Bureau of Mines
Report of Investigations 5195

STUDIES OF THE SNETTISHAM MAGNETITE DEPOSIT, SOUTHEASTERN ALASKA

BY R. L. THORNE AND R. R. WELLS

United States Department of the Interior — February 1956

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UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary
BUREAU OF MINES
Thos. H. Miller, Acting Director

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by

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SUMMARY

The Snettisham Peninsula, 30 miles southeast of Juneau, Alaska, was studied by the Bureau of Mines to obtain basic information about the size, grade, and metallurgical characteristics of a large basic intrusive containing titaniferous magnetite. The investigation, which was part of a continuing program to determine the potential reserves of iron and titanium ores in Alaska, included transit and magnetometer surveys, followed by diamond core drilling and metallurgical testing.

The magnetic attraction of a part of the Snettisham Peninsula is noted on early navigational charts prepared by the Coast and Geodetic Survey. Reconnaissance examinations by the Geological Survey and a preliminary dip needle survey by the Territorial Department of Mines indicated the general nature of the basic intrusive, but little was known as to the grade and extent of the magnetite mineralization. The detailed survey by the Bureau of Mines proved an area of approximately 390 acres in which generally high magnetic anomalies with exceptionally high localized anomalies occur. Subsequent drilling across a representative section of the deposit yielded core samples, which assayed from 11 percent to over 45 percent total iron. A large sample of core composited to represent the drilled portion of the deposit assayed 18.9 percent Fe, 2.6 percent TiO_2, and 0.29 percent S, 0.32 percent P, and 0.05 percent V.

Representative samples composited from drill cores were subjected to beneficiation tests at the Juneau Laboratory. Direct magnetic separation of ore ground to minus-150-mesh or staged magnetic separation of 35-mesh ore with concentrates retreated at minus-150-mesh resulted in the recovery of 61 to 64 percent of the total iron in a concentrate assaying about 64 percent iron, 3.5 percent TiO_2, 0.3 percent V, 0.4 percent S, and less than 0.01 percent P. The sulfur content of the concentrate could not be lowered by mechanical methods but was satisfactorily reduced by sintering.

The work by the Bureau of Mines indicated a favorably situated, potentially large deposit containing titaniferous magnetite that can be recovered as a high-grade magnetite concentrate, using standard, comparatively low cost methods of beneficiation.

INTRODUCTION

The rapid depletion of domestic reserves of high-grade iron ore, advances in methods of concentrating lower grade ore, and the continued expansion of heavy industry along the Pacific coast are factors in directing increased attention to the possibility of utilizing Alaskan deposits of iron as sources of supply for local or western industries. The titaniferous magnetite deposits of Southeastern Alaska are of particular interest because of their large size and accessibility and also because of the favorable natural conditions that prevail in the coastal region in which the deposits are situated.

To stimulate interest in the deposits and to provide basic information for possible commercial development the Bureau of Mines has conducted preliminary investigations of the Klukwan deposit near Haines, Alaska, and of the Snettisham deposit near Juneau, Alaska. The results of laboratory beneficiation tests on Klukwan ores have been published;3/ factual data resulting from field and laboratory investigations of the Snettisham deposit are presented in this report.

ACKNOWLEDGMENTS

Geologists of the Geological Survey contributed to the interpretation of field geology and core logging.

Special acknowledgment is made to James A. Williams, associate mining engineer, Territorial Department of Mines, for his preliminary dip-needle survey and report and for collaboration with Bureau of Mines engineers on the magnetic survey. The results of Williams' survey provided the immediate incentive that led to the initiation of field investigations by the Bureau of Mines.

Thanks are given to W. S. Pekovich for permission to use the data from an airborne magnetometer survey of the area made by a Canadian company subsequent to the Bureau of Mines investigation.

LOCATION AND ACCESSIBILITY

The Snettisham deposit is on the mainland in the southern part of the Juneau mining district 30 miles southeast of Juneau, Alaska. The deposit is within Alaska District Survey 160 at latitude 57° 59'N. and longitude 133° 46' W. (figs. 1 and 2). The magnetite-bearing material extends from approximately 1,000 feet southwest of Sentinel Point for 2 miles along the southeastern shoreline of Port Snettisham.

Port Snettisham is part of a deep, semiprotected system of inland waterways that permit year-round shipping along the southeastern Alaskan and Canadian coasts. The construction of a short dock at the property would provide direct access for ocean-going vessels; year-round barge transportation along the inland waterways has proved feasible. Present access is by small boat or pontoon-equipped plane, which may be chartered in Juneau.

PHYSICAL FEATURES AND CLIMATE

The magnetiferous deposit is near the northern end of Snettisham Peninsula, a ridge 2,500 to 3,000 feet high, 15 miles long, and about 4 miles wide. The topography and general geology of the magnetite-bearing area are illustrated by figure 3.

Most of the terrain overlying the deposit is steep and precipitous, but at the western edge a portion of it is a hilly lowland that was the site of the once-active town of Snettisham. The shoreline is abrupt and rocky but there are several places where docks have been successfully established in the past.

Dense evergreen vegetation covers the area from the shoreline to an altitude of 2,000 feet. In some logged-off and swampy areas scrub and second-growth timber grow profusely, but virgin spruce and hemlock predominate. Berry bushes, devils club, and other vegetation cover all rock exposures except on the steepest slopes.

The potential of nearby hydroelectric power sites has been calculated from accurate measurements to be at least 65,400 primary horsepower. The estimate is

3/ Wells, R. R., and Thorne, R. L., Concentration of Klukwan Alaska Magnetite Ore: Bureau of Mines Rept. of Investigations 4984, 1953, 15 pp.

