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IRON MOUNTAIN TITANIFEROUS MAGNETITE DEPOSITS, FREMONT COUNTY, COLO.

By R. M. Becker, S. S. Shannon, Jr.
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UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
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IRON MOUNTAIN TITANIFEROUS MAGNETITE DEPOSIT, FREMONT COUNTY, COLO.[1]

by

R. M. Becker,[2] S. S. Shannon, Jr.,[3] and C. K. Rose[4]

INTRODUCTION AND SUMMARY

As part of the Bureau of Mines program for examining the Nation's iron and titanium resources, magnetic, gravity, and geologic surveys were made to permit an estimate of the extent and magnitude of the Iron Mountain, Colorado, titaniferous magnetite deposit.

Gabbro is the dominant rock type of the area. Within the gabbro are lenses of titaniferous magnetite, 5 to 25 feet wide and as much as several hundred feet long. These lenses comprise a zone which has scattered occurrences of magnetite for 2,200 feet. To the west, the gabbro grades into a strip of pyroxenite that in turn borders a large monzonite mass.

A wedgelike broadening of the pyroxenite with depth accompanied by little or no increase in the titaniferous magnetite is considered a reasonable interpretation of the field data. The iron deposits appear to be limited and discontinuous.

ACKNOWLEDGMENTS

This investigation was made under a cooperative fellowship agreement, dated July 1, 1956, between the Bureau of Mines and the Colorado School of Mines and was the subject of a master's thesis in geophysics. The School of Mines provided the gravity meter and the magnetometer used in this survey, and Prof. Paul Rodgers of the geophysics department offered much valued advice and assistance.

The Bear Creek Mining Company furnished their field susceptibility meter. The Burroughs Corporation installed a demonstration computer at the Denver

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[1] Work on manuscript completed April 1960.
[2] Mining methods research engineer, Denver Mining Research Center, Bureau of Mines, Denver, Colo.
[3] Mining engineer, Division of Mineral Resources, Bureau of Mines, Denver, Colo.
[4] Supervising mining engineer (deceased), Division of Mineral Resources, Bureau of Mines, Denver, Colo.

Mining Research Center in the summer of 1959; it proved helpful in the interpretation of the gravity data.

Special acknowledgment is due the owners and lessee of the property for their interest and cooperation in the field investigation.

LOCATION AND ACCESSIBILITY

The Iron Mountain titaniferous magnetite deposit is in the south-central part of Fremont County, Colo., 12 miles southwest of Canon City and 15 miles north-northeast of Westcliffe. The area investigated by the Bureau of Mines is northwest of Pine Creek in secs. 3 and 4, T. 20 S., R. 72 W., 6th principal meridian (fig. 1).

A line of the Denver and Rio Grande Western Railroad follows the Arkansas River from Canon City to Texas Creek, 16 miles northwest of Iron Mountain.

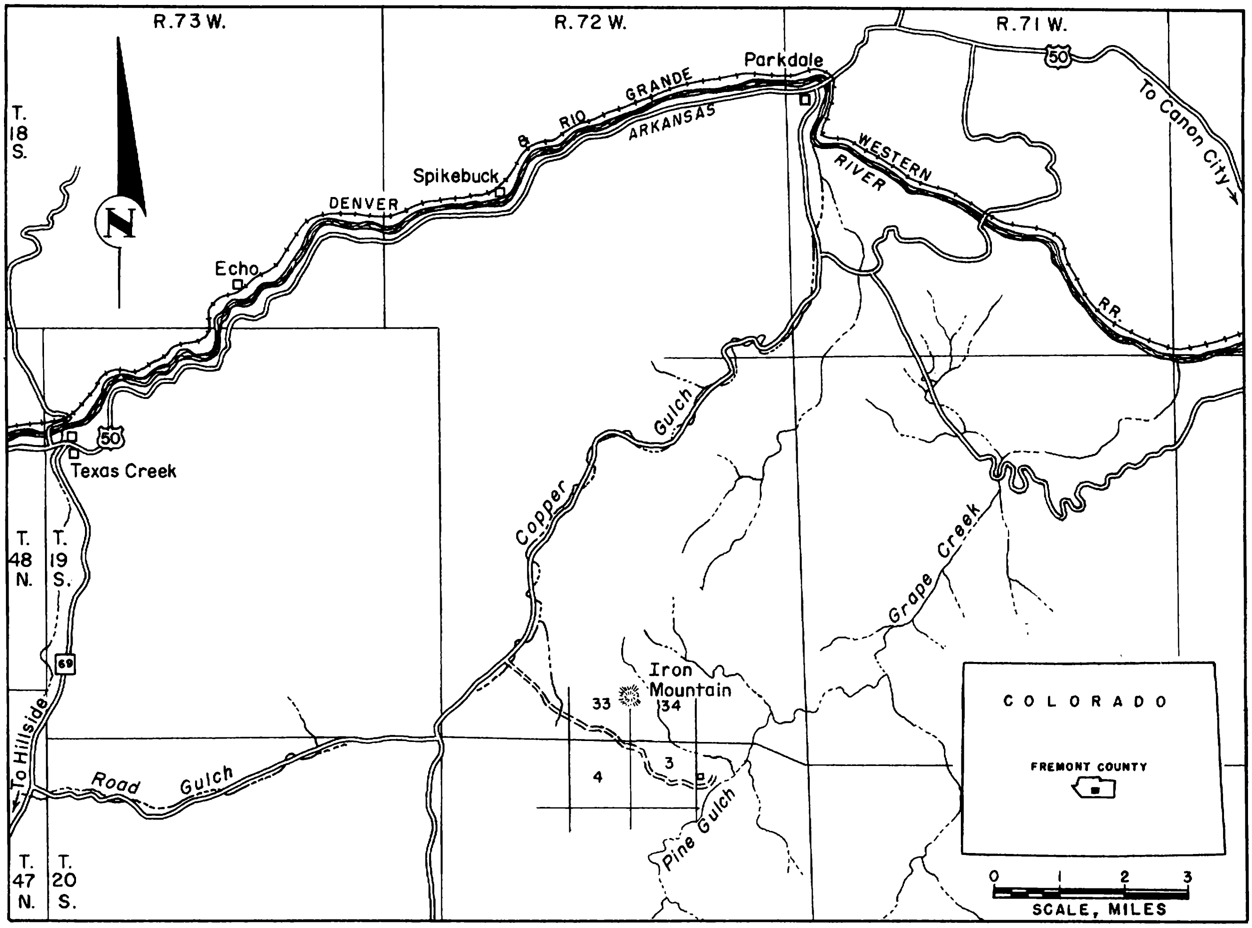

FIGURE 1. - Location Map, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.

Topographic coverage of the area is provided by an advance print of a U.S. Geological Survey 7½-minute quadrangle (Canon City No. 2 SW.) with a scale of 1:62,500. The area is also covered by the Forest Service map of the San Isabel National Forest published in 1948 by the U.S. Department of Agriculture.

PHYSICAL FEATURES AND CLIMATE

The topography is partly mountainous with relief seldom exceeding 1,200 feet; intermittent streams dissect the area. Pinons grow along the slopes and hills, and grass sparsely covers the lower areas. Grazing in the lower elevations is the major land use.

The titaniferous magnetite deposit is in the northwest part of a mile-long alluvial basin just south of Iron Mountain. The grid area ranges from 7,000 to 7,350 feet in altitude.

Pine Creek, which borders the alluvial basin on the east, has a limited flow of water during dry periods. Adequate water for a sizable mining operation could probably be obtained by drilling a shallow well in the alluvial gravel of Pine Creek near its intersection with Iron Wash. Additional water could be obtained from Grape Creek, approximately 4½ miles southeast of the deposit.

The climate of the Iron Mountain area is characterized by moderate winters and cool summers. The mean annual temperature is 42.9° F. at Westcliffe, Colo., 15 miles south-southwest of the deposit at an altitude of 7,860 feet. The average annual precipitation at Westcliffe is 16.65 inches, most of which occurs in the spring and summer. The mean annual snowfall is 78.5 inches; maximum depths accumulate in March and April. The precipitation at Westcliffe probably exceeds that at Iron Mountain because of the proximity of Westcliffe to the Sangre de Cristo Mountains.

HISTORY AND PRODUCTION[5]

Claims on the Iron Mountain titaniferous magnetite deposit were patented in 1872, and small-scale production began in 1873. Ore was hauled by wagon to Canon City and then by rail to the steel mill at Pueblo. Prior to 1880, ownership of the deposit passed to the interests controlling the Pueblo mill--predecessors of The Colorado Fuel and Iron Co. In 1880, a branch line of the Denver and Rio Grande Western Railroad was constructed from Canon City up Grape Creek to Silver Cliff. This line, abandoned in 1888, passed within 4½ miles of the Iron Mountain deposit. Plans made to construct a spur to the deposit were never carried out, probably because of the discovery that the high titanium content made the ore unsuitable for iron and steel. Total production from the deposit prior to 1955 probably did not exceed a few thousand tons.

[5]Adapted from Singewald, J. T., The Titaniferous Iron Ores in the United States: Bureau of Mines Bull. 64, 1913, pp. 128-129.

The Colorado Fuel and Iron Co. sold its Iron Mountain holdings in 1945. Subsequently, several transfers of the property occurred. In 1947, the ownership passed to A. C. and H. L. Ellison of Hillside, Colo. In 1959, the deposit was owned by six members of the Ellison family.

The Fremont Construction Co. and its successor, the Florence Aggregate Co., produced magnetite aggregate in 1955 and 1956. These companies operated a screening and crushing plant capable of producing 150 tons per day of minus ¼-inch aggregate. The crushed product was trucked to Texas Creek, Colo., and shipped by rail to Texas for use as a heavy aggregate in the concrete coating for pipelines to be sunk underwater. An aggregate having a minimum specific gravity of 4.25 was required for this use. There was no production from the deposit during 1957-60.

DESCRIPTION OF DEPOSIT

Four principal Precambrian rock types are in the immediate area of the deposit. A large mass of monzonite occurs along the western edge of the mapped area. A strip of pyroxenite, as much as 600 feet wide, commonly borders the monzonite and grades into gabbro, which covers most of the remaining area. Within the gabbro are lenses of magnetite, 5 to 25 feet wide and as much as several hundred feet long. In addition, dikes of intermediate composition transect the gabbro, pyroxenite, magnetite lenses, and possibly the monzonite.

The lenses of titaniferous magnetite are restricted to several discontinuous, subparallel zones in the gabbro which trend N. 25° E. to N. 15° W. Most of the lenses have steep westerly dips. Scattered occurrences of magnetite have been mapped for 2,200 feet along the strike of these zones. Near the outcrops the overburden contains much magnetite float.

The contact of the magnetite with the gabbro is normally sharp or gradational over several inches; the percentage of plagioclase decreases and iron content increases from the gabbro toward the magnetite. Along the south wall of the main pit, the transition zone includes several alternating layers of magnetite and gabbro that concordantly underlie the main magnetite lens. This layering of magnetite and gabbro was also observed elsewhere. In addition to the normal contact between magnetite and gabbro, three fault or shear contacts were observed in two pits. Away from the pits the gabbro-magnetite contact is commonly obscured by overburden.

The transition from gabbro to pyroxenite is gradational but may extend several hundred feet; the percentage of ferromagnesian minerals gradually increases towards the pyroxenite. The only outcrop showing the contact between gabbro and monzonite is in the southwest part of the mapped area. The contact is a shear zone with fragments of gabbro and titaniferous magnetite included in the monzonite. In other places the pyroxenite facies of the gabbroic rock adjoins the monzonite. Although the contact is obscured by float, it may be traced easily for 2,000 feet by the sharp line of demarcation between the dark-colored pyroxenite and light-colored monzonite float.

