. A granite dike two feet wide, not shown

on the map, cuts the same rocks about 200 feet north of North Chugwater Creek. There are crushed and deeply weathered zones 6 inches wide at both contacts of the magnetite-ilmenite and the granite.

On the west side of the mountain are 8 small magnetite-ilmenite dikes striking northeast. One of these, 150 feet downslope from the crest of the ridge and about 250 feet southwest of the mapped granite mass, is 50 feet long, maintains a constant width of 5 feet throughout most of its length, and shows sharp contacts with the anorthosite. Another minor dike 900 feet west of the small granite mass is 80 feet long and 30 feet wide, and shows sharp contacts with the anorthosite. On the north side of the creek 700 feet downstream from the east side of the main dike a minor dike 5 feet wide strikes north, extends 50 feet upslope, and presents sharp contacts with the anorthosite. South of Chugwater Creek and 300 feet from the east side of the main dike a minor magnetite-ilmenite dike 150 feet long and 20 feet wide strikes southwest. The sharp vertical contact between the dike and anorthosite is well exposed and shows normal anorthosite abutting directly against a band of magnetite-ilmenite 1 foot wide; the band in place contains almost 50 percent of olivine. Between this band and the solid magnetite-ilmenite of the interior of the dike there is a soft crumbly band 2 feet wide composed of magnetite-ilmenite, olivine, and plagioclase. In the middle of the crumbly band is a band of magnetite-ilmenite 1 inch wide standing vertically and parallel to the anorthosite contact.

Between this dike and the south end of the main Iron Mountain dike there is a lens-shaped body of magnetite-ilmenite 90 feet long and 25 feet wide striking northeast and dipping approximately 40 degrees to the southeast. The strike and dip correspond to the strike and dip of one of the main sets of joints in the anorthosite, indicating that the magnetite-ilmenite may have been intruded along a joint in the anorthosite. There are small off-shoots from the main dike apparently injected along fractures in the anorthosite, as the anorthosite is fractured for about 2 inches from the contacts.

Two thousand feet west of the main Iron Mountain dike and on the crest of a high ridge sloping to the south there is a group of three dikes. The largest, 225 feet long and 20 feet wide, strikes N. 70° E. The two smaller ones lie 450 feet south of the large one, strike north, are approximately 125 feet long, and vary from 20 to 30 feet in width. No sharp contacts with the anorthosite can be seen, and the ore appears to be of the same character as that of the main dike.

Approximately 1,000 feet south of the center of sec. 22, on the crest of a ridge, are two minor dikes striking north. The larger is about 10 feet wide and extends for 100 feet; the smaller is 3 feet wide and extends for about 15 feet. No contacts with the anorthosite are exposed.

Outside of the mapped area (Fig. 2) and 1,000 feet north of the center of sec. 22 is a minor dike 80 feet long and 10 feet wide striking north. Contacts of the dike are not exposed. Approximately 700 feet southeast of the south end of the main dike there is a minor dike striking north and extending for 300 feet along the crest of a low ridge. The

dike varies in width up to 20 feet, and its contacts are not exposed. This dike locally contains as much as 10 percent of olivine.

Megascopically there appears to be little difference between the ore from the main Iron Mountain dike and that from the smaller dikes. Although polished surfaces of materials from the smaller dikes were not prepared, it is probable that they have the same proportions and relations of magnetite and ilmenite as the material from the main dike.

An estimate of tonnage of ore in the main Iron Mountain dike from the surface down to the elevation of the creek at the gorge was made on the basis of the assumptions that the dike contacts continue vertically in depth, i.e., that the dike does not pinch or swell downward, and that the average specific gravity of the ore is 4.9. Using this specific gravity a ton of ore has a volume of 6.53 cubic feet. The surface area of the dike between two adjacent contours was determined by use of a planimeter, and the mean elevation between the two contours was used to determine depth to the 6,825-foot level. By the procedure described the figure 43,936,000 tons was obtained as the amount of ore in the dike above the 6,825-foot level. Mining operations above this elevation would not be complicated by ground water. Tonnage per foot of depth of the dike is approximately 113,000. There are no indications that the dike thins in depth. If it does, however, there would still be many million tons of ore above creek level.