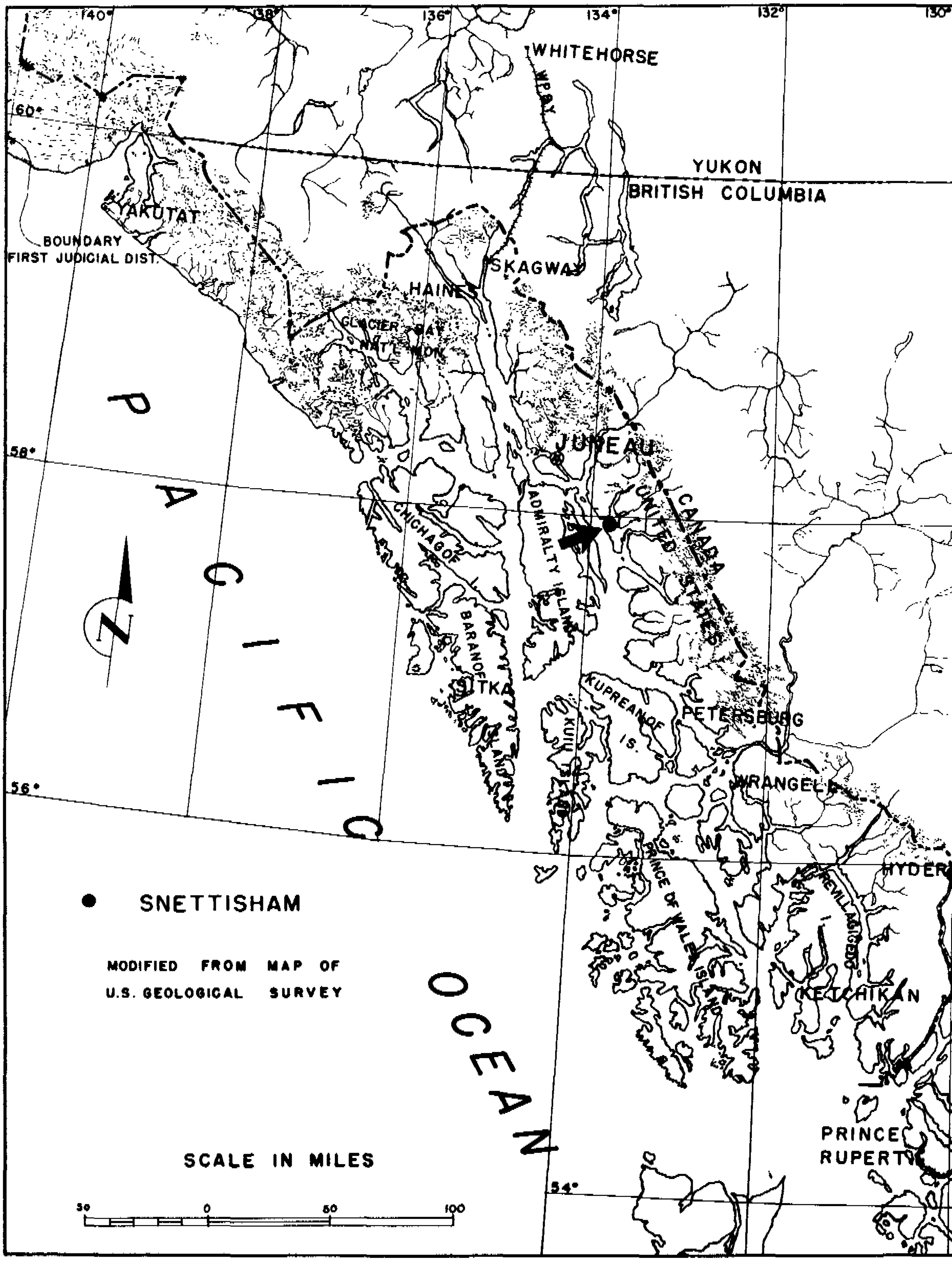

Figure 1. - Index map Southeastern Alaska

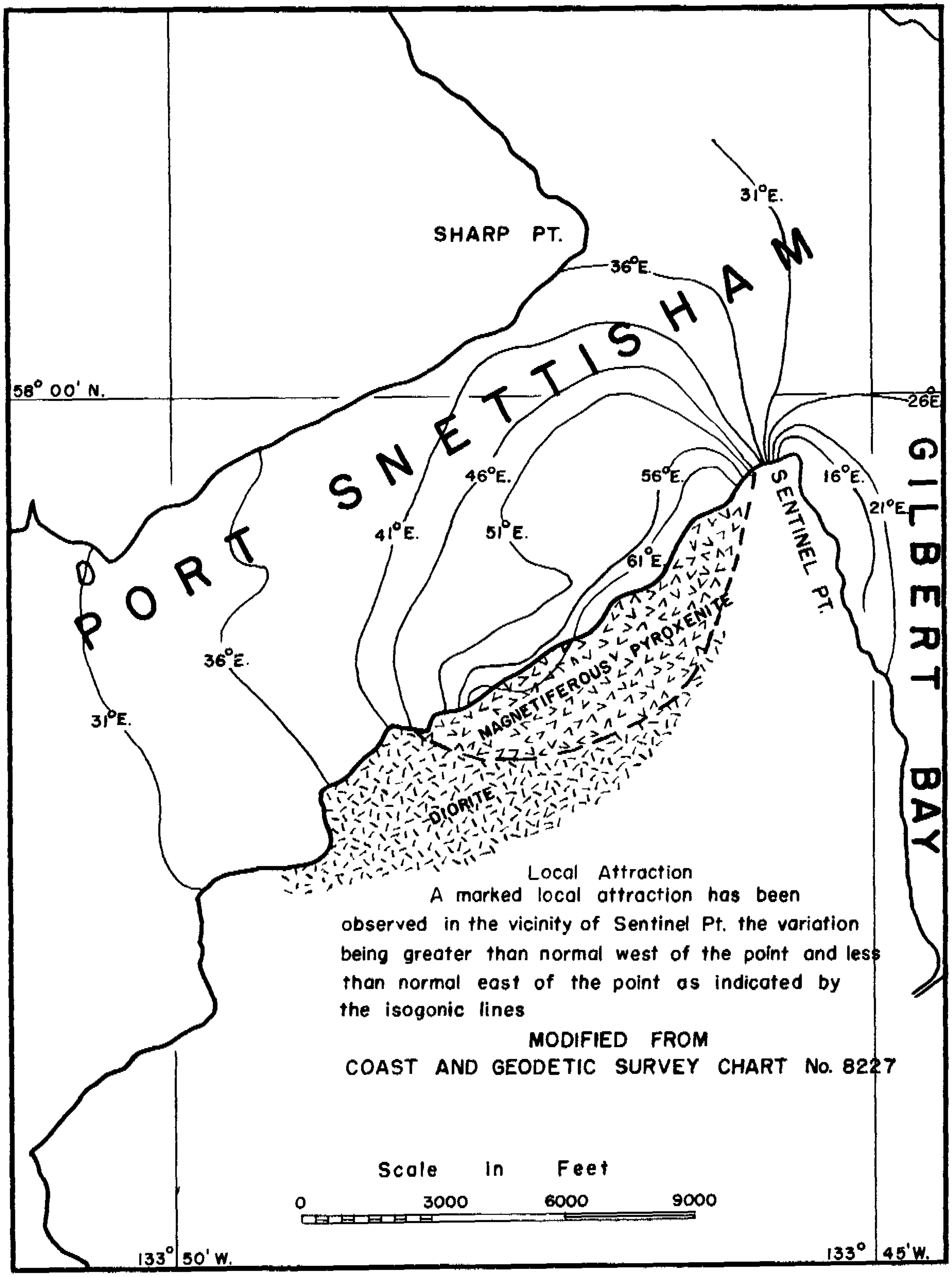

Figure 2. - Magnetic variation in Port Snettisham.

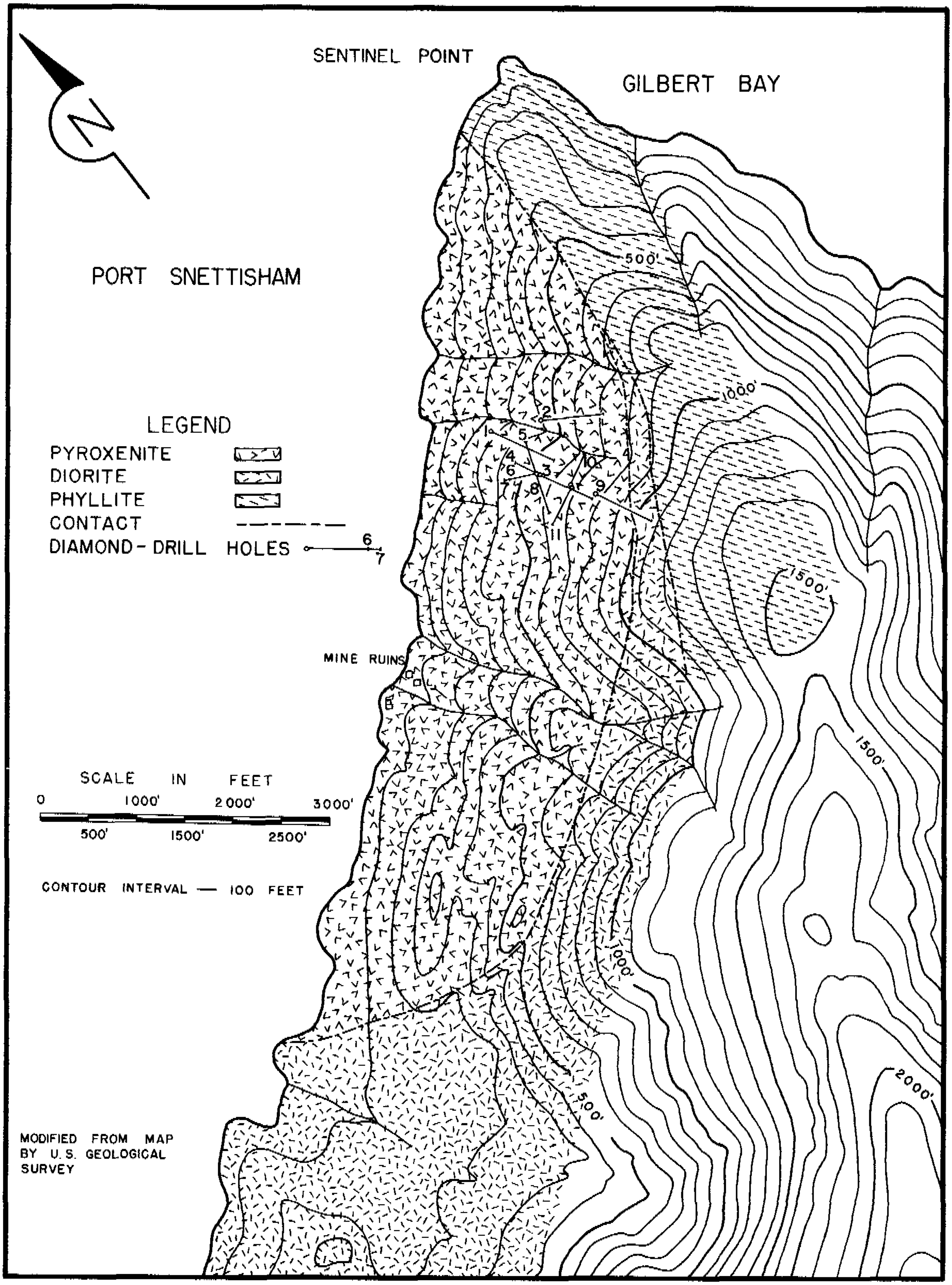

Figure 3. - Topographic and geologic map.

based on the flow from the watersheds of Crater, Long, and Sweetheart Lakes only; it does not consider the power potential of either the Speel or the Whiting Rivers.

The climate is temperate but wet. The nearest weather recording stations are at Juneau and at Five Finger Light, which are equidistant to the north and south, respectively. In 1949 the mean annual temperature of Juneau was 41.3° F.; the mean annual precipitation was 99.29 inches. Corresponding records at Five Finger Light were 42.9° and 70.2 inches. Records kept for 7 years at Speel River, approximately 5 miles north of the iron deposit, show an average annual precipitation of 143.33 inches.

LABOR AND LIVING CONDITIONS

The Snettisham Peninsula is a primitive and undeveloped area. The necessary prerequisites for good living conditions are present, however, in the ready access to waterpower potential, good drinking water, abundant timber, and a good townsite. At present only one permanent resident lives on the Snettisham Peninsula; all labor would have to be brought to the area. The type of labor required for open-pit mining is similar to that required for road construction in mountainous areas; a roving group of men skilled in such work is available in Alaska.

HISTORY AND OWNERSHIP

Snettisham was an active gold-mining camp near the turn of the century. The Crystal and Friday mines were operated by the Alaska Snettisham Gold Mining Co. from 1899 through 1905. The company had 21 lode and millsite claims surveyed for patent, with improvements valued at $26,100. The records, however, indicate that there was no application for patent. Sporadic gold mining was continued in the area until the early 1930's.

Evidence has existed for some time as to the probability of the presence of a large magnetite-bearing ore body in the Snettisham area. A. F. Buddington[4/] and Theodore Chapin[5/] described masses of hornblende and hornblende-pyroxenite with accessory magnetite, apatite, and plagioclase on the northern end of the Snettisham Peninsula; they also mention "a 6-foot vein of practically solid titaniferous magnetite" near the post office at Snettisham. In 1918 an open cut was made on this vein, and 4 or 5 tons of ore was shipped to the Treadwell mines at Douglas, Alaska. The material is reported to have carried 4 or 5 percent titanium.

N. H. Heck[6/] of the United States Coast and Geodetic Survey reported that a crew working with the steamer Explorer mapped the magnetic lines in the vicinity of the Snettisham Peninsula. The study revealed a magnetic disturbance throughout an area of 20 square miles of land and water and an intense magnetic disturbance throughout an area of 8 square miles. This information later was incorporated in U. S. Geodetic Survey Chart 8227; it is shown as figure 2.

Mineral Survey 2188 (fig. 4) shows the mining claims in the area covered by this investigation. The first eight claims of the Magnetite group were located by Robert E. Coughlin and W. S. Pekovich in August 1950; they extended along the east shore of Port Snettisham from 600 feet south to 3,600 feet south of Sentinel Point. The number of claims was increased to 18 in 1953.