The plagioclase laths in the magnetite are often alined or oriented along a preferred plane. In places it is possible to determine the attitude of this gneissic structure which always approximately parallels the attitude of the enclosing magnetite lens. The gneissic structure in the gabbro, caused by the alinement of ferromagnesian minerals, is somewhat less distinct but is occasionally mappable. Within several hundred feet of the magnetite lenses, the gneissic structure in the gabbro is also subparallel to the attitude of the lenses. These orientation features proved helpful in tracing the occurrences of magnetite.

Monzonite

Monzonite is mainly restricted to a large mass that borders the western edge of the map area. The weathering of this coarse-grained rock forms a distinctive buff-colored rubble composed of subhedral crystals of feldspar. Pinkish-gray orthoclase and light-gray plagioclase are the chief minerals. Dark-gray to black biotite, hornblende, and magnetite are the principal accessory minerals; sericite and limonite occur as alteration products.

Pyroxenite

Pyroxenite occurs on Iron Mountain and on a line of prominent knobs extending southwestward from Iron Mountain along the western margin of the mapped area. Weathering of the pyroxenite produces dark-gray blocks and rubble along the slopes and dark-gray pyroxenite sand in the washes.

This medium- to coarse-grained rock is marked by a few plagioclase crystals and occasional limonite spots. The principal mineral is augite. Plagioclase (An_{54}), biotite, magnetite, and spinel are common accessory minerals; apatite, hornblende, and olivine are less common. Alteration products include limonite, sericite, and perhaps some hornblende.

The pyroxenite grades into gabbro. In the field, this transition zone was mapped as pyroxenite if the mafic minerals appeared predominant and as gabbro if the plagioclase appeared predominant. The gneissic structure in the pyroxenite transition zone is mappable in places.

Gabbro

Gabbro is the principal rock cropping out in the mapped area and is the dominant rock type except along the western margin.

The gabbro is commonly a medium-grained gray phanerite. One specimen, however, has a fine granular texture. The essential minerals are augite and plagioclase (An_{38} - An_{80}). Magnetite, olivine, and biotite are the principal accessory minerals. Hornblende and spinel are less common. Sericite and limonite occur as secondary minerals.

The alinement of mafic minerals occasionally produces a gneissic structure that is mappable. In the vicinity of magnetite lenses, the gneissic structure is subparallel to the attitude of the lenses. This structure, however, is not apparent in hand specimens.

Titaniferous Magnetite

Titaniferous magnetite occurs in a series of subparallel, discontinuous lenses along an arc that strikes from N. 25° E. to N. 15° W. The lenses, as much as 25 feet thick and over 400 feet long, generally dip steeply to the west. Scattered outcrops have been mapped along the arc for 2,200 feet.

The massive, dark-gray titaniferous magnetite is marked by laths of light-gray plagioclase (An_{37}). Magnetite, the chief mineral, is accompanied by a variable amount of plagioclase and is closely associated with ilmenite and spinel. Other accessory minerals include augite, biotite, and olivine. Under the microscope, rims of light-brown pleochroic hornblende commonly separate magnetite from plagioclase. Sericite, limonite, and much of the hornblende occur as alteration products.

The plagioclase laths in the magnetite often have a preferred orientation. Where the attitude of this orientation can be determined, it is always approximately parallel to the attitude of the enclosing magnetite lens. The longest lens of magnetite was traced by following the strike of this orientation from outcrop to outcrop.

Dikes

Numerous dikes of diorite, andesite, quartz monzonite, phonolite, and basalt occur in the mapped area. They generally have northwesterly strikes and steep dips. They transect the gabbro, pyroxenite, and magnetite lenses and perhaps to a lesser degree the monzonite; however, little mapping was done beyond the monzonite contact.

The light-gray diorite dikes have three distinct textures: coarse-, medium-, and fine-grained. The coarse-grained to pegmatitic diorite approaches anorthosite in mineral composition. The andesites are characterized by scattered phenocrysts in pale brown, gray, or red ground masses. The quartz monzonites are light brown to reddish orange, and the one phonolite dike is a medium-gray aphanite. Megascopically, the basalt differs from the phonolite in having a darker gray color and calcite-filled cavities.

WORK BY THE BUREAU OF MINES

J. T. Singewald of the Bureau of Mines examined the deposit in 1912 during a study of the titaniferous iron deposits of the United States.[6] In 1948-49 the Bureau of Mines conducted a limited dip-needle survey of the deposit. A 2,100-foot north-south base line was established, and east-west crosslines, generally less than 500 feet long, were set on 100-foot intervals. The dip-needle survey consisted of recording observations every 5 feet along the crosslines within the area of magnetite; it indicated, within reasonable limits, the outline of most ore occurrences. Six surface samples were taken

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[6] Singewald, J. T., The Titaniferous Iron Ores in the United States. Their Composition and Economic Value: Bureau of Mines Bull. 64, 1913, 145 pp.

for partial analysis and metallurgical evaluation. Partial analyses and approximate locations of these samples are listed in table 1. Samples 1 through 5 were titaniferous magnetite, and sample 6 was pyroxenite.

TABLE 1. - Partial analyses and location of samples

Sample No.	Percent Fe	Percent TiO_2	Approximate location on present grid
1	49.0	14.0	1,050 ft. S. and 100 ft. E.
2	47.9	13.5	2,150 ft. S. and 200 ft. E.
3	48.6	13.7	2,100 ft. S. and 300 ft. E.
4	50.7	14.1	1,750 ft. S. and 200 ft. E.
5	49.4	13.9	450 ft. S. and 400 ft. E.
6	12.9	3.2	1,400 ft. S. and 1,000 ft. W.

Survey Control and Geologic Mapping

In 1958 a 4,400-foot base line was established due north along the trend of the deposit and coordinated with the land subdivisions and the 7½-minute Canon City No. 2 SW. quadrangle. Initially, 42,800 feet of crosslines were extended normal to the base line at 400-foot intervals. Later, 5,900 feet of crosslines were added within the grid area at 200-foot intervals, and a central crossline was extended 2,000 feet westward. These line extensions and additions were made to obtain additional geophysical detail (fig. 2).

Geophysical stations were generally at 50-foot intervals along the base line and the crosslines. Some smaller intervals were used near the main pit, and 200-foot intervals were used along the westward extension off the main area. All horizontal control was maintained by using a theodolite and steel tape.

Vertical control for the grid area was carried 1 mile east from a point of known elevation on the Canon City No. 2 SW. quadrangle. This point was accurate within a foot, so absolute elevations will have this accuracy. Using a self-leveling level, relative elevations of all geophysical stations were established to within a tenth of a foot.

The grid-survey control was a great aid to the geologic and topographic mapping. A map of the 1.2 square miles incorporating the grid and surrounding region with a scale of 1 inch equals 200 feet and a contour interval of 10 feet was made with an alidade and planetable (fig. 3). During the topographic mapping an outcrop map was also made (fig. 4). Rock specimens were collected from the grid area, and their densities were determined. Thin sections were made of the major rock types, and the mineral composition and rock classification was determined by examination with a petrographic microscope. This work was done in the Bureau of Mines laboratory at Denver, Colo.

Magnetics

Magnetic observations were made at 954 stations using a vertical-intensity magnetometer. The magnetometer was used as a null instrument by

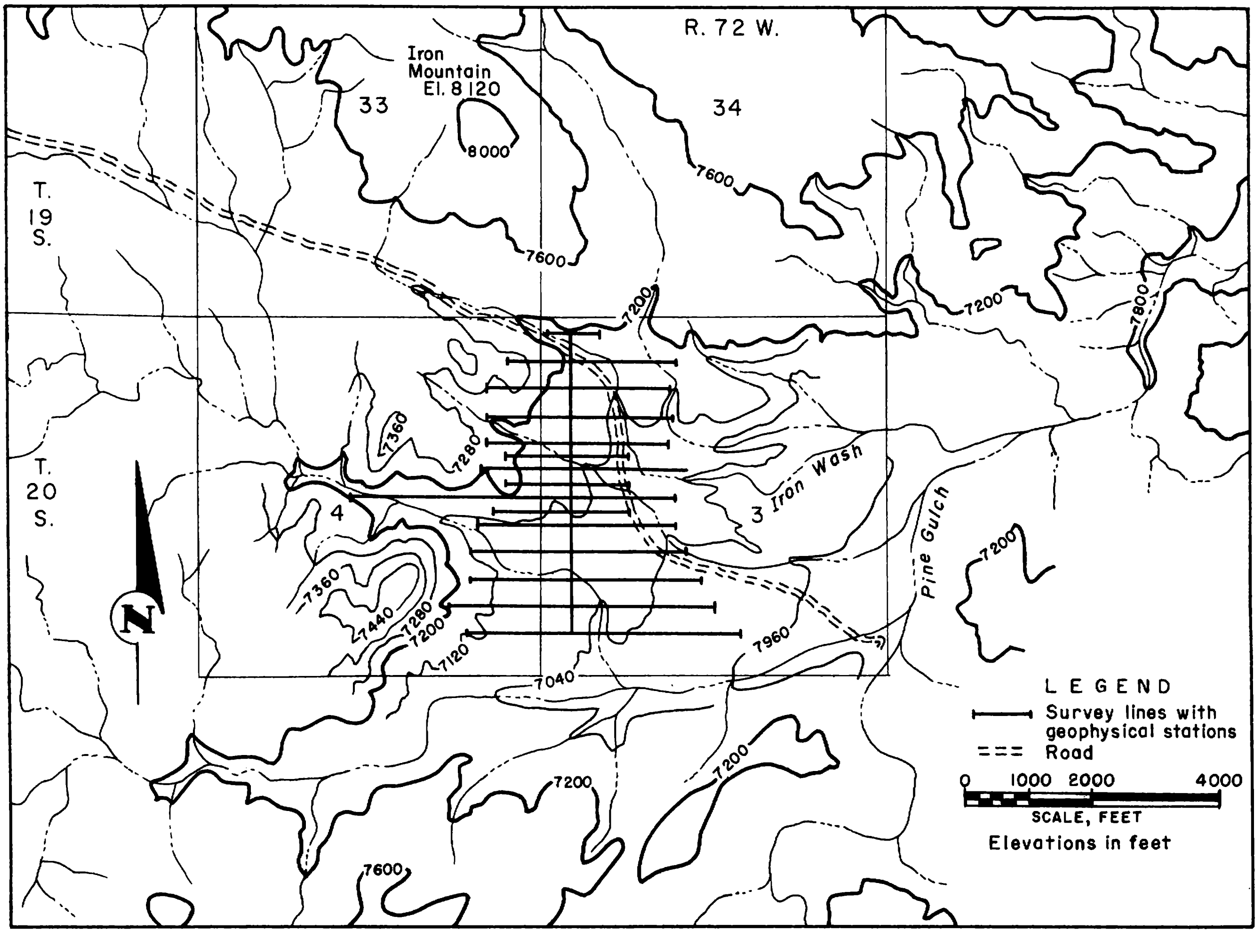

FIGURE 2. - Grid Location Map, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.

using the field from the calibrating coil to cancel the earth's field at each station. The magnetic intensity was calculated from the milliamperes of coil current necessary to zero the magnetometer, the direction of the current in the coil, and the coil constant in gammas per milliampere. The usual procedure is to record the magnetic intensity directly. The method used was ideal for the area covered; areas of extreme magnetic relief could be traversed rapidly without losing accuracy in the readings over areas of low magnetic relief.