Three samples of the Iron Mountain ore were analyzed for V_2O_5 , TiO_2 , and Fe by H. H. Spieth, Instructor in Chemistry, and for P_2O_5 by Otto McCreary, Associate Research Chemist, both at the University of Wyoming. The samples were selected along a straight line across the dike 200 feet north of the gorge. Samples 8-A and 8-J were taken 25 feet in from the contacts and 8-E in the middle of the dike. The analyses are as follows:

Sample No.	V_2O_5	TiO_2	Fe	P_2O_5
8-A	0.37%	28%	50%	0.0%
8-E	0.35	27	52	0.0
8-J	0.46	27	52	0.0

The analyses indicate that there is little or no variations in TiO_2 content across the dike and also show that theoretically the ore is 52 percent ilmenite. Magnetite and ilmenite form complex solutions (18: 30), and titanium may be present not only as TiO_2 in pure ilmenite ($FeTiO_3$) but also as titanium oxide in solid solution in magnetite (23: 419). This is probably the explanation for the failure of attempts to prepare high iron concentrates of the ore by magnetic separation (21: 124).

The V_2O_5 was determined because only two of the previous analyses of Iron Mountain ore (6: 10) include it, and the recovery of vanadium from ilmenite has frequently been seriously proposed, as methods of extraction are technically practicable (9: 908). Kemp (11: 396) infers that, as vanadinite is isomorphous with apatite, V_2O_5 replaces some of the P_2O_5 in the apatite assumed to be present in the Adirondack ores. On this basis it was considered possible that the Iron

ANALYSES OF IRON MOUNTAIN ORE

	1	2	3	4	5	6	7	8	9
TiO ₂	23.49%	23.32%	23.18%	22.43%	21.75%	19.47%	21.85%	20.68%	14.06%
SiO ₂76		2.15	1.21					1.64
Fe ₂ O ₃	45.03		48.97	47.21					83.43
FeO.....	17.96		24.55	25.80					
Al ₂ O ₃	3.98								
Cr ₂ O ₃	2.45							.16	
Mn ₂ O ₃	1.53								
CaO.....	1.11								1.14
MgO.....	1.56								.22
ZnO.....	.47								
P.....	Trace							.011	.036
S.....	1.44		.03	1.14				.04	.03
Fe.....	45.49	50.83	53.33	51.72	52.31	54.48	51.93	49.66	58.40

1. J. P. Carson, Analyst, Preliminary report of the U. S. Geol. Survey of Wyoming and portions of contiguous territories: p. 14, 1878.
2. O. D. Allen, Analyst, Geol. Expl. 40th Par. Rept: vol. 2, p. 14, 1878.
3. Prof. Richards, Analyst, Geol. Expl. 40th Par. Rept: vol. 2, p. 15, 1878.
4. W. C. Knight, Analyst, Univ. of Wyo. Experiment Station Bull. 14, p. 177, 1893.
5. A. C. Fieldner, Analyst, U. S. Bureau of Mines Bull. 64, p. 120, 1913.
6. A. C. Fieldner, Analyst, U. S. Bureau of Mines Bull. 64, p. 120, 1913.
7. A. C. Fieldner, Analyst, U. S. Bureau of Mines Bull. 64, p. 120, 1913.
8. E. C. Sullivan, Analyst, U. S. Geol. Survey Bull. 315, p. 209, 1907.
9. Analysis by Columbia Engineering Works, U. S. Geol. Survey Bull. 315, p. 209, 1907.

ANALYSES OF IRON MOUNTAIN ORE

	10	11
Ferric Oxide	36.24 %	45.26 %
Ferrous Oxide	28.18	23.21
Silica	4.00	0.54
Titanium Oxide	22.85	23.00
Aluminum Oxide	7.25	6.79
Chromium Oxide	0.031	0.026
Manganese Dioxide	0.077	0.042
Sulphur Trioxide	0.056	0.035
Vanadium Oxide	0.402	0.367
Zirconium Oxide	Trace	Trace
Total	99.086	99.270
Metallic Iron	47.27 %	49.70 %
Titanium	13.71	13.80
Sulphur	0.056	0.034
Phosphorus	None	None

10. Analysis made in the Union Pacific research laboratories; Union Pacific Industrial Circular No. 3, p. 10, 1929.
11. Analysis made in the Union Pacific research laboratories; Union Pacific Industrial Circular No. 3, p. 10, 1929.

Mountain ore might have a high V_2O_3 content, as apatite is an abundant mineral in some of the dikes of the Laramie Range. The small amount of V_2O_3 and the lack of P_2O_5 in the analyses indicate that the V_2O_3 is not present as a replacement in the apatite molecule. Vanadium-bearing titaniferous magnetites from Mine Centre, Ontario (10: 213), are similar in composition to the Iron Mountain ore. In the hope of obtaining information concerning the manner of occurrence of the vanadium in these Canadian ores, spark spectra were produced. The failure to obtain vanadium lines shows that the amount of vanadium is too small for its presence to be disclosed by this mode of excitation. The V_2O_3 content of the Iron Mountain ore is comparable with that of the titaniferous magnetites from other parts of the world (11: 396) (10: 213) (9: 908), in which the vanadium content is invariably reported as less than half of one percent.