4/ Buddington, A. F., Investigations in Southeastern Alaska: Geol. Survey Bull. 773, 1923, pp. 133-134.

5/ Buddington, A. F., and Chapin, Theodore, Geology and Mineral Deposits of Southeastern Alaska: Geol. Survey Bull. 800, 1929, pp. 197-198.

6/ Heck, N. H., Where the Compass Fails to Guide: Sci. Am., March 1923, p. 192.

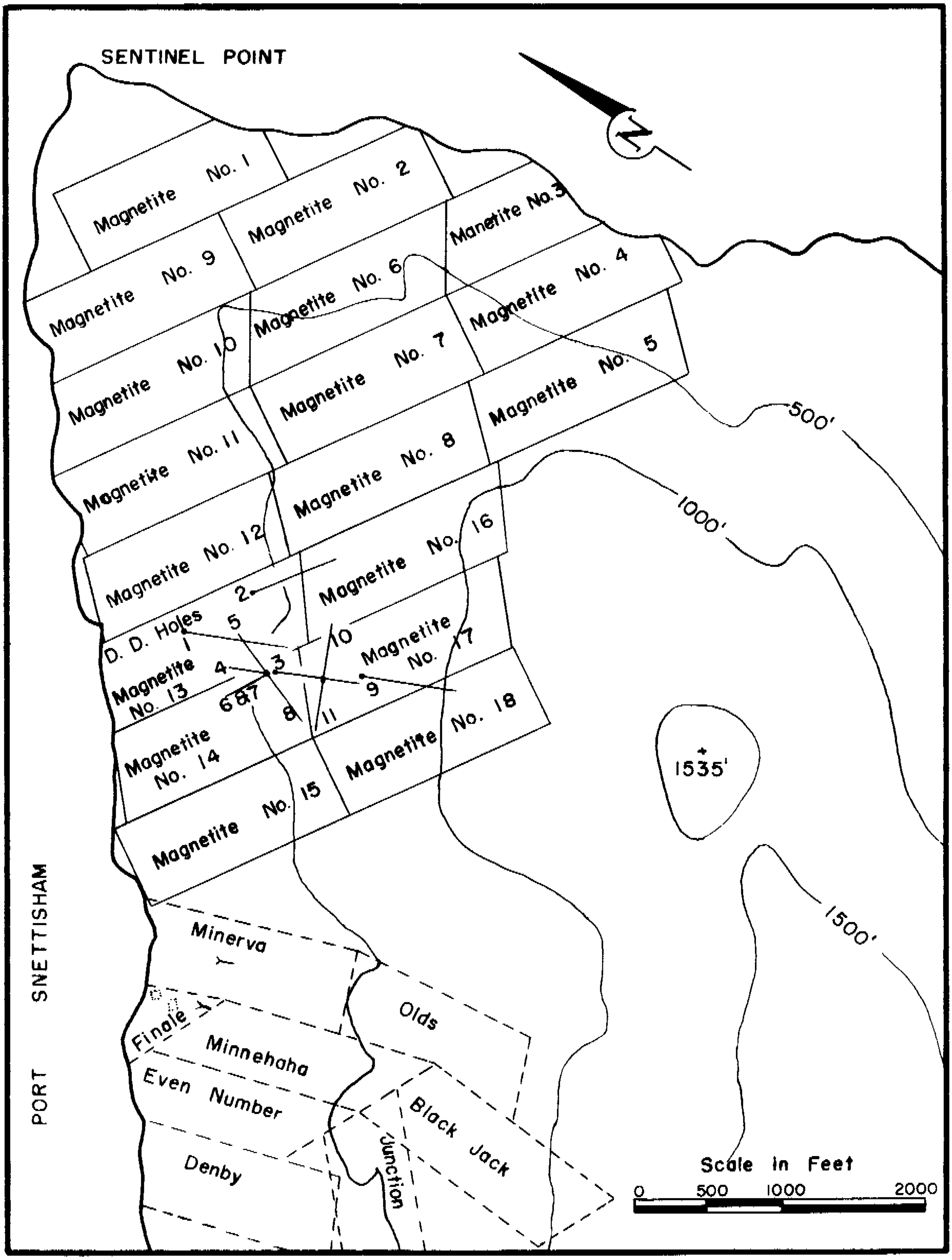

Figure 4. - Sketch map of Snettisham claims.

DESCRIPTION OF THE DEPOSIT

General Geology

The northern part of Snettisham Peninsula is composed of diorite and pyroxenite, which has been intruded into phyllite. Near the abandoned mining town of Snettisham, pyroxenite is exposed along the beach and extends inland for a considerable distance (fig. 3). To the east, toward Sentinel Point, the pyroxenite is in contact with the phyllite, into which some sill-like layers of pyroxenite have been injected. To the south the pyroxenite is in gradational contact with diorite, as is indicated by float, by change in magnetic attraction, and by drill hole 9, which penetrated the contact zone (figs. 7, 8, and 15); outcrops are infrequent because of the heavy cover of soil and vegetation.

The pyroxenite is intruded by dikes of diorite and aplite and, more rarely, by narrow vein dikes of white alkali-calcic plagioclase. Aerial photographs of the Port Snettisham area indicate that the regional topography has been influenced greatly by a series of major fractures, which trend N. 15° W. and are intersected by another series of approximately parallel fractures trending N. 45° E. Within the area underlain by pyroxenite no major faulting is indicated by the topography; furthermore, no large fractures were encountered in the drill holes, although some movement within the intrusive is indicated by flow structure exhibited in the drill core.

Character and Size

The northwestern part of the intrusive mass is composed of pyroxenite and associated variants containing magnetite, which occurs generally disseminated but also in localized concentrations. The remainder of the intrusive is diorite, which also contains magnetite but in considerably smaller percentages than does the pyroxenite. Hornblende is a major constituent of the pyroxenite; in parts of the deposit it is the dominant dark mineral.

Extreme variation in texture characterizes the pyroxenite deposit. Coarse-grained pegmatitic phases occur within the mass; they may consist of pyroxene and/or hornblende or pyroxene, hornblende biotite, and magnetite in varying proportions, including dominant magnetite. Occasionally chlorite is intergrown with the other minerals. The magnetite commonly is associated with sphene, apatite, epidote, and very small amounts of pyrrhotite, chalcopyrite, ilmenite, and spinel.

As mentioned above, the magnetite is disseminated generally throughout the pyroxenite mass in fairly uniform amounts, but higher grade concentrations are indicated by float, by occasional outcrops, and by core-drill samples. Buddington[7/] mentions a 6-foot vein of virtually solid ilmenitic magnetite outcropping on the beach about 100 yards east of the first point opposite the site of the post office building at the old Snettisham mine camp. This cropping could not be identified during the Bureau of Mines investigation; however, massive magnetite float is abundant in the vicinity of the old camp, and a small cropping north of the location mentioned by Buddington yielded samples that assayed 43 percent total iron. Massive magnetite is exposed in the bed of the small stream flowing between diamond-drill holes 1 and 2 (fig. 3) at approximately 600 feet altitude. Drill holes, 1, 2, 4, 6, and 7 all encountered massive magnetite or above-average, magnetite-enriched pyroxenite in core sections ranging from 2 feet to over 50 feet in length. The

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7/ Work cited in footnote 4 (p. 6).

size, continuity, and manner of occurrence of the high-grade magnetite encountered in the drill holes were not determined, but the incidence of such occurrence is believed to be normal for the drilled section of the pyroxenite intrusive.

The magnetite-bearing pyroxenite intrusive occupies a land area of approximately 390 acres along the northeast shore of Snettisham Peninsula, as shown in figure 3. The shape of the exposed portion of the deposit is roughly that of the segment of a circle, with the chord length along the shore approximating 9,600 feet. The widest west-east section is approximately 2,400 feet; altitudes range from sea level to 1,000 feet. The pyroxenite extends northwestward under the waters of Snettisham Inlet for an unknown distance.

FIELD STUDIES

Transit Survey

The transit survey, which was planned as a basis for a magnetic survey and for locating diamond-drill holes, was begun in December 1952. True bearings were determined by transit observations on the North or Polar Star. From a starting point established approximately 10,000 feet southwest of Sentinel Point at the mean high-tide line on the southeast shore of Port Snettisham, a meandering traverse nearly 3,500 feet long was surveyed northeastward to the site of the old mine ruins shown in figure 3. The straight-line distance covered by the meandering traverse is 2,850 feet.

From the old mine ruins a 5,500-foot baseline bearing N. 46° 10' E. and roughly parallel to the shore was established, with hubs for a magnetic grid survey at 100-foot intervals. Transverse lines bearing S. 59° E. were turned from the baseline at 500-foot intervals and extended inland from 600 to more than 2,000 feet; lines were marked at 100-foot intervals for magnetic observations. The grid covered an area of approximately 200 acres.

All drill holes, as well as all control points along the pyroxenite-diorite-phyllite contact, were tied to the basic grid with transit and tape. A shoreline traverse slightly more than 3,000 feet long was used to correlate the transit survey with a detailed work map obtained from the Topographic Division of the Geological Survey. Contours were transposed from the work map where not available from direct measurement.

Magnetic Survey

The isomagnetic lines covering the diamond-drill holes and the area south of them were determined entirely from interpretations of dip-needle readings (fig. 5). The isomagnetic lines north of the diamond-drill holes were plotted directly from readings of a vertical-type magnetometer.

Dip-needle readings were correlated with readings of the vertical magnetometer and reduced to a common scale as follows: The base reading for the vertical magnetometer was established well outside the local magnetic field. The magnetic readings at marked stations along a transverse line were taken with a dip needle; then the readings were repeated by using the vertical magnetometer on the same stations. From the gamma readings taken on identical stations with the vertical magnetometer, a dip-needle reading of 30° was determined to be equivalent to 7,000 gammas and a reading of 80° equivalent to 17,000 gammas. Comparison of the results obtained with the two instruments demonstrated enough uniformity to justify conversion of the dip-needle readings to gammas on this basis. All isomagnetic lines were therefore plotted in gammas.