The operation required two men. Between stations the magnetometer operator carried the magnetometer, tripod, and a belt-attached potentiometer case; the notekeeper carried the calibration coil and a case containing the milliammeter, battery, and leadwires. At the station the magnetometer operator leveled the tripod plate and oriented it with a compass. The magnetometer was locked on the oriented plate and leveled. The calibrating coil, now connected to the milliammeter by a plugged-in leadwire, was placed over the magnetometer. The magnetometer operator plugged the leadwire into the potentiometer case to complete the circuit. As the magnetometer balance was released, the magnetometer operator adjusted the potentiometers on his belt to vary the coil current and return the balance to zero. Meanwhile, the notekeeper, on signal, reversed the current direction and set the milliammeter on the most sensitive range possible. When the magnetometer was zeroed, he recorded the milliamperes, current direction, and other pertinent data.

The magnetometer was set at 79 gammas per scale division. The nulling accuracy was less than a tenth of a scale division, so the magnetometer accuracy was within about 5 gammas. Thus, the accuracy of the observation was largely dependent on whether two or three significant figures could be read on the sensitive multirange milliammeter. With the equipment used, the range of the magnetometer was better than -60,000 gammas to +60,000 gammas with an accuracy of generally three and sometimes two significant figures. Only once was this range exceeded in the survey.

Two magnetic observations, 180° apart, were taken at each station. Over areas of high magnetic relief, 3- to 4-minute intervals between readings were usual, whereas over areas of low magnetic relief, the interval between readings was 2 to 3 minutes. Ninety to one hundred stations were commonly occupied each day. Base checks were taken at least every 2 hours. With a more modern magnetometer the method would be faster; the magnetometer and calibrating coil could be kept on the tripod between stations, and the orientation could be omitted. The method may have more application in regions of high magnetic relief. The advantages of the method are the use of one instrument with a wide magnetic range, accuracy that depends on the magnitude of the magnetic field, and fairly rapid coverage.

The observations ranged from -36,700 gammas to more than +63,200 gammas. The field data were reduced for instrument drift and plotted on a map. The drift corrections in regions of more extreme magnetic relief were often not significant. The magnetic-contour map was constructed from the reduced data; each of the plotted stations along the survey lines represents the location at which a magnetic reading was taken (fig. 5). Because of the extreme values caused by surface or near-surface magnetite, the contouring was restricted to the range from -2,000 gammas to +10,000 gammas with a 2,000-gamma contour interval. Areas above +10,000 gammas are lineated, and areas below -2,000 gammas are crosshatched.

Susceptibility measurements were made in the field using a Mooney[7]-type susceptibility meter. These measurements were made on 14 outcrops of monzonite, gabbro, pyroxenite, and titaniferous magnetite. The results are summarized in table 2.

Gravity

Gravity observations were made at 1,085 stations in the grid area. Gravity readings were taken on all magnetic stations, and additional readings were taken on a closely spaced grid about the main pit and along the westward line extension off the main grid area.

[7]Mooney, H. M., Magnetic Susceptibility Measurements in Minnesota: Geophysics, vol. 17, No. 3, July 1952, pp. 531-543.

TABLE 2. - Apparent susceptibility measurements, K = 10^{-6} C.G.S. units

Measurement	Monzonite	Gabbro	Pyroxenite	Titaniferous magnetite
1.............................	1,470	7,720	10,700	63,500
2.............................	1,485	3,460	5,260	50,400
3.............................	1,720	2,350	2,020	-
4.............................	-	1,963	-	-
5.............................	-	2,445	-	-
6.............................	-	2,517	-	-
Mean..........................	1,558	3,409	5,993	56,950
Standard deviation..............	114.5	1,980	3,581	6,550

Two gravity observations within 0.025 milligal of each other were recorded at each station. The average of these readings was taken as the observed gravity at the station. The height of the instrument plate and the time were also recorded for each station. Base checks were made at intervals of ½ to 1 hour during the morning when the temperature gradient was high. After the trend of the drift curve for the day was established, the interval between base checks was lengthened to a maximum of 2 hours. If there was a marked variation in the air temperature, the interval between base checks was again shortened.

The gravity data were corrected for instrument drift, latitude, free air, and Bouguer and terrain effects. The latitude correction was a reduction in the data by 0.024088 milligals per 100 feet to the north. A profile across a wash in gabbro gave a reduction density of 2.8 grams per cubic centimeter (fig. 6). This density was used to compute the Bouguer and terrain corrections.

The terrain corrections were made using Sandberg's[8] tables for an inclined plane in conjunction with the usual Hammer zones. Generally, corrections for Hammer zones A, B, often C, and sometimes D were made using the tables for the inclined plane. The remaining zone corrections through zone H were made using Hammer's chart as reproduced by Nettleton.[9] For zones A through E the topography for the corrections was based on the 1 inch equals 200 feet plane table survey; for zones F through H, the 7½-minute Canon City No. 2 SW. quadrangle provided the topographic control. The magnitude of the terrain corrections ranged from 0.19 milligals over alluvium in the southern part of the grid to 1.10 milligals on the knob adjacent to Iron Mountain in the northwestern part of the grid. Station elevations were based on 17 level traverses; one tied the grid area to the previously mentioned quadrangle. All level closures were within 0.1 foot. The reduction datum selected was 7,100 feet.

Not all the gravity data were reduced. This is particularly true in the main pit area where a closely spaced grid was established. Reduction of data

[8] Sandberg, C. H., Terrain Corrections for an Inclined Plane in Gravity Computations: Geophysics, vol. 23, No. 4, October 1958, pp. 701-711.

[9] Nettleton, L. L., Geophysical Prospecting for Oil: McGraw-Hill Book Co., New York, N.Y., 1940, p. 145.

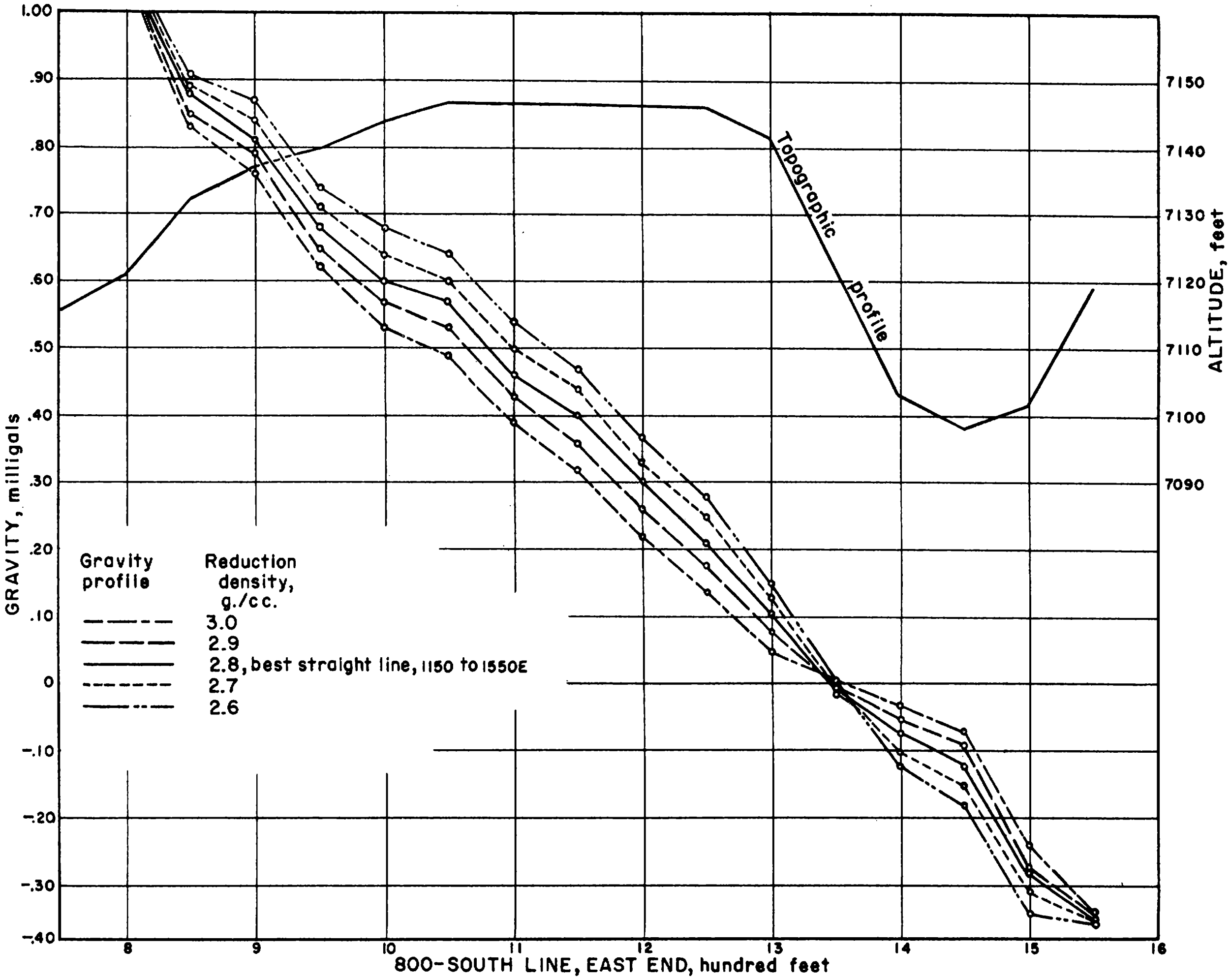

FIGURE 6. - Gravity Profiles Over Gabbro Using Several Reduction Densities.

from two lines that crossed the pit and subsequent geologic mapping indicated that the pit data could not be used to estimate quantitatively the remaining tonnage of minable magnetite. The reduced gravity data are presented on cross sections (figs. 7-11). A gravity-contour map was also constructed from the reduced gravity data (fig. 12). The plotted stations along the survey lines represent the location at which gravity data were used to construct the contour map.

Density determinations were made on rock specimens brought to the laboratory. The results of density determinations for monzonite, gabbro, pyroxenite, and titaniferous magnetite from different locations are summarized in table 3.

TABLE 3. - Specific gravity determinations

Measurement	Monzonite	Gabbro	Pyroxenite	Titaniferous magnetite
1..............................	2.59	3.05	3.33	4.33
2..............................	2.64	3.13	3.62	4.90
3..............................	2.67	3.13	3.41	4.39
4..............................	2.56	3.31	3.19	4.63
5..............................	2.59	2.99	-	-
6..............................	-	2.95	-	-
7..............................	-	2.92	-	-
8..............................	-	3.05	-	-
9..............................	-	2.93	-	-
Mean...........................	2.61	3.05	3.39	4.48
Standard deviation.............	.039	.118	.156	.265

INTERPRETATION

Magnetics

Quantitative calculations of magnetic anomalies over highly magnetic materials are not necessarily accurate because the intensity of magnetization (I) may not be proportional to the magnetic susceptibility (k). This fact limits the utility of these calculations as an interpretive tool for deposits composed largely of magnetite. In addition, at the deposit being considered, there is considerable titaniferous magnetite float near the magnetite lenses. This float tends to obscure and perhaps broaden the anomaly caused by magnetite in place. The magnetic interpretation is, therefore, largely qualitative.

Anomaly calculations (if carried out) would involve (1) making a volume integration because the reduction to a surface integral is not necessarily valid for highly magnetic material or (2) taking the derivative of the vertical-gravity field in the direction of the intensity of magnetization (I).

The average and the standard deviation of the susceptibilities for the major rock types are given in table 2. The monzonite is much more uniform magnetically than the gabbro-related rocks. For instance, no magnetic contours cross the west end of the zero-south line which is over monzonite. The gabbro is also fairly uniform magnetically on the north and northeast side of Iron Wash. This uniformity is best illustrated by the lack of magnetic contours on the 400-north line which is adjacent to gabbro outcrops. Gabbro in the rest of the area and the rocks closely related to the gabbro, the pyroxenite, and titaniferous magnetite are quite variable magnetically.