Previous analyses of Iron Mountain ore given on page 10. In general there is little difference between analyses, and, except for a slightly lower TiO_2 content, they differ but little from the analyses made by Spieth and McCreary.

SHANTON DEPOSIT

The Shanton deposit is located 4 miles southwest of Iron Mountain on the old Shanton ranch in the $NE\frac{1}{4}SW\frac{1}{4}$ sec. 8, T. 18 N., R. 71 W., and is easily accessible by a road from the Bridger ranch 3 miles west of the deposit. This and the Iron Mountain deposit are the only ones which have been described in the literature. In the topographic mapping of the deposit (Fig. 3) the elevation of the starting point was established by aneroid barometer, and contour lines probably do not show true elevations above sea level. Relative elevations are accurate within several tenths of a foot, as the mapping was done with plane table and telescopic alidade.

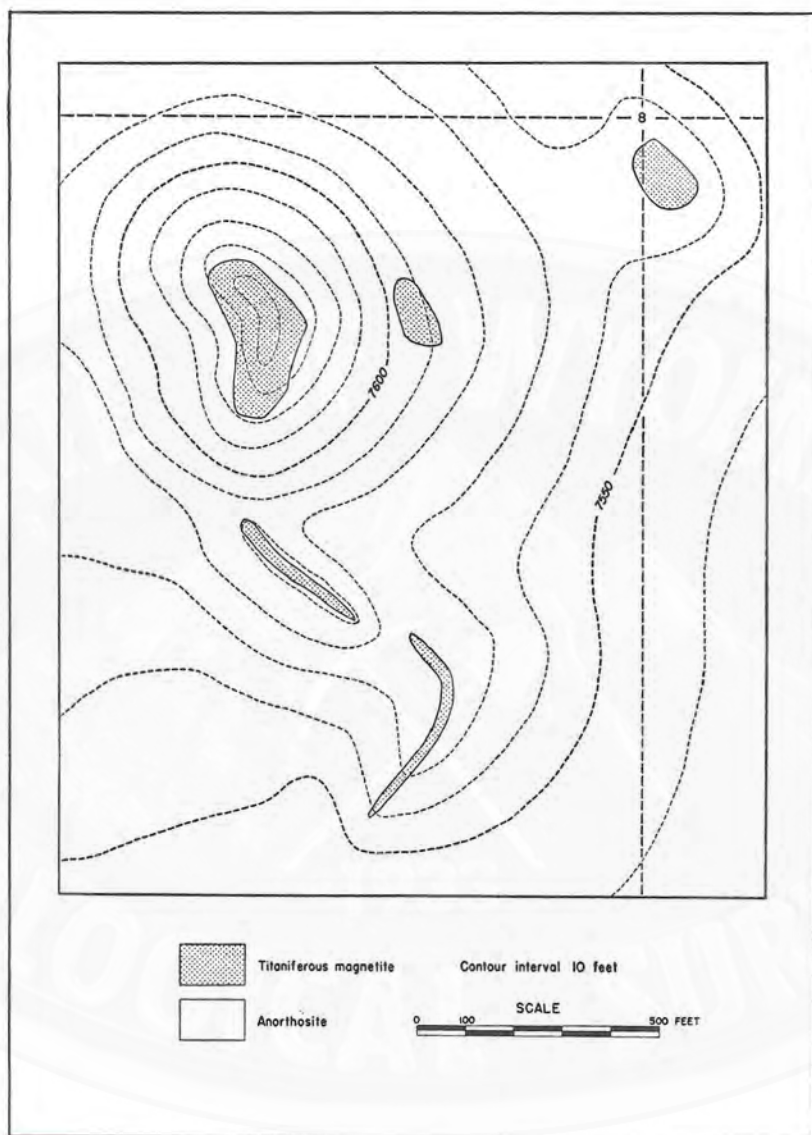


Fig. 3. Geologic and topographic map of the Shanton deposit.

The dikes occur in an area of low relief and form the summits of small hills covered by loose pieces of magnetite-ilmenite. They occur in massive anorthosite cut by granite dikes and, although no sharp contacts between dikes and anorthosite are exposed, are apparently of the same intrusive nature as the dikes at Iron Mountain. The two southern-

most are probably parts of the same body and are connected a short distance underground.