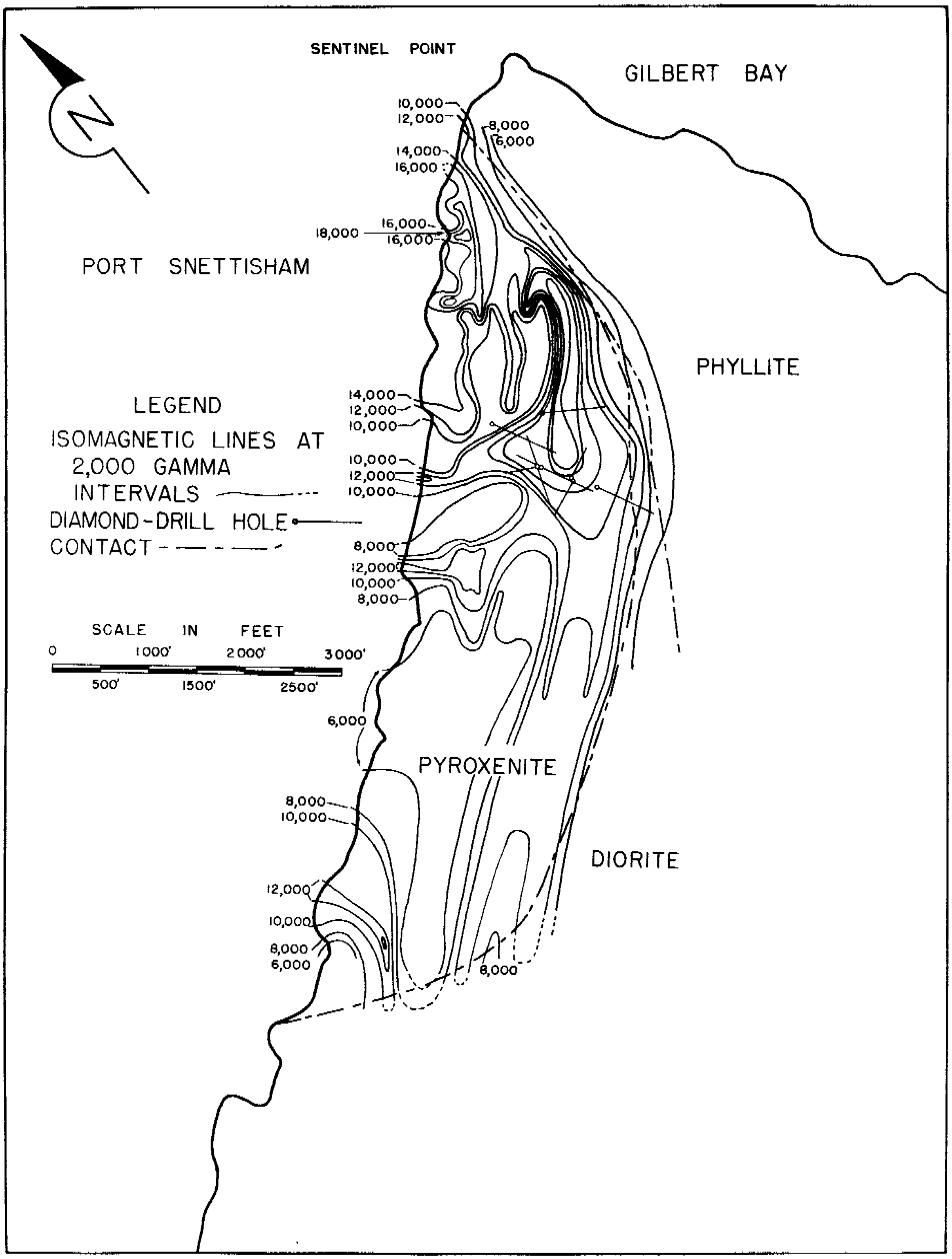

Figure 5. - Magnetometer survey.

After the Bureau of Mines study was completed, the owners of the property employed a Canadian company to survey the Snettisham magnetite deposit with an airborne magnetometer. The results of this survey are shown in figure 6. The airborne survey appears, on comparison with the survey on ground level, to indicate a similar overall magnetic anomaly. The accuracy of both surveys has no doubt been impaired to some extent by the rugged topography. Flight lines could not be planned so that all points were equidistant from the ground level. In conducting the ground survey the masses of magnetic material that were higher than the instrument, even though they were not vertically above it, could be expected to alter the normal reading.

The area of maximum anomaly, as indicated by the airborne survey, was near the southwest end of the area of maximum anomaly indicated by the surface survey. The diamond drilling was within the area of maximum anomaly indicated by the airborne survey.

Diamond Core Drilling

Because of the limitations of other methods of sampling diamond core drilling was employed to investigate and sample a typical area having high, vertical magnetic intensity. Drilling began on February 19, 1953, and, except for a period when the project was recessed from May 20 to June 20, 1953, continued until August 24, 1953.

The diamond drilling was done by Bureau of Mines personnel. A skid-mounted, gasoline-engine-driven diamond drill was used. The drill weighed approximately 1,600 pounds and had a 14-horsepower rating and a specified capacity of 900 feet of EX hole or 750 feet of AX hole.

The drill was floated to shore on a plank platform lashed to two 14-foot skiffs. After the skiffs were beached the drill was winched ashore, using its own power. All movement of the drill from setup to setup was with the drill-mounted winch, anchored by cable to some immobile object ahead. The rods and other parts of the drilling equipment were either pulled along behind on a stone boat or, in bad positions, winched up to the drill after it had been safely anchored. Much of the gasoline, oil, and other supplies was back-packed from the shore to the drill sites.

The heavily timbered slopes provided adequate places for anchoring the cable, but fallen timber formed obstructions, which had to be removed or bypassed.

The first two drill holes were completed under winter conditions, with the crew housed in a wood-floored, sidewall tent. When work was resumed in June 1953 the camp was moved to a site on the beach near hole 1. The progress of the work through the winter demonstrated the relative mildness of the climate and the possibility of moving in and making a reasonably comprehensive investigation with a small, well-trained labor force under conditions existing in Southeastern Alaska.

Eleven drill-hole locations were chosen to provide assay and geologic data on a section across the area of highest anomaly and to determine whether certain high-grade parts of the section represented erratic lenses or banded segregations that might be recovered by selective mining. A section 1,900 feet long was explored to a depth of 1,000 feet by 6,546 linear feet of drill holes.

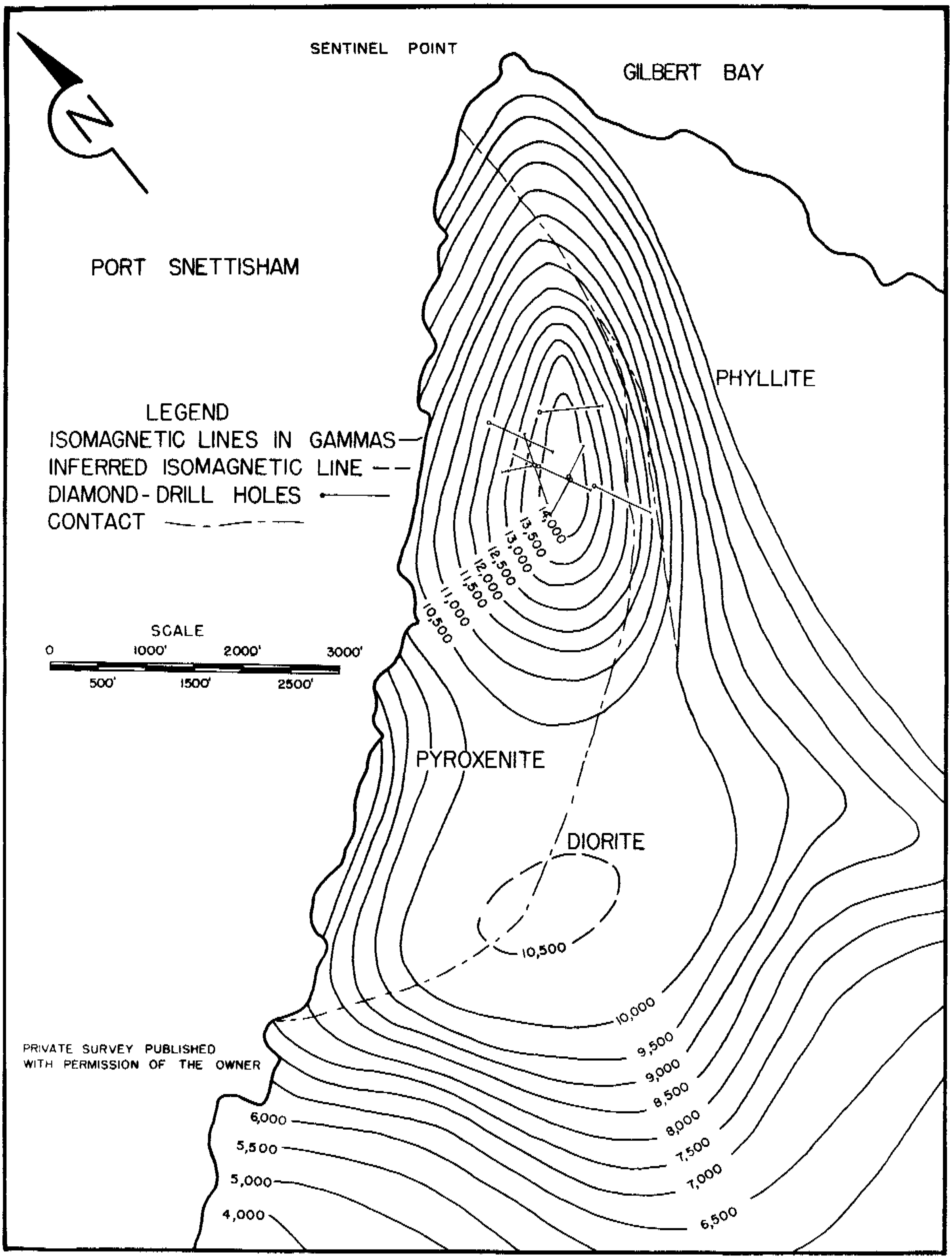

Figure 6. - Airborne magnetometer survey.