The magnetic contour map reveals the small size and discontinuous nature of the more highly magnetic zones (the lineated and crosshatched areas). Three of these areas probably represent single lenses of titaniferous magnetite; they are labeled A,[10] B, and C on the magnetic contour map. Areas D and E each probably represent several lenses. These five areas constitute the major magnetic anomalies covered by the survey.

[10] These areas are not to be confused with Hammer zones given on page 10.

Area A is well substantiated by outcrops. This appears to be one continuous tabular lens of titaniferous magnetite, 20 to 25 feet wide and about 800 feet long, with a dip of about 70° to the northwest. The flatter dip of the intensity-of-magnetization vector (normal for the area) accounts for the observed southwest shift of the magnetic high off the line of magnetite outcrops.

Several outcrops within areas B and C suggest that each of these areas also represents a single, narrow lens of titaniferous magnetite. Within areas D and E there are some exposures of both magnetite and gabbro; however, the considerable amount of magnetite in the surface sands and gravels tends to mask the occurrences and make the interpretation more difficult.

If the width of the magnetite structures increased considerably and they perhaps merged with depth, a broad magnetic high might be expected from east to west across the grid. Superimposed on this broad high would be the local observed anomalies due to the near-surface material. No broad high seems to be present across the map; instead, the anomalies are quite localized. This suggests little or no increase in the size of the magnetite structures with depth.

Gravity

Quantitative calculations are extremely useful in interpreting gravity data. When combined with known and probable geological conditions, the possible subsurface interpretations often may be narrowed to several choices. In the present case the gravity anomaly is rather large, elongated along the base line, and high near the magnetite lenses. Along the 2,000-foot south line the anomaly exceeds 8.5 milligals, and the peak of the anomaly is 1,400 feet east of the monzonite-pyroxenite contact. The question is: Can the anomaly be explained reasonably by differences in rock type along, or must there be considerably more titaniferous magnetite at depth to explain both the magnitude and shape of the anomaly?

The gravity profile along the 200-foot south line was selected as the curve to try to match with the gravity profile of a reasonable subsurface distribution of monzonite, pyroxenite, and gabbro. The surface geology was fairly well determined by field mapping. The 2,000-foot line extension to the west off the main grid area was entirely over monzonite. Where exposed, the strip of pyroxenite adjacent to the monzonite ranges from 300 to 600 feet in width. The contact between the pyroxenite and monzonite dips about 70° to the east. The width of pyroxenite selected for computation was 500 feet. The remainder of the line is almost entirely over gabbro. With the gravity anomaly elongated normal to the section and the section about midway along the length of the anomaly, two-dimensional gravity computations are appropriate. Finally, the densities of monzonite, pyroxenite, and gabbro are taken as 2.6, 3.4, and 3.0 grams per cubic centimeter, respectively.

The vertical component of gravity for a prism of infinite length along the y-axis and of a trapezoidal cross section may be derived in the usual way. The geometry is illustrated in figure 13. The vertical component of gravity (A_z) is:

$$A_z = \gamma\rho \iiint \frac{\cos\theta \, dx \, dy \, dz}{r^2}$$

$$= \gamma\rho \int_{d_1}^{d_2} z dz \int_{z \operatorname{ctn}\theta + x_1}^{z \operatorname{ctn}\phi + x_2} dx \int_{-\infty}^{\infty} (x^2 + y^2 + z^2)^{-3/2} dy$$

$$= \gamma\rho \Big\{ 2\Big[(d_2 + x_2 \sin\phi\cos\phi)\tan^{-1}\frac{d_2 \operatorname{ctn}\phi + x_2}{d_2} - (d_1 + x_2 \sin\phi\cos\phi)\tan^{-1}\frac{d_1 \operatorname{ctn}\phi + x_2}{d_1}$$

$$- (d_2 + x_1 \sin\theta\cos\theta)\tan^{-1}\frac{d_2 \operatorname{ctn}\theta + x_1}{d_2} + (d_1 + x_1 \sin\theta\cos\theta)\tan^{-1}\frac{d_1 \operatorname{ctn}\theta + x_2}{d_1} \Big]$$

$$+ x_2 \sin^2\phi \ln \frac{d_2^{\,2} + (d_2 \operatorname{ctn}\phi + x_2)^2}{d_1^{\,2} + (d_1 \operatorname{ctn}\phi + x_2)^2} + x_1 \sin^2\theta \ln \frac{d_1^{\,2} + (d_1 \operatorname{ctn}\theta + x_1)^2}{d_2^{\,2} + (d_2 \operatorname{ctn}\theta + x_1)^2} \Big\} .$$

The gravitational constant is γ, the density is ρ, $\cos\theta = z/r$ and $r^2 = x^2 + y^2 + z^2$. The particular form of A_z is readily obtained when the relation $\tan^{-1} a = \frac{i}{2} \ln \frac{1-ia}{1+ia}$ is introduced prior to the last integration and when the same relation in the form $\ln (b + ia) = \frac{1}{2} \ln (b^2 + a^2) + i\tan^{-1} \frac{a}{b}$ is used following integration.

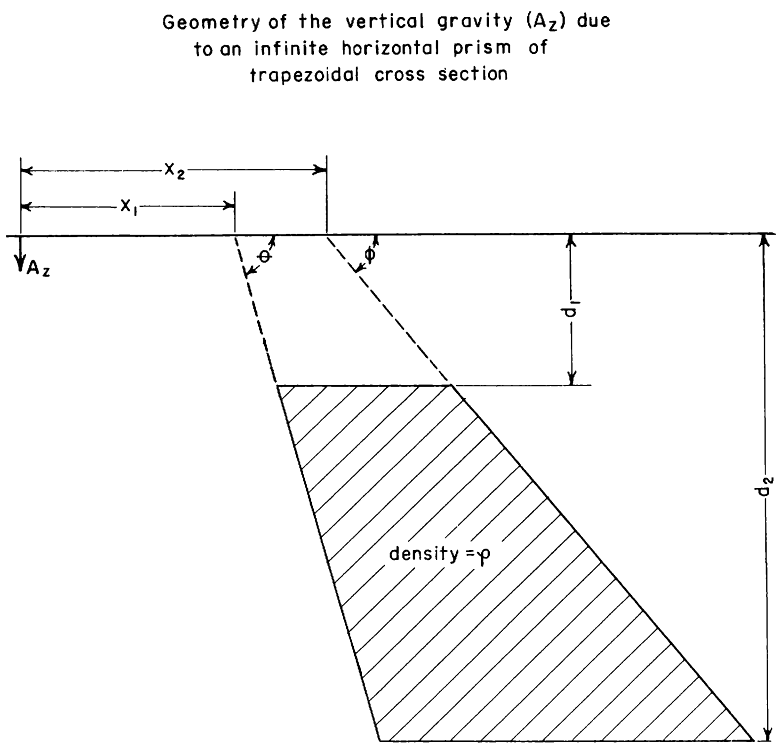

FIGURE 13. - Geometry of Theoretical Gravity.

This equation was programed on a computer, and the curves of figures 14 and 15 represent the theoretical gravity over the several mass distributions. Because the rocks along the line were at or near the surface, the depth to the top of the rocks (d_1) was always taken as 1 foot.

Figure 14 is a series of curves for a 70°-dipping zone of pyroxenite bounded on one side by monzonite and on the other side by gabbro. Since the relative gravity is all that is desired, the density contrast of

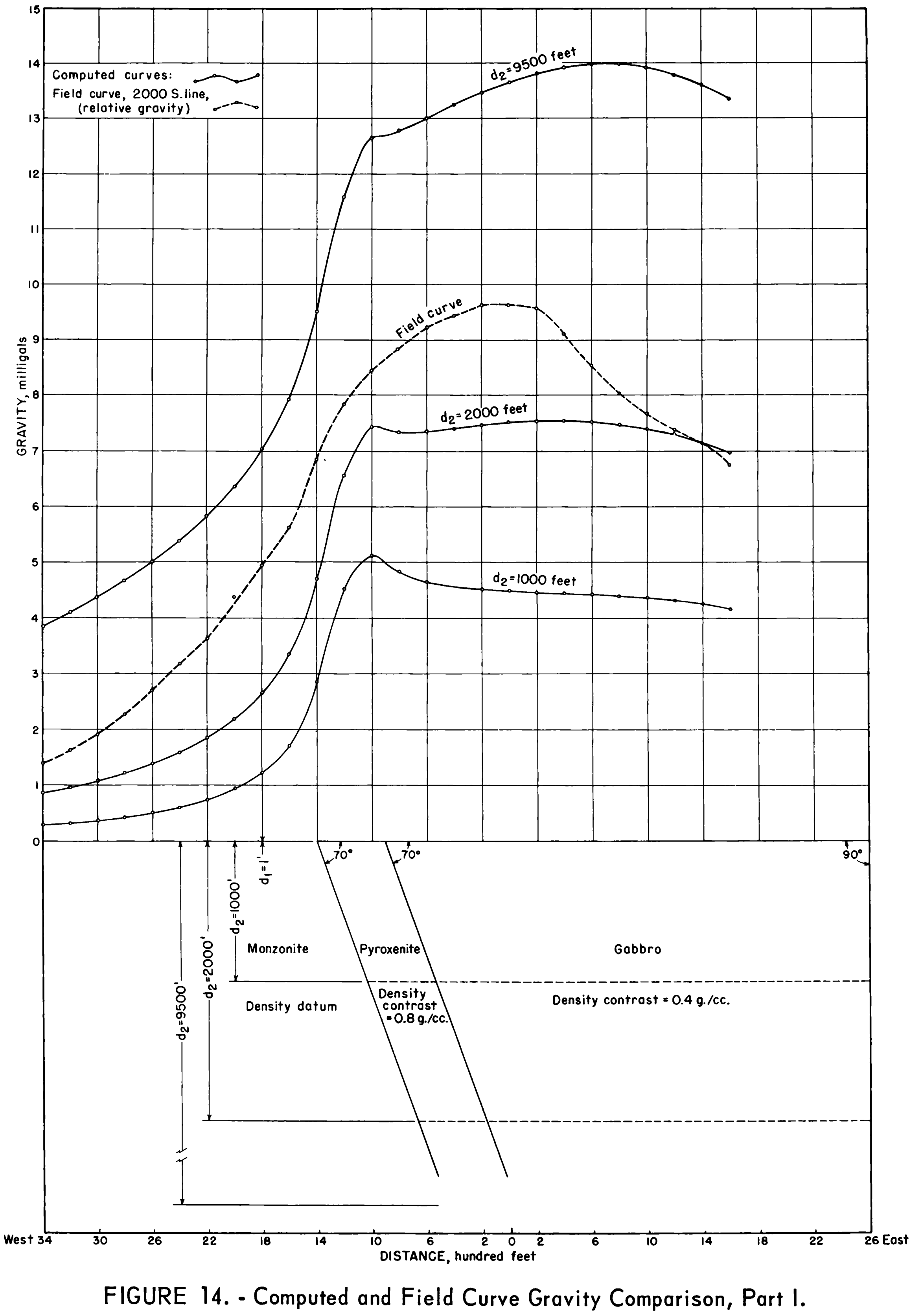

FIGURE 14. - Computed and Field Curve Gravity Comparison, Part I.

pyroxenite (0.8) and gabbro (0.4) with monzonite is used in the calculations. The curves are for the base of the pyroxenite and gabbro at depths (d_2) of 1,000, 2,000, and 9,500 feet. As noted in the figure, the magnitude but not the shape of the field anomaly may be duplicated by this geometry and density contrast. There is always a peak over the pyroxenite with a second high developing to the east of the field high as the base (d_2) of the pyroxenite and gabbro is increased. The calculated curve for this geometry is not an acceptable approximation of the shape of the field curve.