Megascopically the magnetite-ilmenite is identical with that at Iron Mountain except that no olivine is visible. A polished surface of the dike rock shows a granular aggregate of interlocking magnetite and ilmenite grains, and ilmenite intergrowths in the magnetite. The ilmenite occurs within the magnetite as intersecting elongated bands along octahedral parting and as irregular blebs of varying sizes.

If one uses the same assumptions and methods for estimating tonnage as at Iron Mountain, the deposit contains approximately 11,890 tons of ore per foot of depth.

A sample of the ore taken from the center of the largest dike was analyzed by H. H. Spieth for V_2O_5 , TiO_2 , and Fe, and by Otto McCreary for P_2O_5 . The results are as follows:

Sample No.	V_2O_5	TiO_2	Fe	P_2O_5
B-2	0.53%	25%	51%	0.0%

The analysis indicates that there is essentially no difference between the Iron Mountain and Shanton ores. The following analyses show a TiO_2 and Fe content similar to the above analysis.

ANALYSES OF SHANTON ORE

Analysis No.	TiO_2	Fe
1	21.08%	51.50%
2	19.98	52.98

1. Analyst, A. C. Fieldner, U. S. Bur. Mines Bull. 64, p. 120, 1913.
2. Analyst, A. C. Fieldner, U. S. Bur. Mines Bull. 64, p. 120, 1913.

TAYLOR DEPOSIT

The deposit (Fig. 1) is located on the old Taylor ranch in the SE $\frac{1}{4}$ sec. 35, T. 21 N., R. 71 W. Eight separate patches of magnetite-ilmenite protrude slightly above the surrounding anorthosite (Fig. 4). No contacts between magnetite-ilmenite and anorthosite are exposed, but there appears to be no gradation between the anorthosite and ore, as no rock types intermediate between typical anorthosite a few feet from the dike and the magnetite-ilmenite were found. Locally the magnetite-ilmenite contains as much as 60 percent of apatite; in thin section small amounts of pleonaste and mica are associated with the magnetite-ilmenite. In places the apatite occurs in bands, which are apparently parallel to the dike contacts. A polished surface of the material shows the metallic mineral to be almost entirely ilmenite with only a very small amount of magnetite. This may not be the case throughout the deposit as only one polished surface was prepared. The ilmenite is commonly twinned and surrounds and includes euhedral crystals of apatite, indicating later crystallization of ilmenite.

If results are based on the same assumptions as those used for Iron Mountain, the deposit contains approximately 2,382 tons of ore per foot of depth. A sample with high apatite content was selected from the large dike in the northeast portion of the map (Fig. 4) and

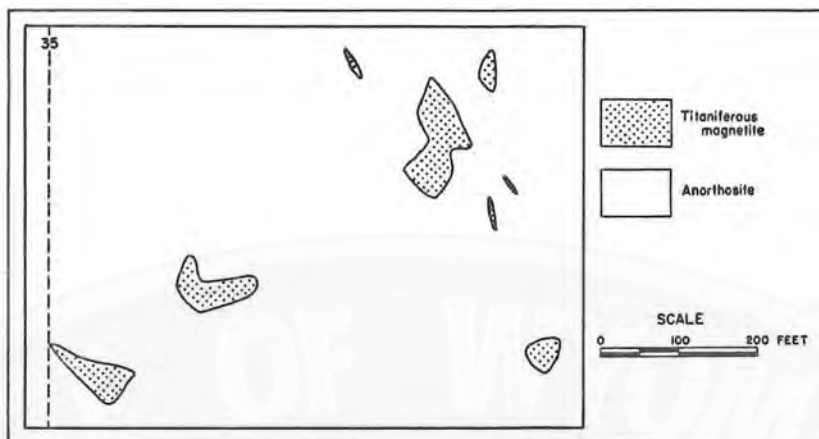


Fig. 4. Geologic map of the Taylor deposit.

analyzed by H. H. Spieth and Otto McCreary. The results are as follows:

Sample No.	V ₂ O ₅	TiO ₂	Fe	P ₂ O ₅
90	0.32%	5%	32%	12.8%

The high P₂O₅ and low TiO₂ and Fe content is to be expected because of the large amount of apatite present in the sample. The low V₂O₅ content, even lower than that of the Iron Mountain samples in which no apatite was visible, is more evidence that V₂O₅ does not replace P₂O₅ in apatite. To the writer's knowledge no other analyses of this ore have been made.

DEPOSIT NO. 1

The deposit, located in the SW $\frac{1}{4}$ sec. 22, T. 21 N., R. 71 W., lies about 1,500 feet north of Wyoming Highway No. 27. It is an irregular dike, strikes north, varies in width from 5 to 100 feet, and extends for 400 feet along the crest of a high anorthosite ridge.