The depth and size of all diamond-drill holes and the amount of core recovered is summarized as follows:

TABLE 1. - Summary of diamond core drilling

Hole No.	DP[1/]	Bit size[2/] NX	BX	AX	EX	Total	Recovered center Feet	Percent
1	2.0	2.0	8.0	840.6		852.6	807.6	94.9
2	15.0		3.0	2.0	722.0	742.0	699.8	96.3
3	3.0		4.0	3.0	732.0	742.0	721.5	97.6
4	5.0			4.0	496.5	505.5	491.3	98.2
5	5.0			4.5	539.5	549.0	508.6	93.5
6	5.0			3.4	431.8	440.2	407.0	93.5
7	10.0			5.6	385.4	401.0	361.7	92.5
8	4.0			6.5	485.6	496.1	472.9	96.1
9	6.0		4.0	5.7	703.9	719.6	683.8	95.8
10	9.5		2.5	3.5	484.7	500.2	476.2	97.0
11	8.0		2.0	5.0	583.0	598.0	580.8	98.4
Total	72.5	2.0	23.5	883.8	5,564.4	6,546.2	6,211.2	95.9

1/ Drive pipe through soil and overburden; deducted from the total drilled before dividing to determine the percentage recovered.

2/ These bit sizes indicate the following core diameter: NX - 2-1/8 inches, BX - 1-5/8 inches, AX - 1-1/8 inches, EX - 7/8 inch.

The drill holes are shown in plan in figure 7 and in section in figures 8 to 15, inclusive.

Core Sampling and Analyses

All AX core from hole 1 was split; half was submitted for analyses, and the remaining portion (representing 94.9 percent of the hole length) was retained and filed in the core library for future reference. Subsequent holes were drilled EX size, and only small, split pieces of core representing a 10-foot length of hole or a particular type of mineralization were retained and filed for future reference; the remaining bulk of the small core was submitted for analyses and later composited for laboratory study. All core was sampled according to mineral characteristics rather than by the length of drill run. Particular care was exercised to break samples at changes in magnetite content or rock type.

All 335 core samples obtained from the 11 holes were analyzed for total iron content; iron analyses and sample descriptions are given in table 2. The samples were composited according to iron content and submitted to the laboratory for more complete chemical analyses and for beneficiation tests; methods and results are in the following sections of this report.

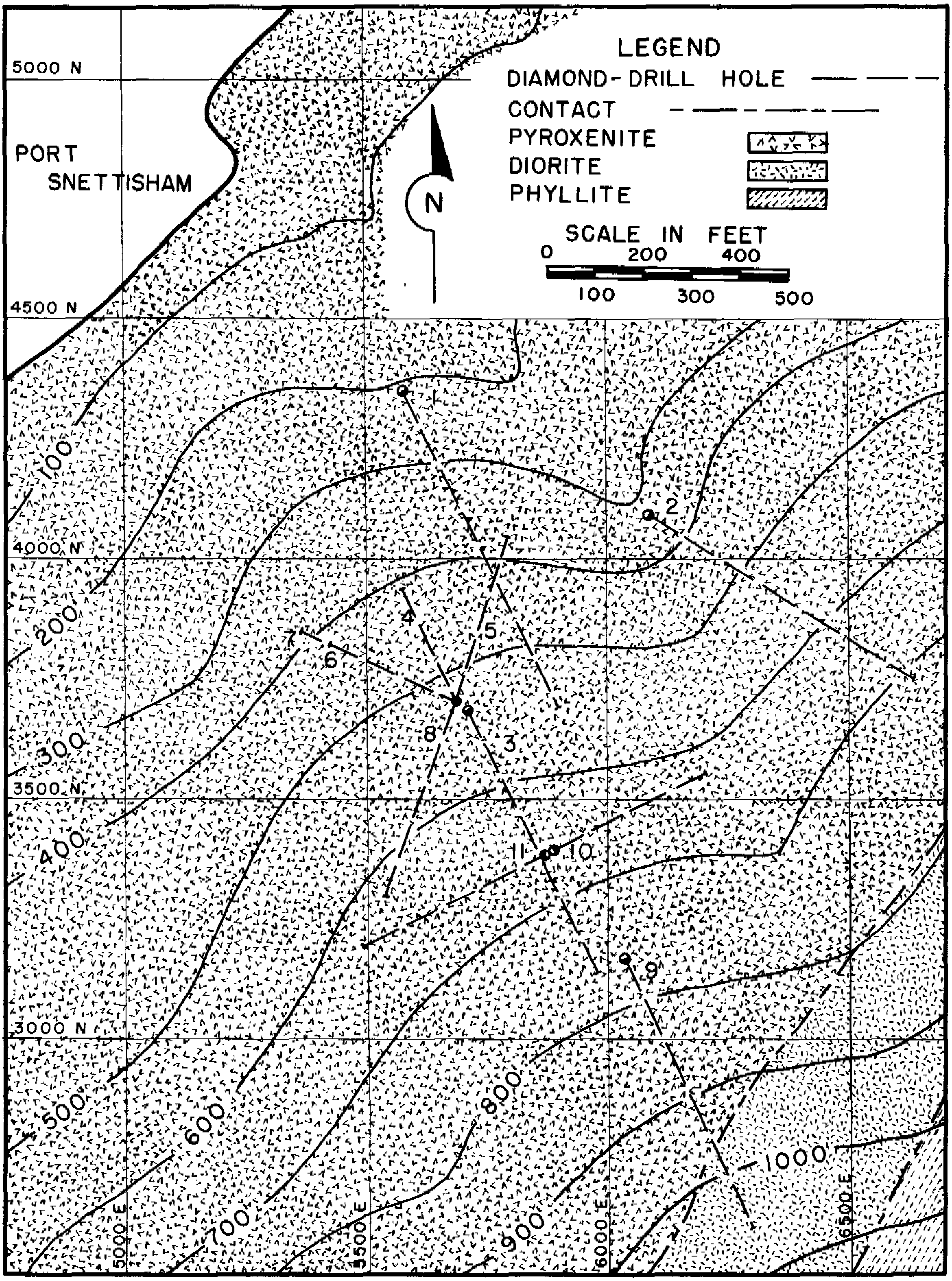

Figure 7. - Map of diamond-drill holes.

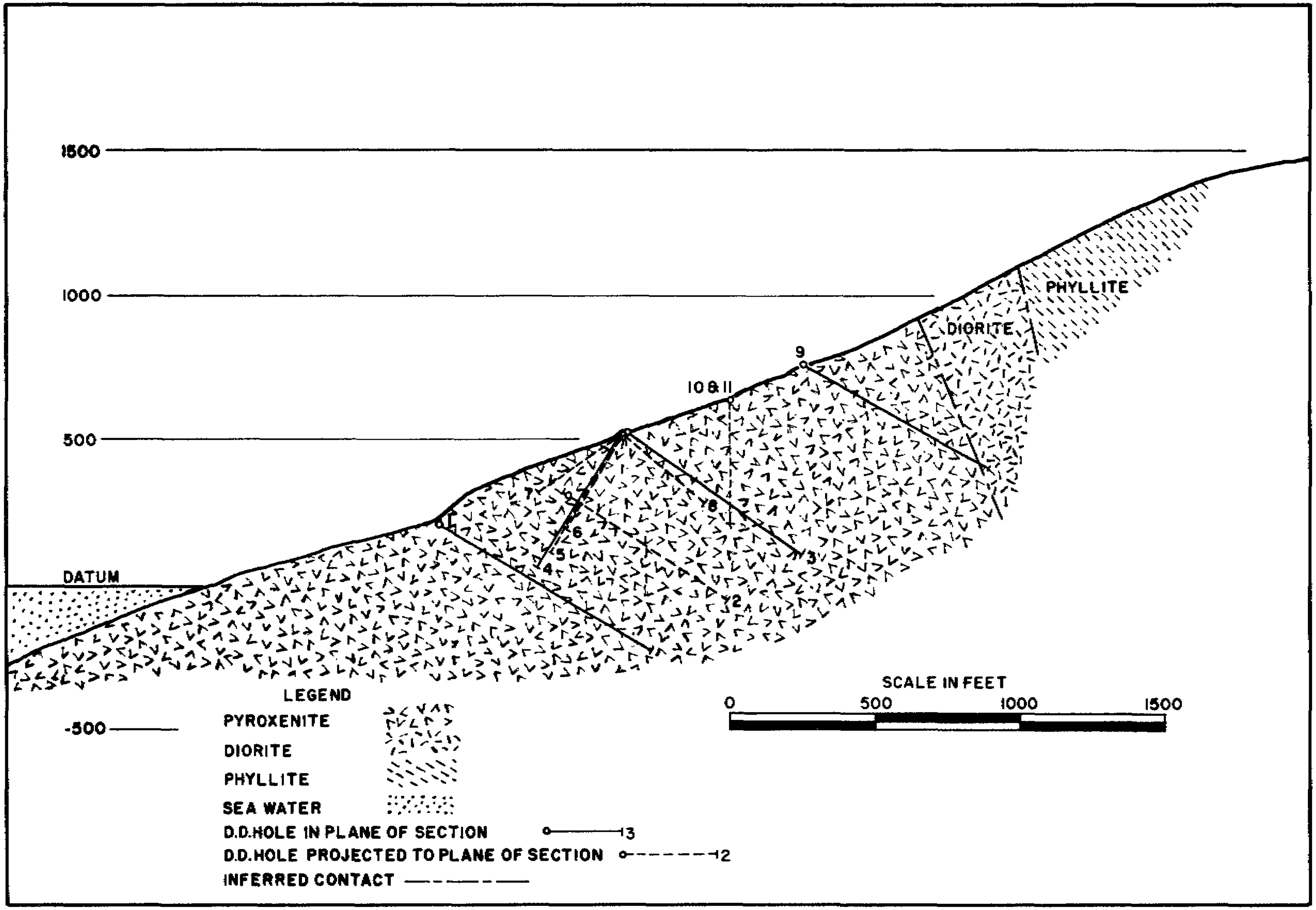

Figure 8. - Vertical section in the plane of diamond drill holes 1, 4, 3, and 9.