As a second try in approximating the shape of the field curve, the curves of figure 15 were obtained. The monzonite-pyroxenite contact was kept at 70°, but the rather indefinite pyroxenite-gabbro contact was reduced to about 34°. The two curves have values of d_2 of 1,000 and 2,000 feet. An anomaly due to a 50-foot-wide tabular lens of titaniferous magnetite in gabbro (density contrast = 1.6) is also plotted in figure 15. This is a larger mass than any known lens of titaniferous magnetite at the deposit; it gives the order of maximum anomaly that could occur over the magnetite. Perhaps 0.5 to 0.7 milligals of the field curve near the baseline is due to the presence of several smaller lenses of titaniferous magnetite between 250 feet west and 250 feet east. With this allowance for magnetite, the computed curve with d_2 equaling 2,000 feet approximates the shape of the field curve fairly well east of the coordinate 1,000-foot west, and the magnitude of the computed anomaly is sufficient.

From 1,000 to 3,400 feet west the arc of the computed curves is much more pronounced than the field curve. The flatter characteristic of the field curve is probably due to end effects of the mass of pyroxenite and gabbro in the southwest portion of figure 16. It may be significant that projected contacts bring this mass of denser rock closest to the 2,000-foot south section (within 300 feet) in the vicinity of the greatest discrepancy of the field and computed curves (around 2,100 feet west). These end effects could reach the order of one to two milligals and thus bring the field and computed curve for d_2 equaling 2,000 feet into fairly good agreement.

The field curve drops to the east a little more than the computed (d_2 = 2,000 foot) curve. This suggests a pyroxenite-gabbro contact with a dip nearer 40° than 34°. With the flat arc of the field curve to the west explained by the end effects of the pyroxenite-gabbro mass just south of the section, the monzonite-pyroxenite contact can be maintained between the mapped dips of 70° to 85°. Thus, the gravity anomaly can be explained reasonably by a wedge of pyroxenite between the monzonite and gabbro with no more (and perhaps less) titaniferous magnetite at depth than there is at surface.

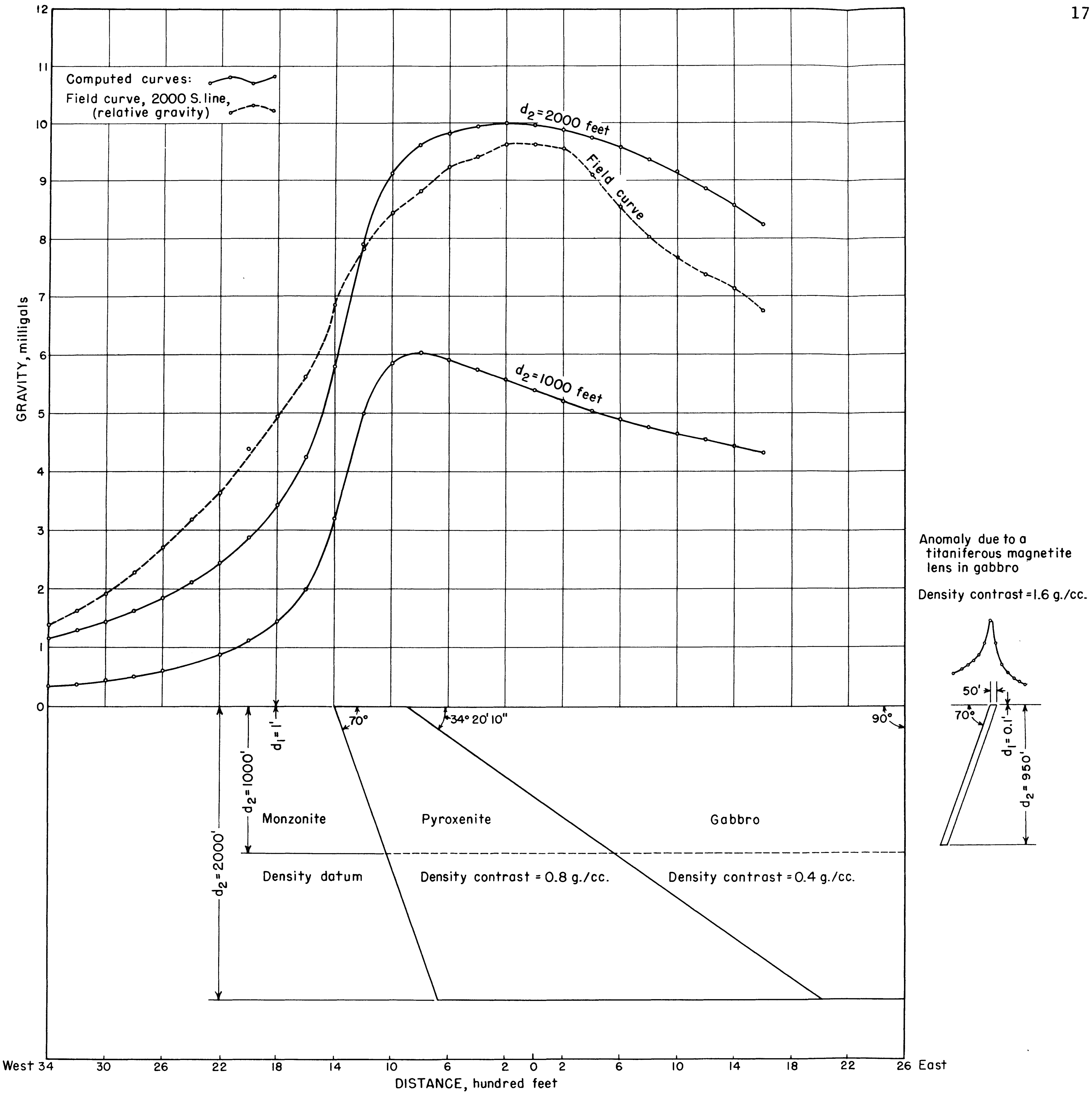

FIGURE 15. - Computed and Field Curve Gravity Comparison, Part II.

Geology

The map of the bedrock geology is largely a combination of the outcrop map and the magnetic-contour map (fig. 16). The cross section along the 2,000 foot-south line is largely a blend of the surface geology and the gravity data (fig. 17). The wedgelike broadening of the strip of pyroxenite with depth accompanied by little or no increase in titaniferous magnetite is considered to be a reasonable interpretation of the field data. The iron deposits appear to be somewhat limited and discontinuous.

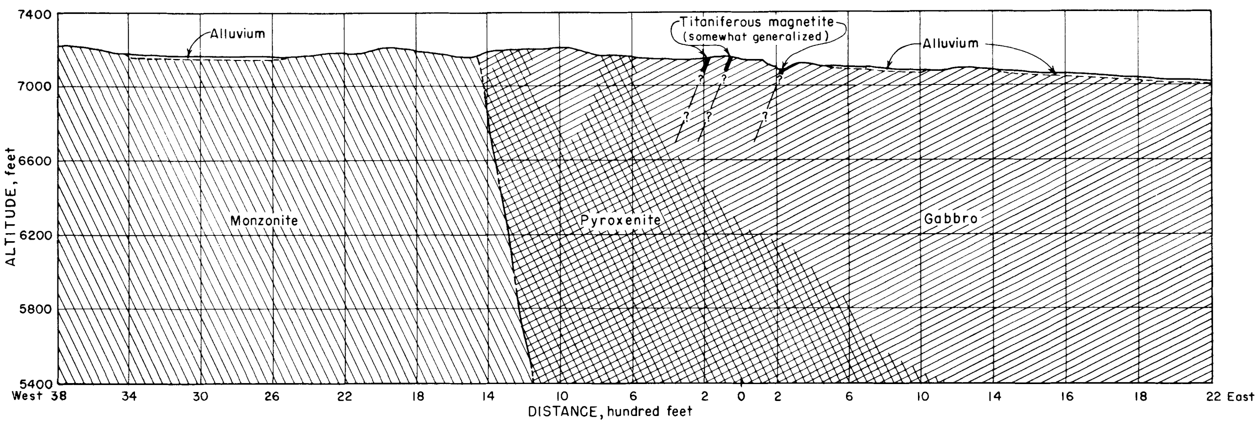

FIGURE 17. - Geologic Interpretation of 2,000-Foot South Cross Section.

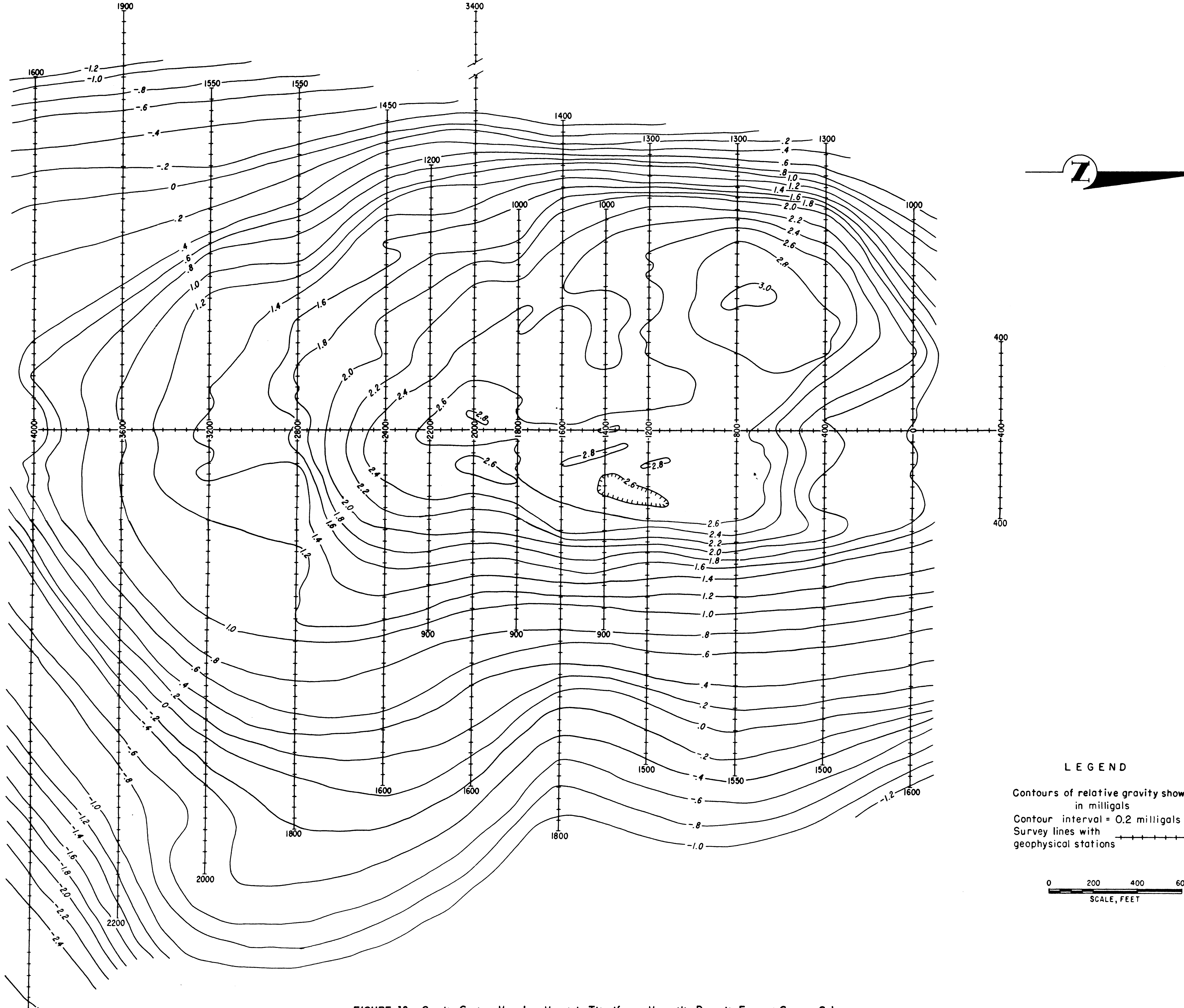

FIGURE 12. - Gravity-Contour Map, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.