The contact of the dike and country rock is well exposed in a prospect hole near the north end of the dike. The granite is the youngest rock, as it cuts through and includes small xenoliths of the others. The gabbro is apparently a differentiate of the anorthosite, and contacts of the dike with gabbro and anorthosite are sharp; no definite age relations between the gabbro and anorthosite could be determined. Included in the dike material was one small xenolith of anorthosite, indicating the later age and intrusive character of the magnetite-ilmenite.

The dike contains locally an abundance of apatite, and also small amounts of pleonaste and biotite associated with the magnetite-ilmenite. A polished surface shows anhedral interlocking grains of magnetite and ilmenite. In the single surface examined none of the ilmenite intergrowths in magnetite, common to the Iron Mountain ore, were observed.

An average sample of the ore was analyzed by H. H. Spieth and Otto McCreary. The results are as follows:

Sample No.	V ₂ O ₅	TiO ₂	Fe	P ₂ O ₅
306	0.34%	19%	47%	2.12%

Except for the P₂O₅ content and somewhat smaller percentages of TiO₂ and Fe, which are explained by the presence of a small amount of apatite, the composition is similar to that of Iron Mountain and Shanton ores. That V₂O₅ is not present as a replacement in apatite is further substantiated by this analysis. The writer knows of no other analyses of this ore.

DEPOSIT No. 2

The deposit is a single dike in the NW $\frac{1}{4}$ sec. 26, T. 21, N., R. 71 W., 50 feet south of the boundary between secs. 26 and 23. The dike strikes east, extends for 600 feet along the crest of a low anorthosite ridge, and varies in width from 5 to 20 feet. No contacts are exposed. The dike appears to be cut near the east end by a northward-striking granite dike. The ore appears to be of the same character as that at Iron Mountain.

DEPOSIT No. 3

This is a small, poorly defined dike in the NE $\frac{1}{4}$ sec. 1, T. 20 N., R. 71 W. The dike occurs in the anorthosite on the east flank of a low hill, strikes N. 70° E., and, because of the mechanical weathering and resultant cover, definite contacts are uncertain. Length probably does not exceed 20 feet and width 3 feet. The ore resembles that at Iron Mountain.

DEPOSIT No. 4

The deposit, consisting of two dikes, is on the old road from Bosler to Wheatland in the SW $\frac{1}{4}$ sec. 2, T. 20 N., R. 71 W. The dikes are intruded into the anorthosite and both strike N. 80° E. No contacts are exposed. The larger dike is 75 feet long and 10 feet wide; the smaller is 8 feet long and 5 feet wide. The dike rock appears to be similar to that at Iron Mountain.

DEPOSIT No. 5

A dike in the SE $\frac{1}{4}$ sec. 32, T. 20 N., R. 72 W., 1,000 feet west of the southeast corner of sec. 32 and 100 feet north of the township boundary, occupies the crest of a small ridge trending east. Because of weathering of the dike and surrounding anorthosite no definite dike outline could be determined. Length does not exceed 30 feet and width varies from 1 to 2 feet.

DEPOSIT No. 6

The deposit is made up of five separate dike-like bodies, one in the NW $\frac{1}{4}$ sec. 4, and four in the NE $\frac{1}{4}$ sec. 4, T. 19 N., R. 72 W. The dike in the NW $\frac{1}{4}$ sec. 4 is irregular in outline, extends 300 feet northwest, and is 100 feet wide. One-fourth of a mile northeast of the above

dike is another, 40 feet long and 2 feet wide, striking northwest. Eight hundred feet east of this dike is an irregular mass 500 feet long and 250 feet wide striking northwest. The deposit is poorly exposed, but appears to be a number of closely spaced parallel dikes striking northwest. Four hundred feet to the east is a dike 50 feet long and 3 feet wide. Four hundred feet farther east is another dike of the same size. Both of these dikes strike northwest.

The dikes are in anorthosite cut by quartz syenite. The dikes have a banded structure. Dark bands containing a high percentage of magnetite-ilmenite alternate with lighter bands containing a small percentage. The lighter bands are composed principally of labradorite and pyroxene with considerable apatite. The bands are parallel to contacts of the dikes and anorthosite. In thin section the magnetite-ilmenite is seen to occur interstitially between anhedral crystals of labradorite and pyroxene and in part replaces them. This would indicate that the magnetite-ilmenite was the last mineral to crystallize. Apatite occurs as euhedral crystals within the other minerals and is the earliest product of crystallization. Although no contacts are exposed, a gradation between dikes and anorthosite is not probable, as typical anorthosite with no change in character extends to within three feet of the dike rock. The banded structure of the dikes and kind of minerals present support the theory that the dikes were formed by an iron-rich gabbroic magma within which partial differentiation took place as it was intruded into the anorthosite.