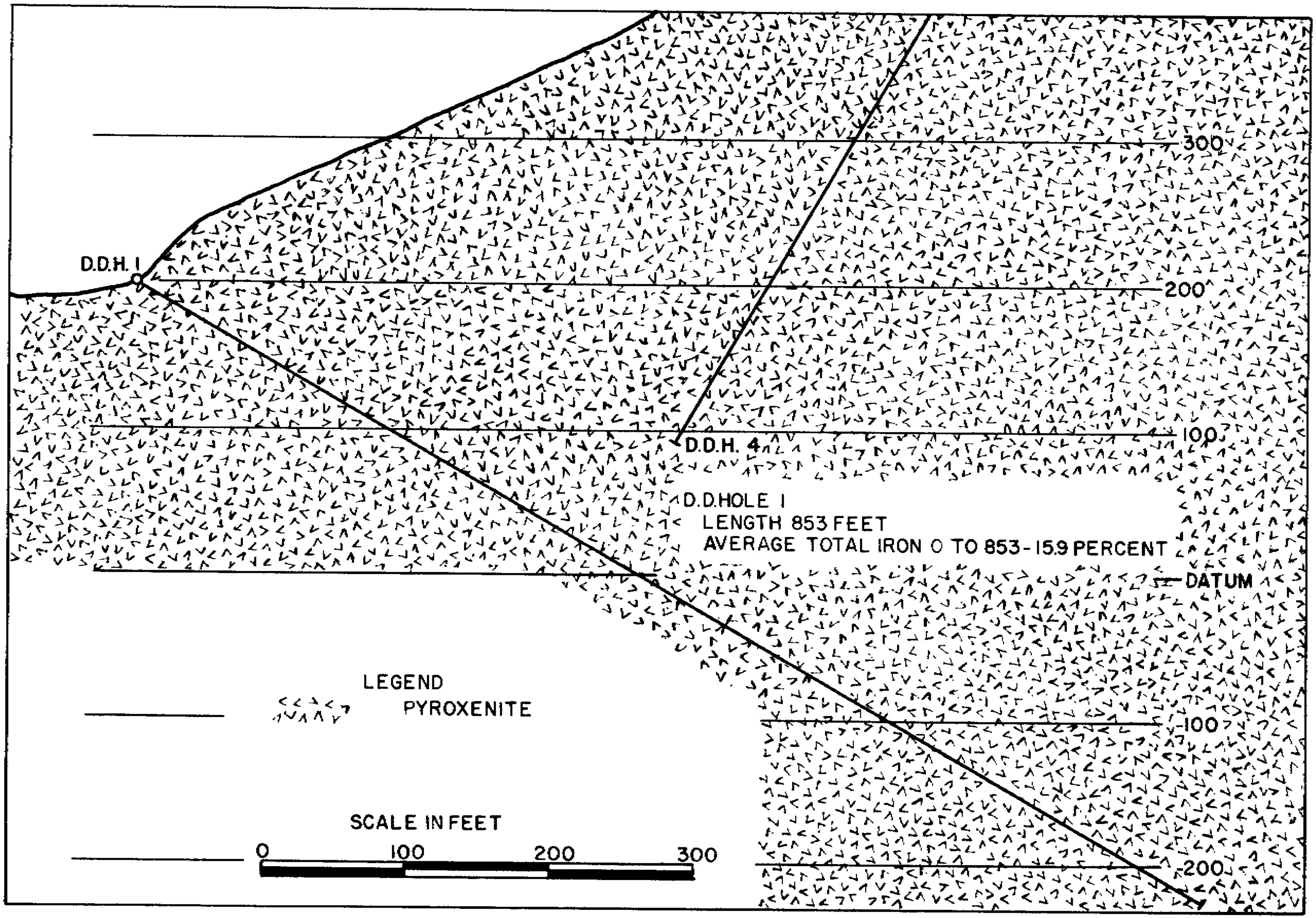

Figure 9. - Vertical section in the plane of diamond-drill hole 1.

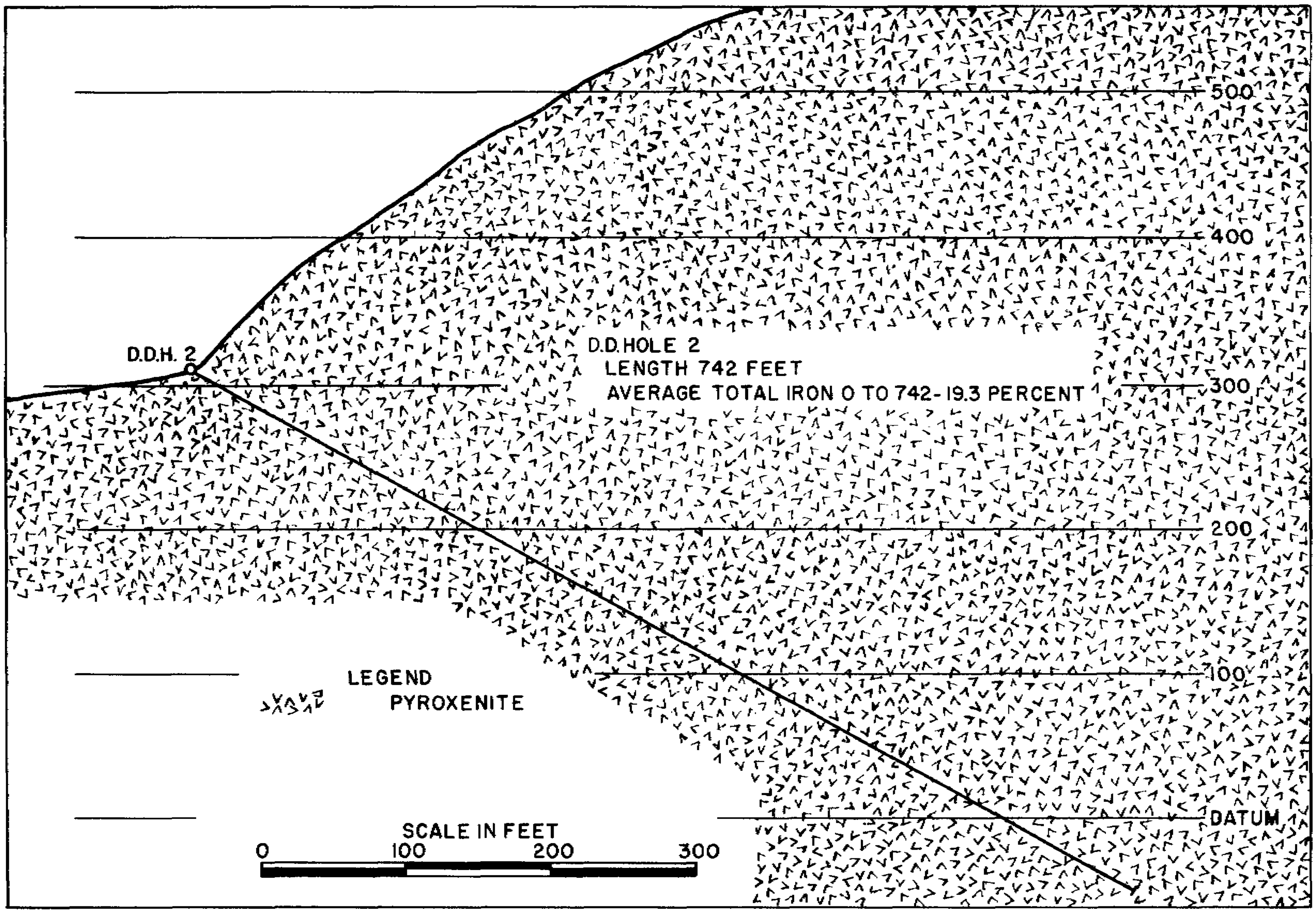

Figure 10. - Vertical section in the plane of diamond-drill hole 2.