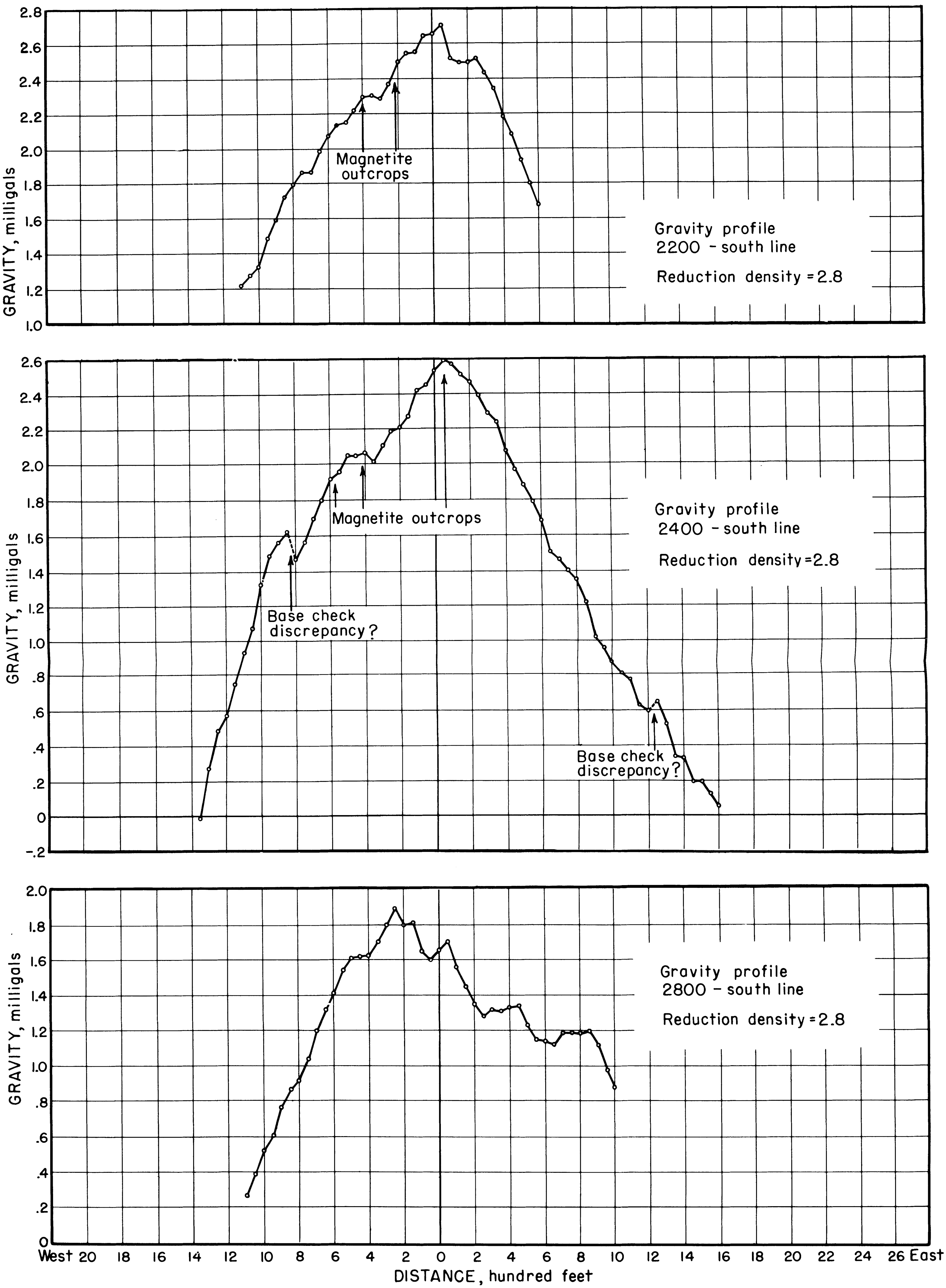

FIGURE 10. - Gravity Profiles—2,200-, 2,400-, and 2,800-Foot South Lines.

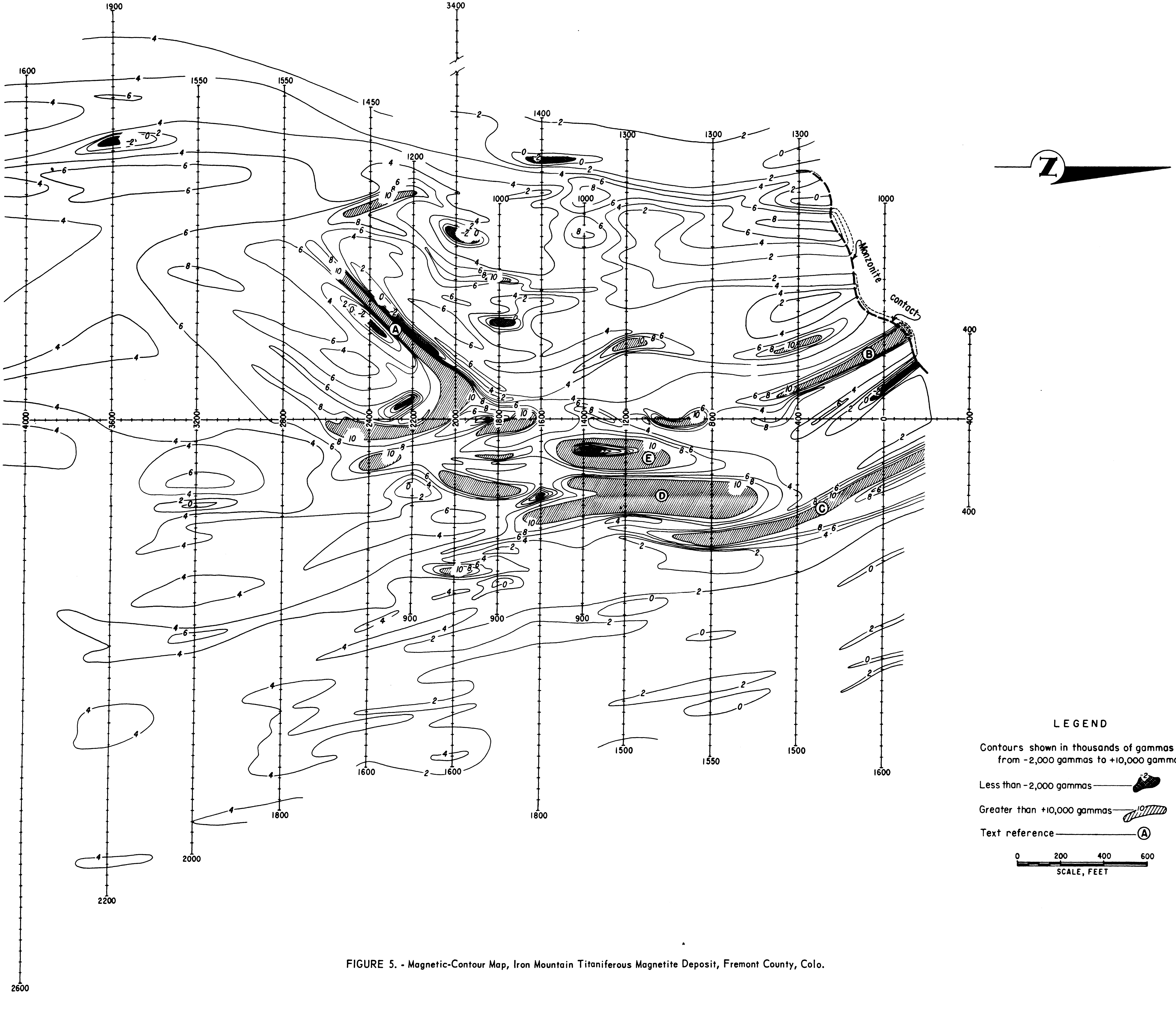

FIGURE 5. - Magnetic-Contour Map, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.

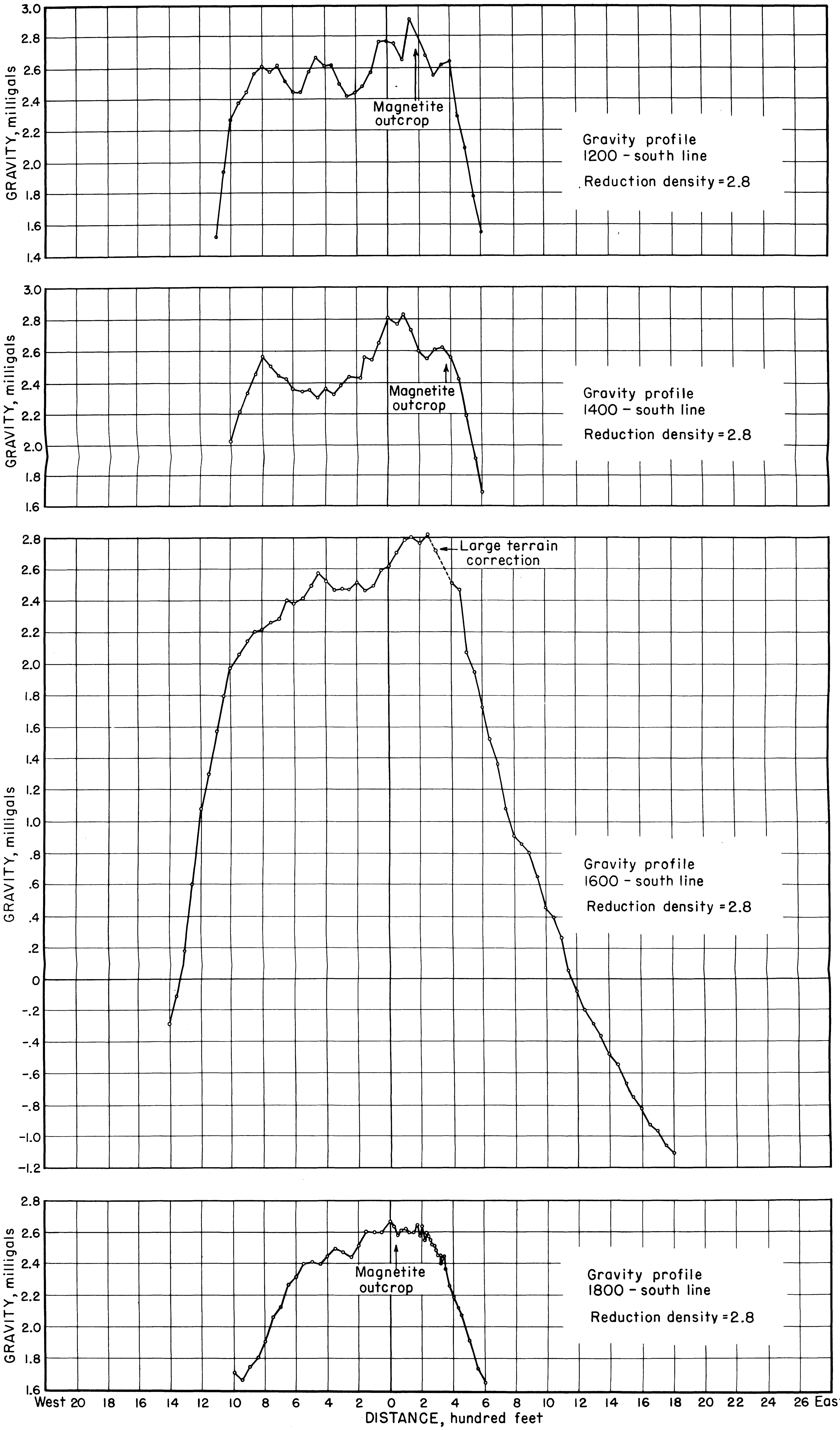

FIGURE 8. - Gravity Profiles—1,200-, 1,400-, 1,600-, and 1,800-Foot South Lines.