DEPOSIT No. 7

The deposit extends for 1,500 feet along the southeast side of a northeast-trending ridge in the $S\frac{1}{2}NE\frac{1}{4}$ sec. 7, T. 19 N., R. 72 W. It is apparently not a continuous dike, but consists of four dikes striking northeast along a straight line. The two western bodies are 10 feet wide and 300 feet long with a 200-foot covered interval between them. The two eastern dikes are 20 feet long, vary in width from 1 to 2 feet, and are separated by a 500-foot covered interval. A trench on the southeast side of the northern dike shows magnetite-ilmenite in sharp contact with anorthosite, and successively to the southeast in a distance of 20 feet there are bands of hornblende schist, biotite schist, and graphite schist enclosed in a granite gneiss. Schistosity is generally parallel to the dike.

A polished surface of material from the second dike from the west shows no ilmenite. The ore consists entirely of coarse-grained magnetite with a small amount of limonite along grain contacts.

DEPOSIT No 8

The deposit consists of six dikes lying along the boundary between secs. 14 and 15, T. 19 N., R. 71 W. Two are in sec. 14 and four in sec. 15. The dikes occur in massive anorthosite; no contacts are exposed. One of the dikes in sec. 15 appears at irregular intervals for about 250 feet along the crest of an east-trending ridge; the widest exposure is about 50 feet. A granite dike striking north cuts the dike near the center of the ridge. Five hundred feet southwest of the above dike are

three small dikes striking east. The largest is 80 feet long and 5 feet wide; the two smaller ones are both 30 feet long and from 1 to 2 feet wide. In sec. 14, 100 feet northeast of the above dikes and 400 feet west of a fault block of Casper limestone, is a dike 70 feet long and 3 feet wide striking north and extending up the south side of an east-trending ridge. No contacts are exposed. Six hundred feet north of this dike is a deposit almost square in outline and approximately 100 feet on a side. The dike and anorthosite are weathered, and no contacts are exposed. The ore appears to be of the same character as that at Iron Mountain.

DEPOSIT No. 9

The surface of the deposit shows a patchy distribution of magnetite-ilmenite extending 400 feet in a straight line along the west flank of a northward-trending ridge in the $S\frac{1}{2}NE\frac{1}{4}$, sec. 26, T. 19 N., R. 72 W. Maximum width is 3 feet. The deposit occurs in weathered anorthosite. Most of the dike rock is soft and crumbly and contains abundant limonite. Small stringers of magnetite-ilmenite extend into the anorthosite, and both are cut by granite-pegmatite.

DEPOSIT No. 10

A dike on the crest of a high anorthosite knob, in the $SW\frac{1}{4}$ sec. 33, T. 19 N., R. 71 W., strikes east for 330 feet, turns sharply, and strikes north for 350 feet. Width varies from 110 to 150 feet. Contacts with the anorthosite are not exposed. Limonite is found along joints and fractures, and the ore is similar to that at Iron Mountain.

DEPOSIT No. 11

Two dikes occur in the anorthosite in the $NW\frac{1}{4}$ sec. 3, T. 18 N., R. 71 W. The larger strikes north on the crest of a high ridge, is 150 feet long, and 8 feet wide. The smaller lies 1,000 feet to the southwest and is 15 feet long and from 1 to 2 feet wide. Contacts with the anorthosite are not exposed. The ore resembles that at Iron Mountain.

DEPOSIT No. 12

A dike strikes north across the nose of a low anorthosite ridge in the $NW\frac{1}{4}$ sec. 15, T. 18 N., R. 71 W. The dike is 30 feet long and varies in width from 25 feet at the north end to 2 feet at the south end. Sharp contacts between the dike and anorthosite show an eight-inch zone of crushed and altered anorthosite and calcium carbonate between solid anorthosite and the magnetite-ilmenite. The dike apparently thickens underground, as the contacts dip outward near the south end.

DEPOSIT No. 13

A dike in the anorthosite in the $SE\frac{1}{4}$ sec. 17, T. 18 N., R. 71 W., strikes $N. 20^{\circ} E.$ for 180 feet. It maintains a width of 40 feet for 80 feet from the south end and beyond this a width of 10 feet. Contacts are covered. Ore resembles that at Iron Mountain.