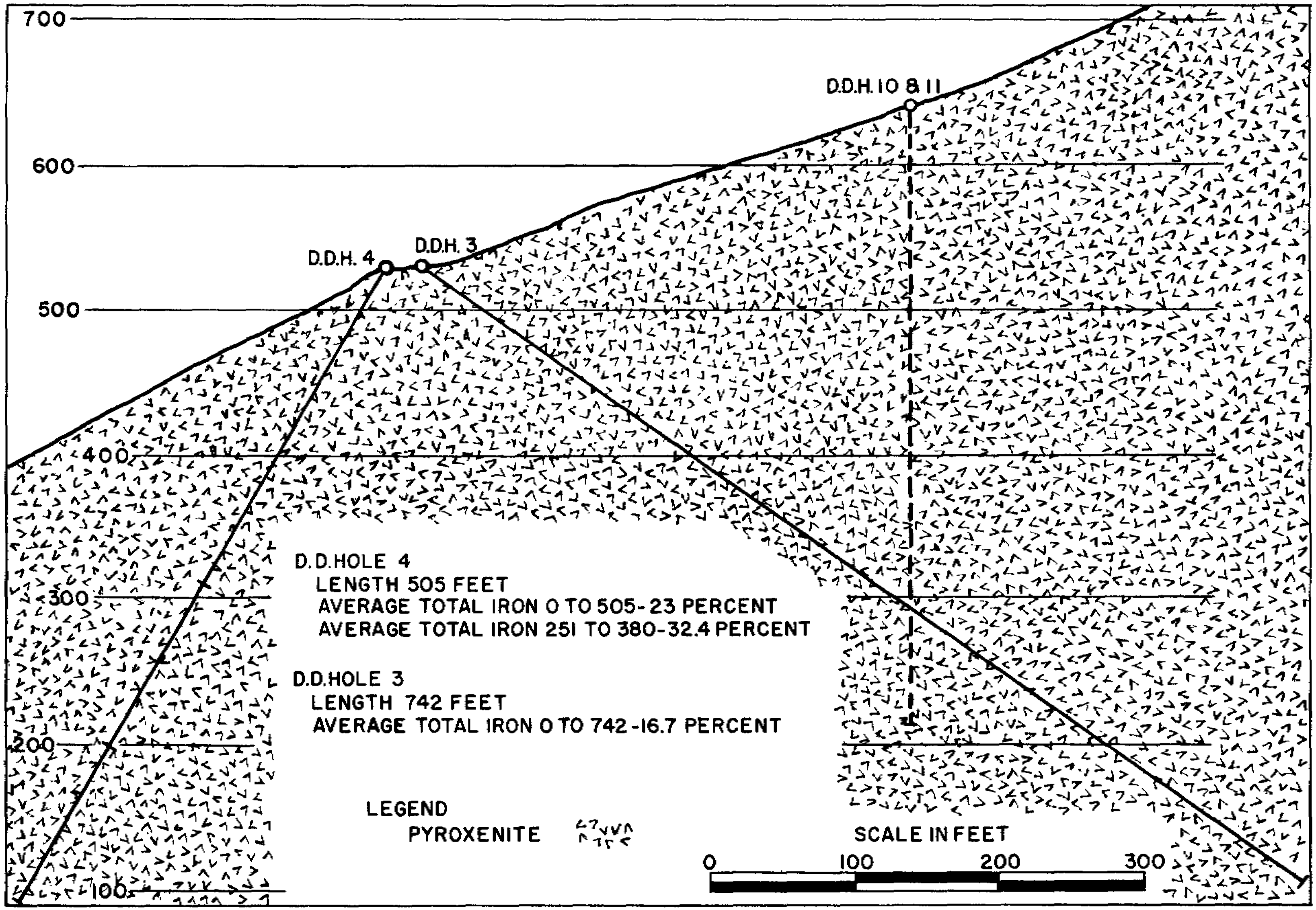

Figure 11. - Vertical section in the plane of diamond-drill holes 4, 8, and 3.

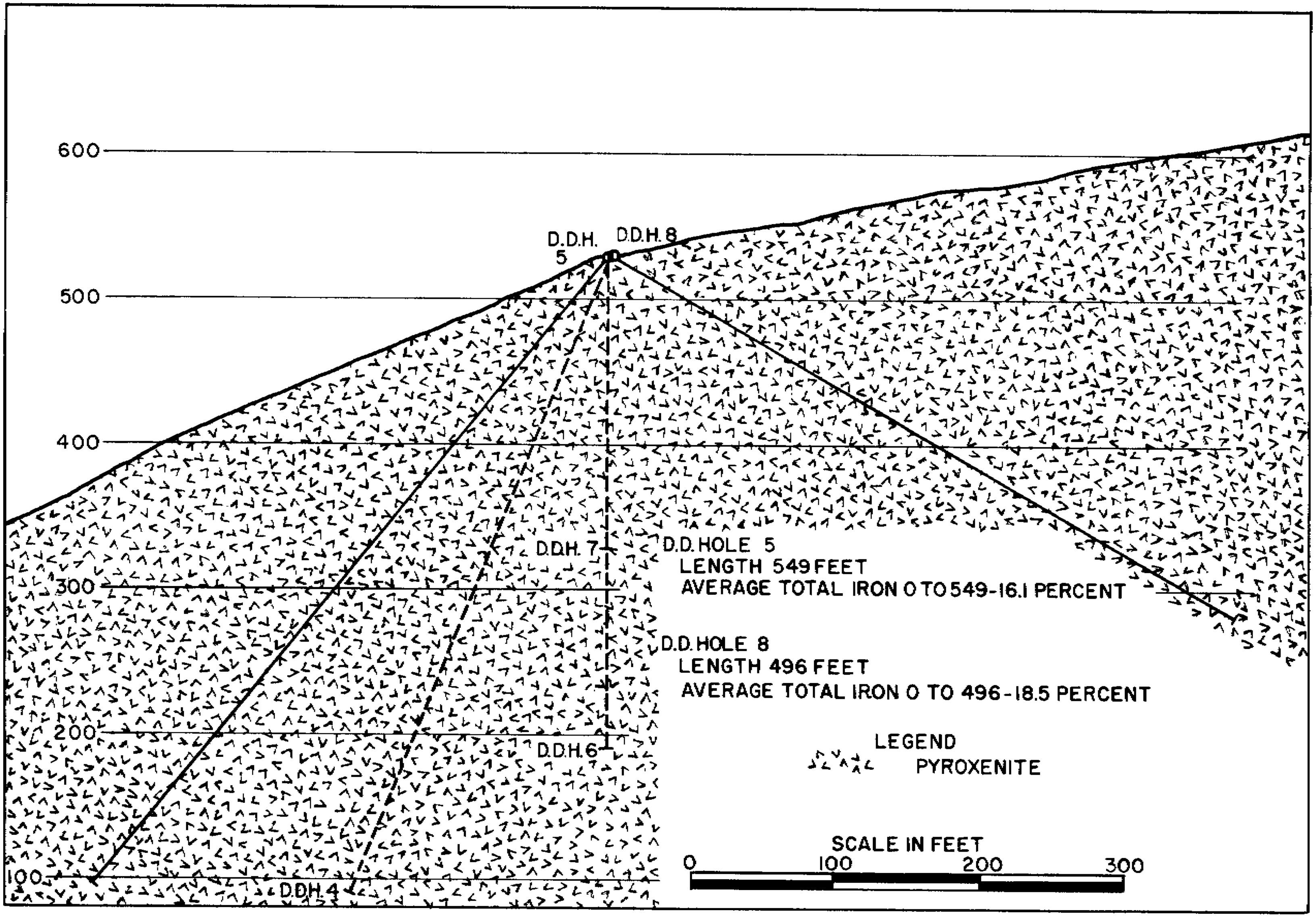

Figure 12. - Vertical section in the plane of diamond-drill holes 5 and 8.

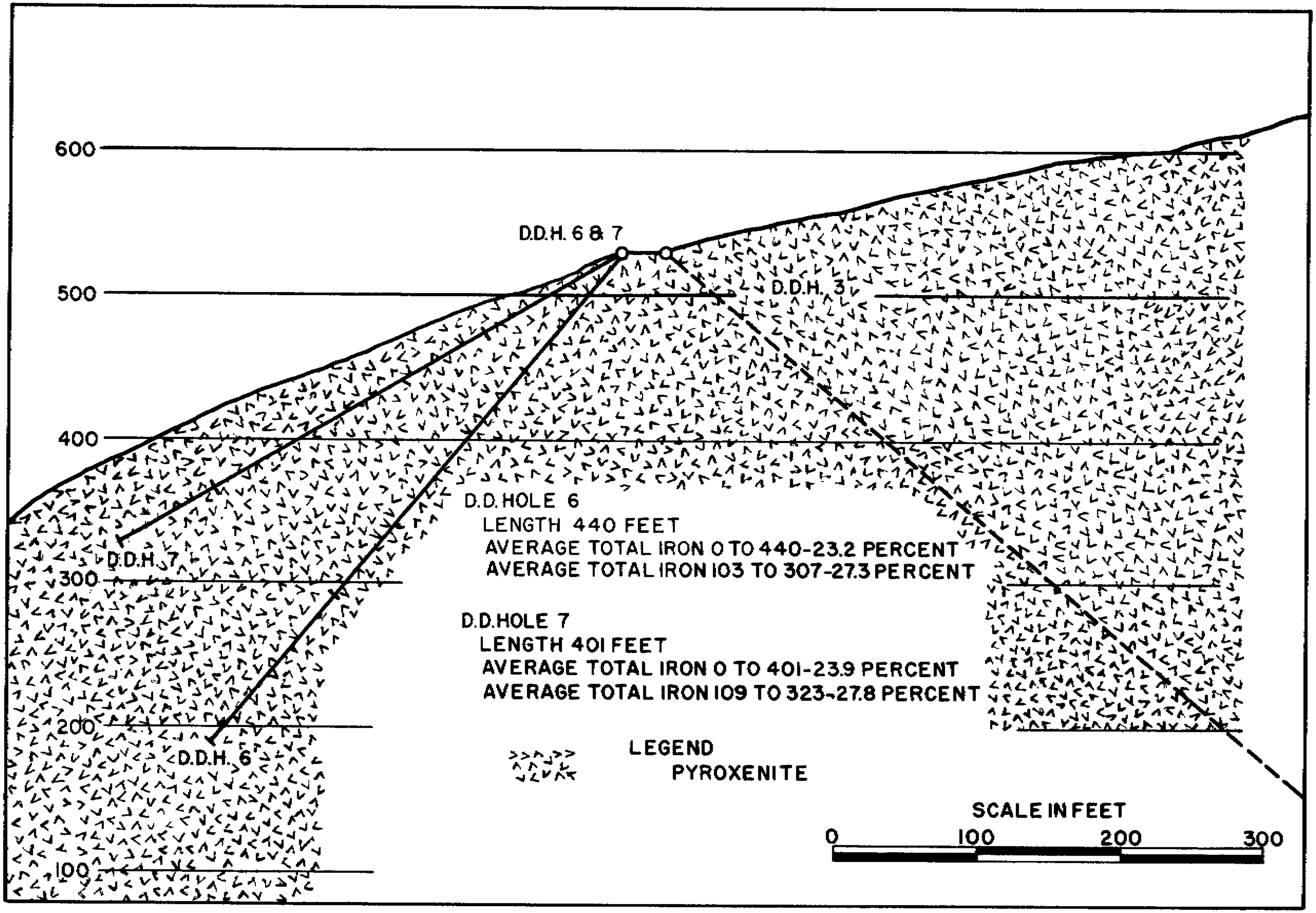

Figure 13. - Vertical section in the plane of diamond-drill holes 6 and 7.