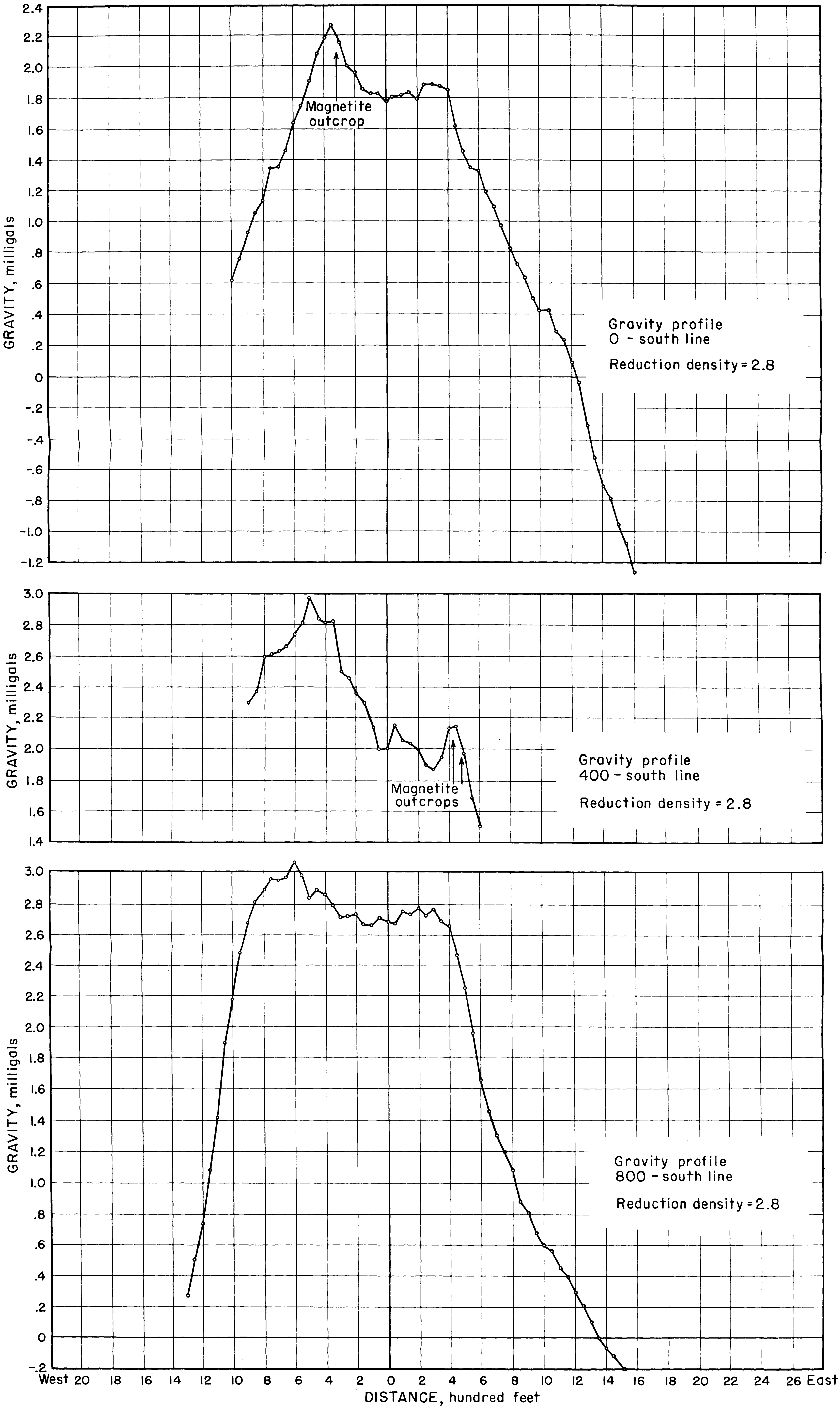

FIGURE 7. - Gravity Profiles—0-, 400-, and 800-Foot South Lines.

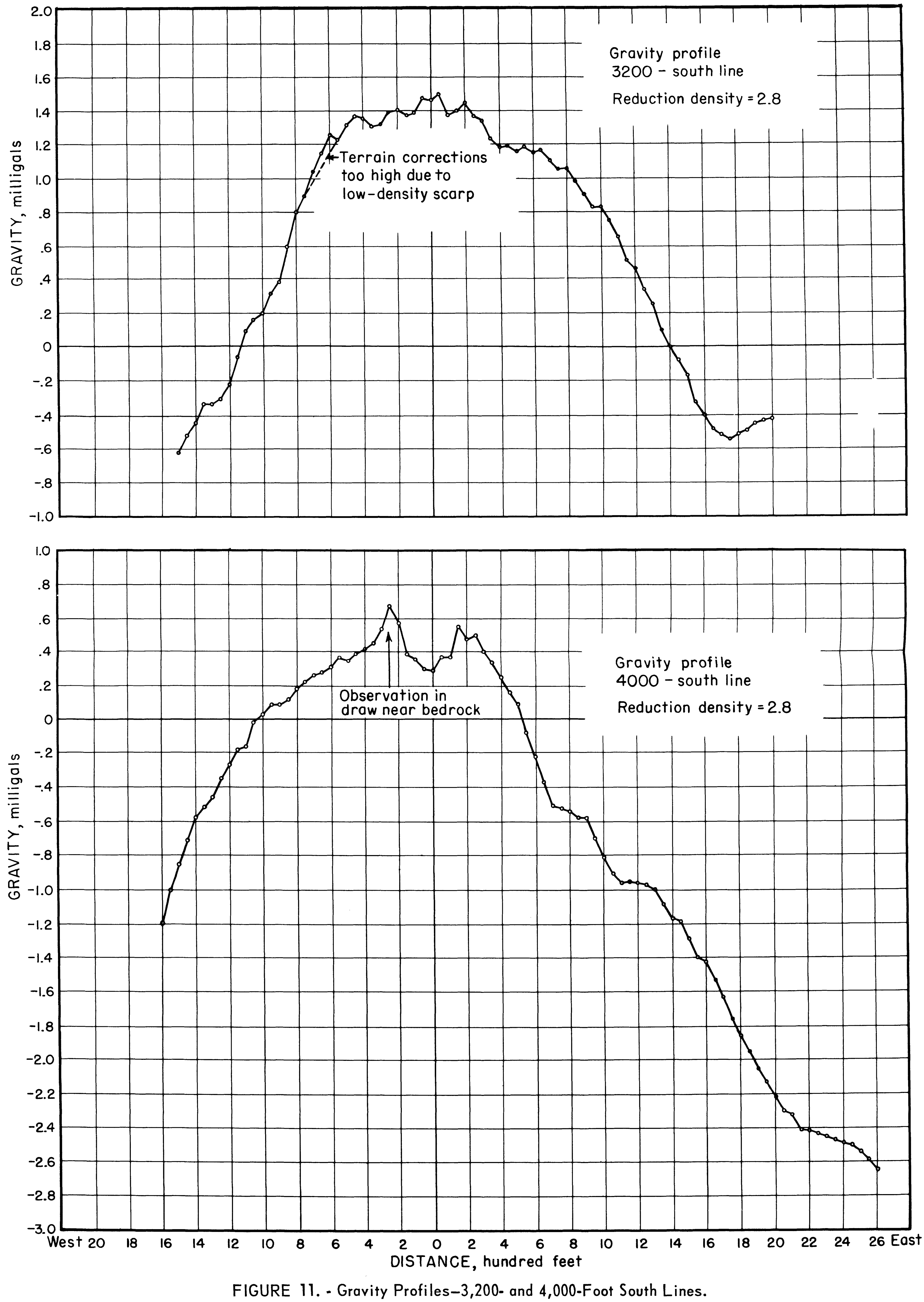

FIGURE 11. - Gravity Profiles–3,200- and 4,000-Foot South Lines.

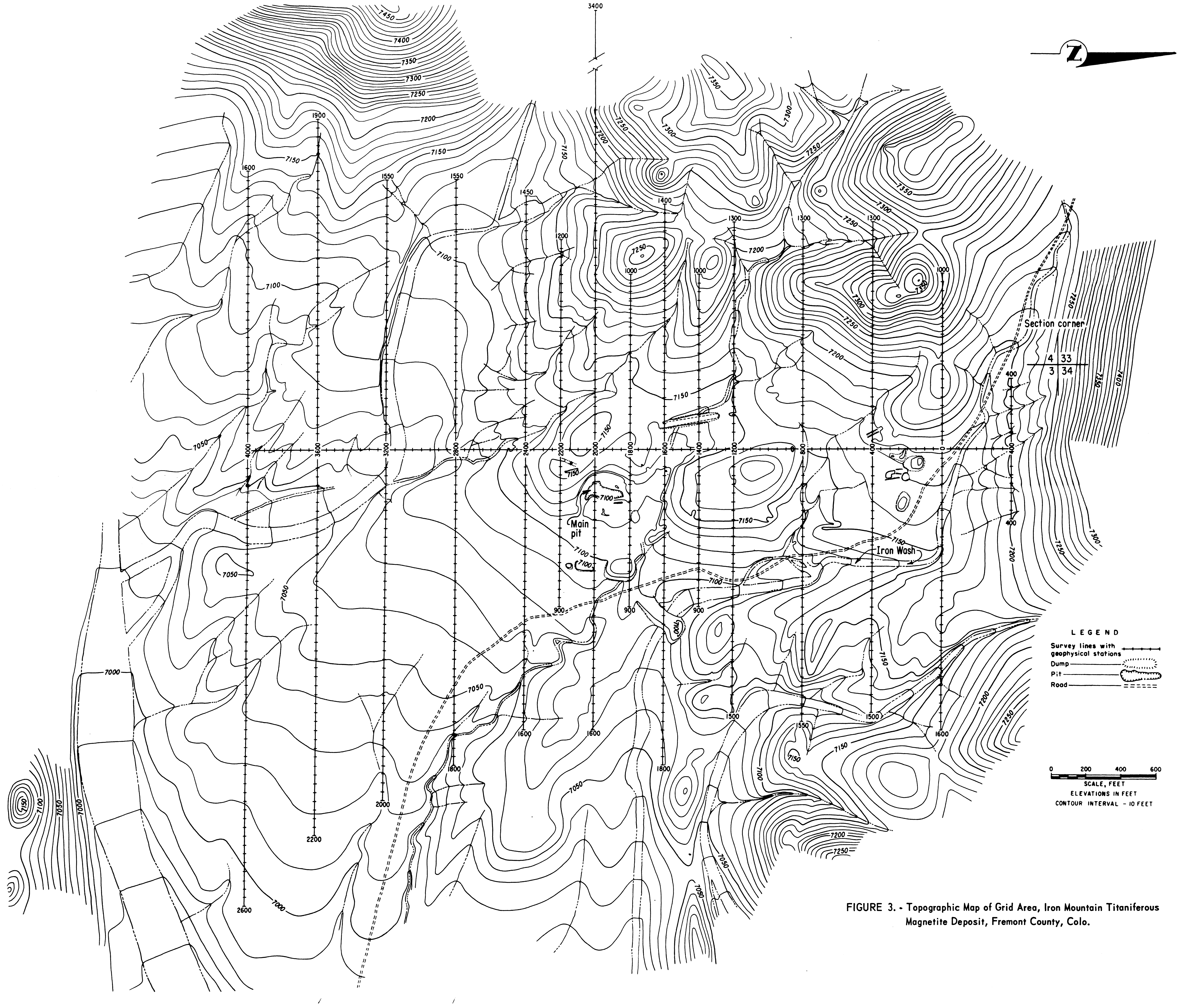

FIGURE 3. - Topographic Map of Grid Area, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.