DEPOSIT NO. 14

The deposit consists of ten dikes in the SE $\frac{1}{4}$ sec. 14, T. 18 N., R. 71 W., about 1,000 feet west of the Paleozoic sediments. Six occur along the crest of an anorthosite ridge trending northeast. The other four lie a few hundred feet to the northwest on the southeast flank of another anorthosite ridge trending northeast. The largest dike is 300 feet long and 50 feet wide; the next largest is 100 feet long and 40 feet wide. They both strike northeast, and may be connected. The rest of the dikes vary in length from 30 to 50 feet and in width from 2 to 4 feet. No contacts are exposed. The ore seems to be of the same character as that at Iron Mountain.

DEPOSIT NO. 15

A dike in the anorthosite in the SE $\frac{1}{4}$ sec. 31, T. 18 N., R. 71 W., is 50 feet long and from 2 to 3 feet wide. No contacts are exposed. The ore is very noticeably magnetic and, in megascopic appearance, resembles that of Iron Mountain.

GENESIS OF THE DEPOSITS

The mode of origin of titaniferous magnetites has been the subject of much discussion, and many theories to account for their genesis have been advanced. A few deposits have been thought to inject the country rock as dikes, but most have been considered as having been formed by magmatic segregation. One event that must have taken place at some time during the history of all of the deposits is a segregation and concentration of magnetite-ilmenite from a parent magma, probably also the parent of anorthosite. Whether this was by liquidation, sinking of early formed crystals, gaseous transfer, diffusion, Ludwig-Soret effect, convection, or gaseous tension is a problem beyond the scope of this paper. The problem considered here is whether the deposits are dikes or products of magmatic segregation in place. On this subject the conclusions of Singewald (21: 121), which are essentially the same as those of Lindgren (16: 984), Kemp (12: 352) (13: 64), and Ball (1: 210) are as follows:

“That the deposit is not a magmatic segregation in situ is evident, and the relations are such as to establish beyond doubt the intrusive character of the ore. The relations existing between anorthosite and deposits of titaniferous iron ores in other regions as in Canada, the Adirondacks, Minnesota, and elsewhere, make it most probable that the anorthosite and iron ore came from the same parent magma. Deepseated magmatic segregation took place. The anorthosite was intruded, and subsequently the iron ore body was intruded into it in the same manner in which the igneous dikes were intruded. The Iron Mountain deposit is therefore the analogue in basic igneous rocks of the large deposits in acidic igneous rocks, of which Kiruna, in Sweden, is the most striking example.”

Fowler (5: 395, 401) states that the relation of the magnetite-ilmenite to the anorthosite is similar to that of the gabbro, and that the deposits have not been intruded as dikes. She says,

"The magnetites do not seem to have penetrated in a dike-like form as did the granitic pegmatites, but to have collected in place. The Iron Mountain magnetite lens shows no evidence of having moved otherwise than with the anorthosite magma itself—the titaniferous magnetite lenses are the end-stage differentiates, or pegmatites, of the anorthosite. Probably because of the viscous nature of the anorthosite itself, the lenses stayed where they segregated, and did not move freely as did the pegmatites of the granite."

That the magnetite-ilmenite deposits are dikes checks with field evidence as seen by the author. If the deposits are magmatic segregations in place, gradational contacts between magnetite-ilmenite and anorthosite would be expected. This is not the case at a single deposit where contacts are exposed. That the magnetite-ilmenite moved through the anorthosite is well substantiated by evidence in the form of a slickensided gouge and breccia at the contacts, the xenolith of anorthosite in the magnetite-ilmenite at Deposit No. 1, and the banded structure of the dikes of Deposit No. 6. That the deposits were probably intruded along planes of weakness in the hot anorthosite is shown by their generally elongate shape, location at the margins of the anorthosite, lack of chilled borders of magnetite-ilmenite against anorthosite, and the general northward trend. In one case, Deposit No. 6, banding within the dike indicates that differentiation was still in progress during intrusion.

In summary, wherever contacts between deposits and anorthosite are exposed, the intrusive nature of the magnetite-ilmenite is evident enough to permit the statement that the deposits intrude the anorthosite in the form of dikes. The term "magmatic injections" has been applied to similar dike-like bodies of magnetite-ilmenite which were differentiated and segregated in depth and then intruded into anorthosite.

POSSIBLE USES OF THE DEPOSITS

FOR IRON

The term titaniferous magnetite is used to designate magnetic iron ores containing more than 2 or 3 percent of titanium (21: 9). Large deposits are known in many parts of the world, but the ores are not used at present as a source of iron because smelting costs are higher than for other iron ores. Experimental attempts toward industrial use of titaniferous magnetites for their iron content have taken two different approaches, (1) special smelting treatment, and (2) elimination of titanium by concentration.

Extensive experiments on smelting were carried out in 1892 by A. J. Rossi (20: 832-864). He showed that slags and pig-iron of excellent quality could be obtained by smelting ores containing 20 per-

cent of TiO_2 , but concerning the cost of the smelting he stated only that it was fairly economical. At this time titaniferous iron ores were being smelted in Canada and Sweden, but at the expense of an enormous increase in fuel consumption above that for other types of ores (20: 865). Iron has been produced by reduction in the electrical furnace, but the experimental data summarized by Ball (1: 212) indicate that the process could be used commercially only when electric energy is very cheap and fuel very expensive.

Singewald (21: 124), working with polished surfaces of Iron Mountain ore, found that ilmenite grains large enough for magnetic separation formed 15.3 percent of the surface and, if perfect separation of these grains were obtained, there would still remain a concentrate with 13.2 percent of TiO_2 . He also shows that there is little advantage in grinding finer than 50 mesh. This is to be expected, as the writer's microscopic examination of a polished surface shows that the ilmenite intergrowths in magnetite are too minute to be separated by 100-mesh crushing. Indications are that a grind somewhat finer than 1,000 mesh would be necessary. It is very improbable that a separation involving such fine grinding could be made profitably under present conditions in the metallurgical industry.

The U. S. Bureau of Mines has carried out experiments in magnetic concentration by heat treatment of the minerals and use of an alternating current magnetic separator, called the H^e separator (3: 105) (4: 3-15). By using a variation in field intensity two samples of heat-treated titaniferous magnetite were separated into a number of fractions varying in composition between 4 and 21.7 percent of TiO_2 . This, however, would probably be of little use in obtaining an iron concentrate from the Iron Mountain ores.

Experiments with the magnetic separation of vanadium-bearing titaniferous magnetites similar in composition to the Iron Mountain material and magnetic concentration of iron sands were made by the Canada Department of Mines (10: 213-218) (10: 97-98). The experiments resulted in concentrates with a TiO_2 content only slightly lower than that of the original ore.

As a result of this experimental work in concentration and smelting it is probable that use of the deposits, at present, as a source of iron ore is not economically feasible.

FOR VANADIUM

Nearly all titaniferous magnetites carry small quantities of vanadium. The vanadium content of the Iron Mountain ore, less than half of one percent, is similar to that of most of the titaniferous magnetites of the world (11: 392). Recovery of vanadium from titaniferous magnetites has frequently been proposed, but it has been found, after careful experimentation, that, although methods of extraction are technically practicable, vanadium can be obtained more cheaply from other sources (9: 908).

FOR TITANIUM

Commercial uses of titanium in recent years have increased rapidly. Imports of ilmenite into the United States increased from 153,993 long tons in 1937 to 201,545 tons in 1938. Because of its great whitening and obliterating power, titanium dioxide is employed widely in paint, rubber, linoleum, leather, plastics, soap, printing inks, paper, textiles, and ceramics. The chief use is in the paint industry, which accounts for nearly 90 percent of the total consumption. The next largest use of titanium is probably in the metallurgical industry as ferrotitanium to deoxidize iron and steel and as an alloying element in aluminum, copper, nickel, iron, and steel (2: 286). Titanium dioxide in the form of powdered rutile has been found of great value as a coating for welding rod. Miscellaneous uses are in smoke screens, sky writing, pyrotechnics, arc light electrodes, tanning, abrasives, medicinal and toilet preparations, and tinting of artificial teeth. Ilmenite, used chiefly for making titanium pigments and to a smaller extent for ferro-alloys, is produced in the United States in Virginia, Arkansas, and California, but the main supply is imported from British India, by far the world's largest producer (17: 759).

It seems entirely possible that the Wyoming deposits could be used as a source for titanium dioxide, particularly those containing a large amount of apatite, such as Deposit No. 1 and the Taylor deposit. Polished surfaces of material from these show that the metallic mineral is principally ilmenite. Magnetic separation from the apatite would not be difficult, and the apatite might be used in production of commercial phosphate. The average composition of the 50-100 mesh tailings in Singewald's concentration experiments on Iron Mountain ore (21: 124) was Fe 30.71 percent, TiO_2 38.29 percent. This TiO_2 content corresponds to tailings containing 73 percent of ilmenite. Analyses of marketed ilmenite concentrates from the world's principal producing areas show a TiO_2 content varying between 36 and 60 percent (9: 906). Concentration of the Wyoming ores might easily produce a product that would compare favorably in TiO_2 content with these ores.

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