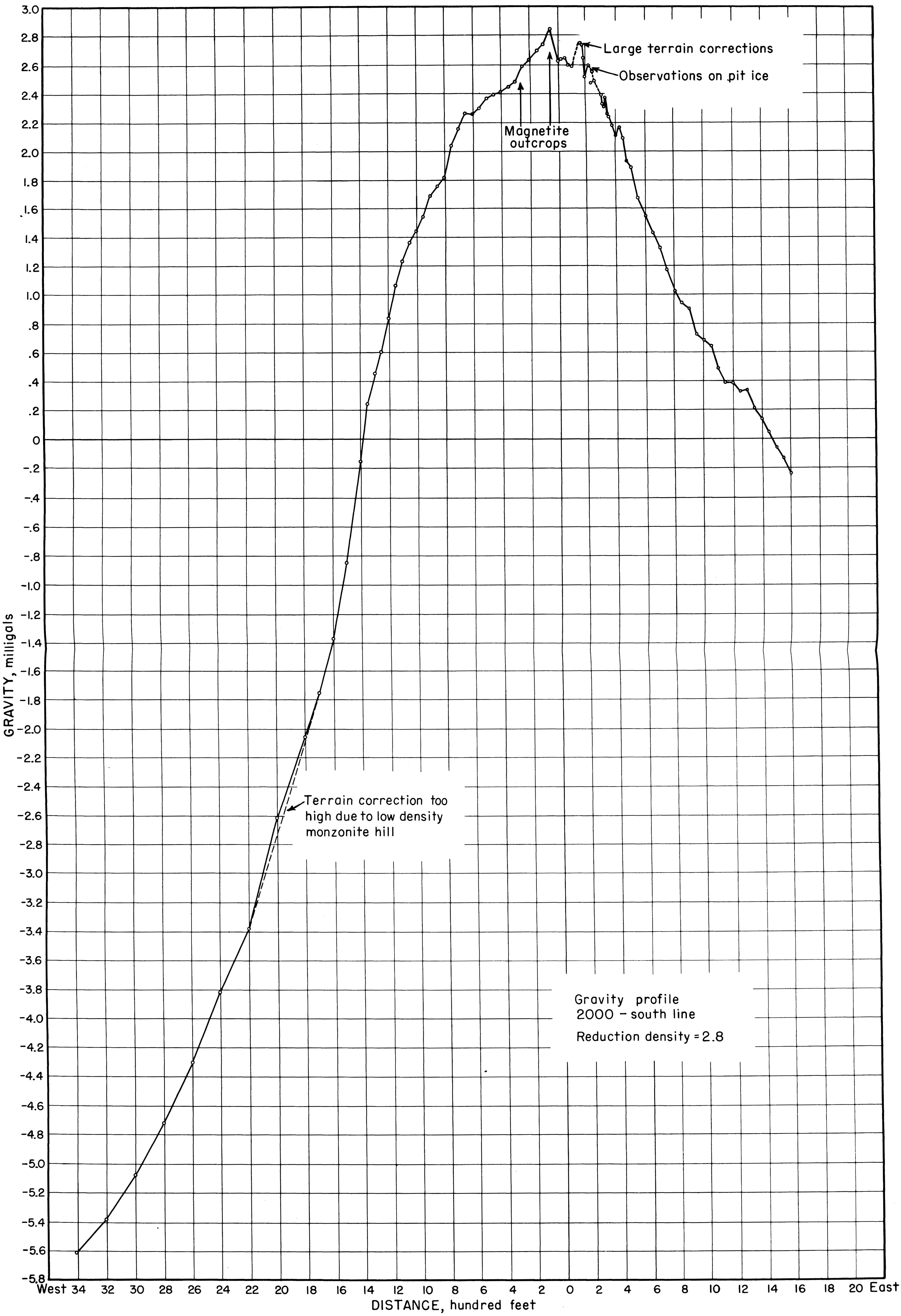

FIGURE 9. - Gravity Profile–2,000-Foot South Lines.

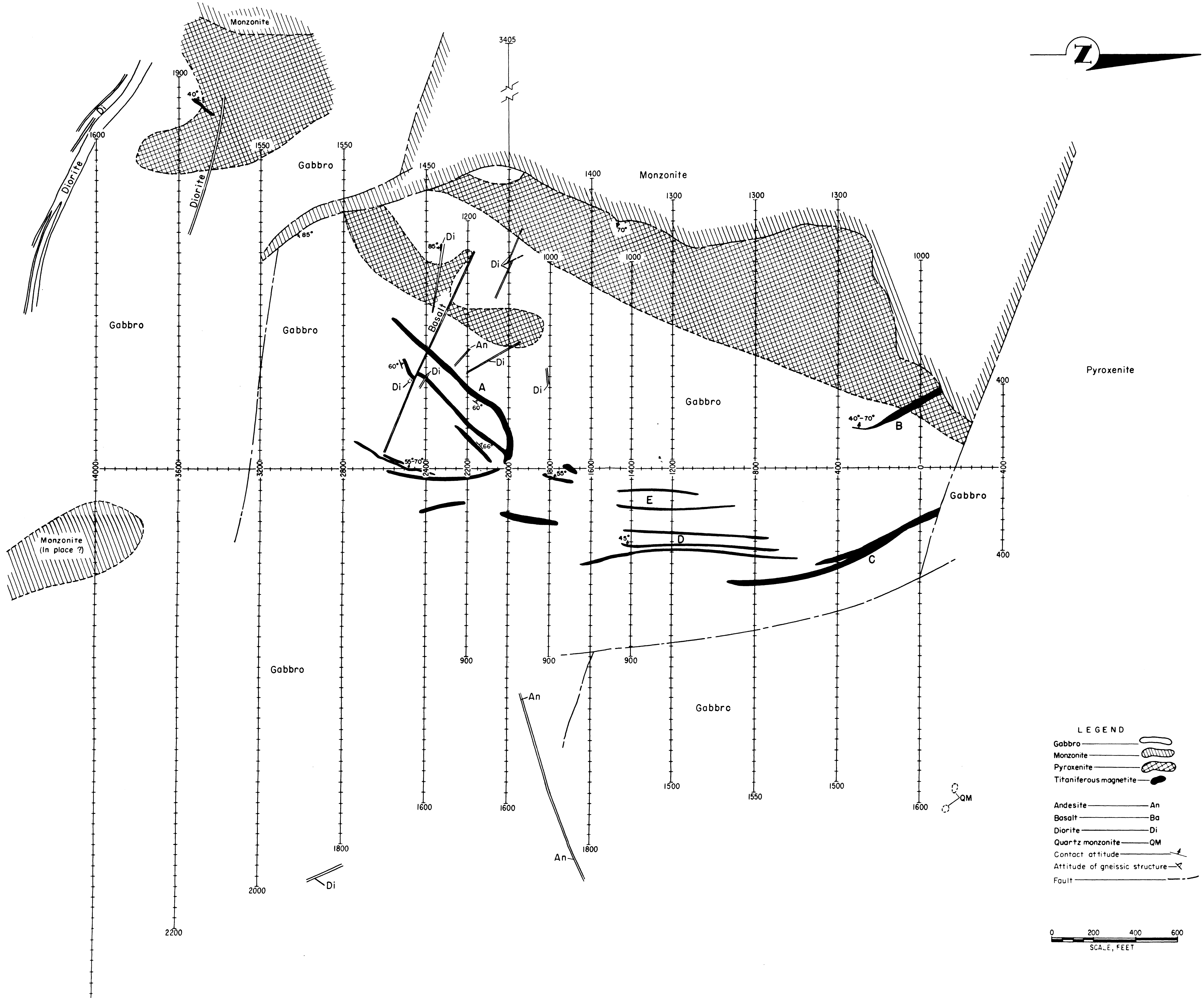

FIGURE 16. - Bedrock Geologic Map, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.

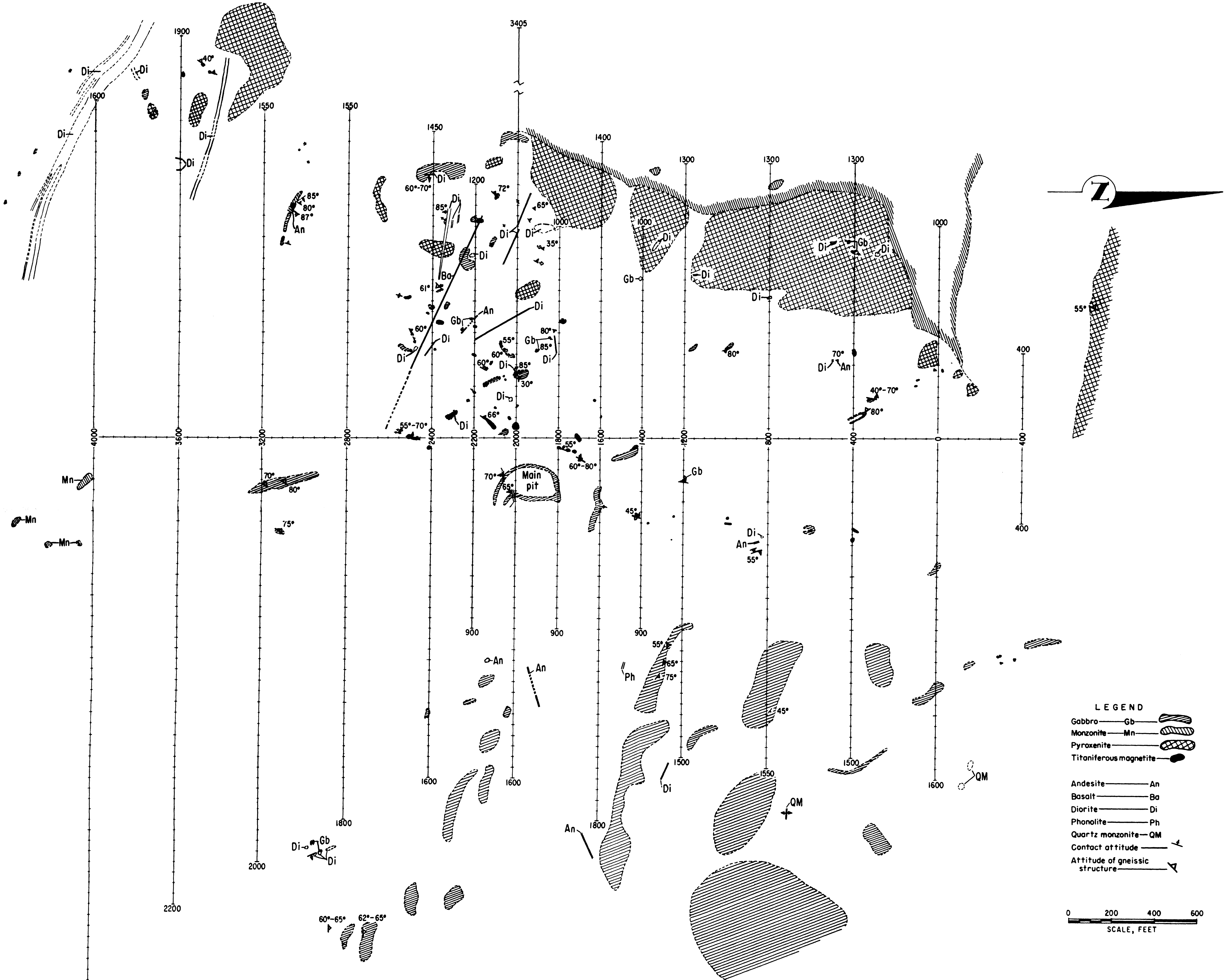

FIGURE 4. - Outcrop Map, Iron Mountain Titaniferous Magnetite Deposit, Fremont County, Colo.