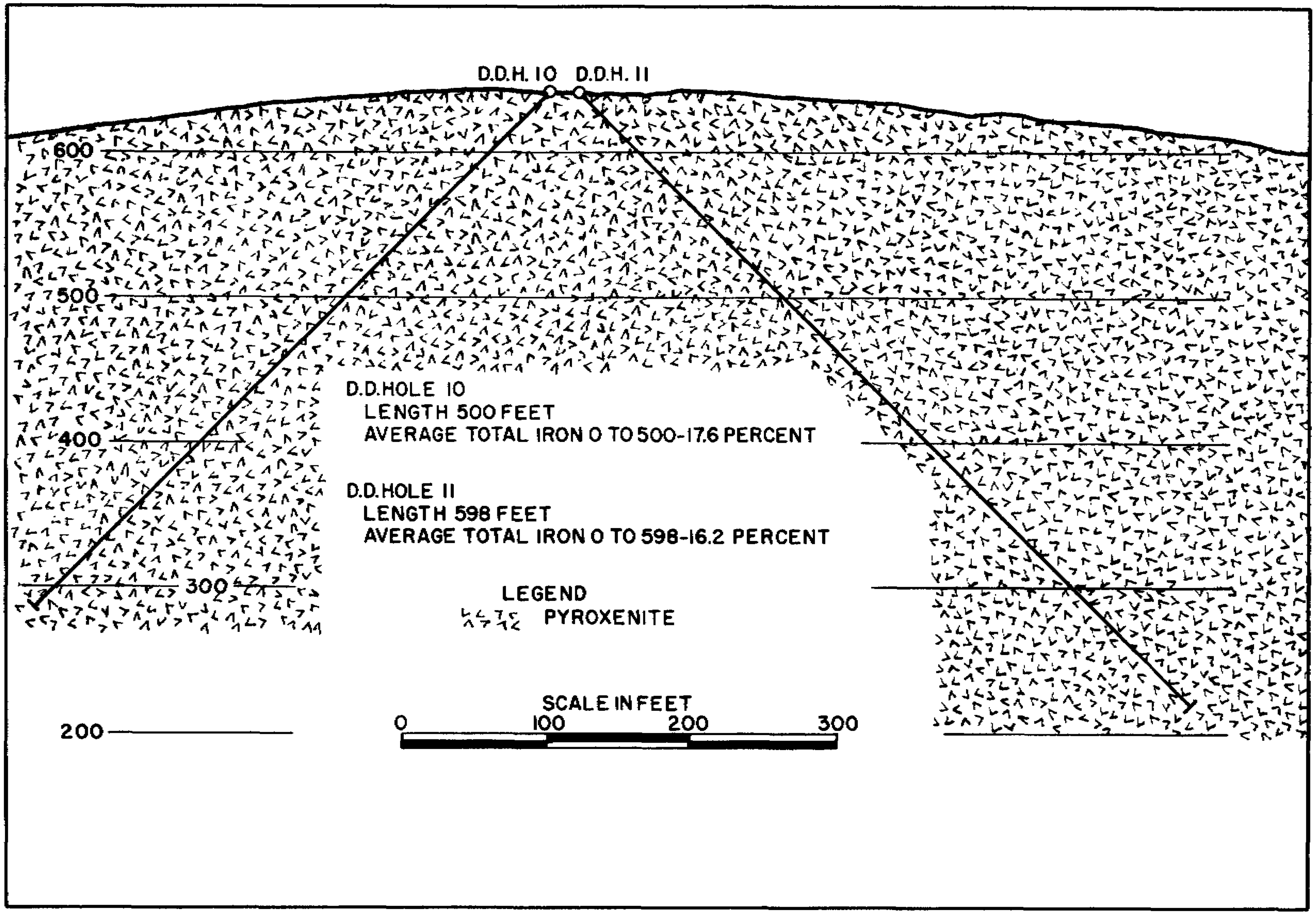

Figure 14. - Vertical section in the plane of diamond-drill holes 10 and 11.

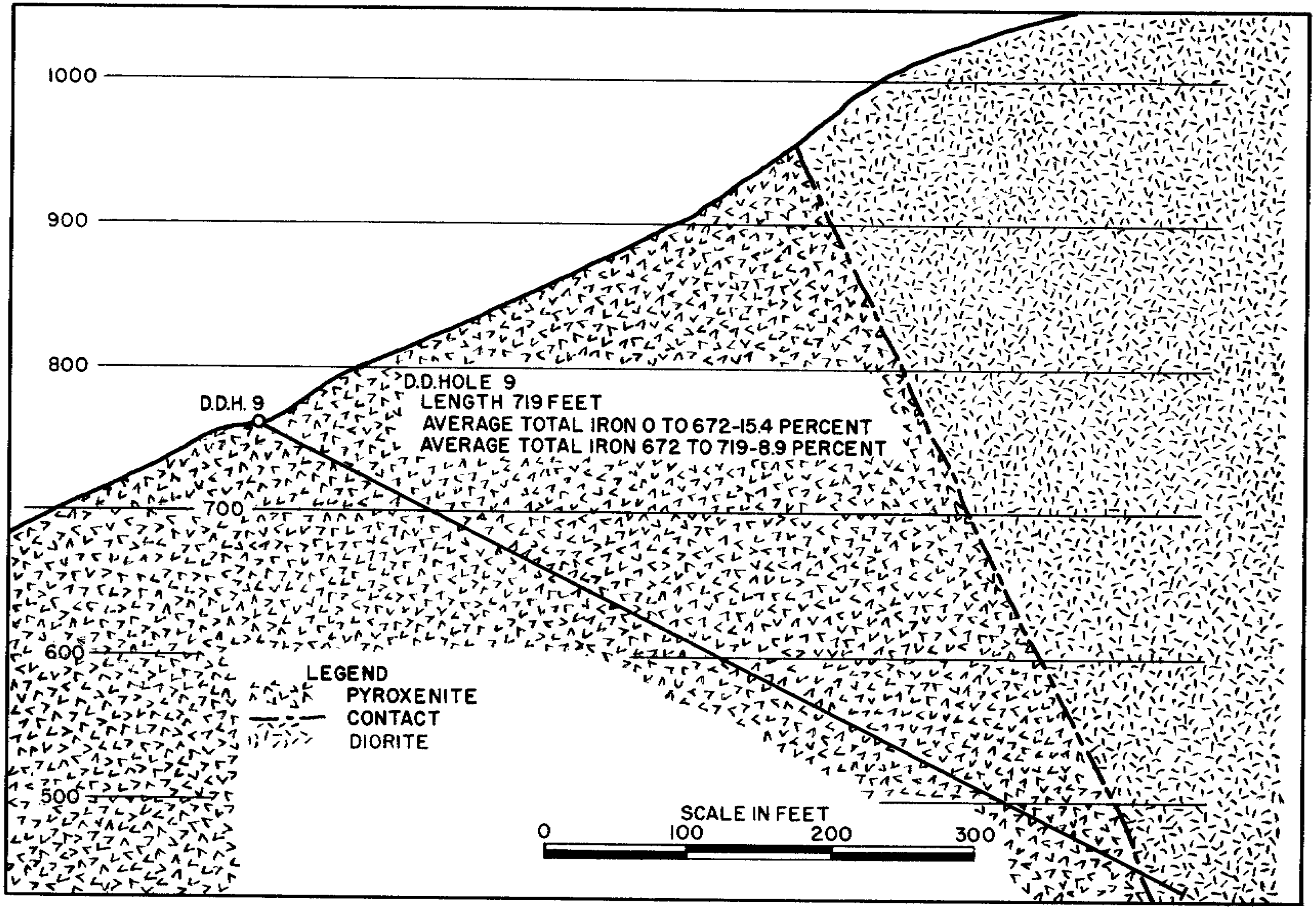

Figure 15. - Vertical section in the plane of diamond-drill hole 9.

TABLE 2. - Core-sample descriptions and total iron analyses

HOLE 1

Location: Lat. 4,352.5, Dep. 5,577.0
Elevation: 201 ft.
Depth: 852.6 ft.

Bearing: S. 25° 51' E.
Inclination: -30°

From-	To-	Feet	Total iron, percent	Description
0	3.0	3.0		Moss and soil overburden.
3.0	12.0	9.0	17.7	Coarse-grained hornblende, augite, and pigeonite, with small amounts of associated magnetite, olivine, apatite, sphene, epidote, biotite, pyrite, and chlorite. Also present are very small amounts of pyrrhotite, chalcopyrite, and ilmenite.
12.0	34.8	22.8	15.5	Same as 3.0-12.0 feet, except altered plagioclase at 27.5-31.5 feet.
34.8	44.0	9.2	16.1	Same as 3.0-12.0 feet, some medium-grained flow structure.
44.0	63.8	19.8	16.0	Coarse mafic as above, with some alkali-calcic plagioclase stringers.
63.8	84.1	20.3	15.3	Same as 44.0-63.8 feet, with more biotite.
84.1	102.1	18.0	15.9	Coarse-grained mafic, with some flow structure.
102.1	112.3	10.2	16.9	Coarse-grained pyroxenite; some increase in magnetite.
112.3	128.8	16.5	17.4	Some pegmatitic segregation.
128.8	149.3	20.5	18.2	Do.
149.3	169.7	20.4	17.0	Coarse-grained pyroxenite, with hornblende masses.
169.7	189.8	20.1	15.9	Do.
189.8	208.8	19.0	16.3	Coarse-grained pyroxenite, with hornblende, some plagioclase, and epidote at 200 feet.
208.8	226.9	18.1	14.9	Hornblende and biotite hornblendite; some pyroxene.
226.9	247.5	20.6	16.0	Coarse-grained amphibole and pyroxene; some plagioclase.
247.5	268.0	20.5	16.7	Coarse-grained pyroxenite, some plagioclase, and some flow structure.
268.0	285.6	17.6	16.7	Coarse pyroxenite.
285.6	304.0	18.4	15.8	Do.
304.0	324.1	20.1	16.0	Coarse-grained pyroxenite, 8 inches diorite at 310 feet and 3 inches plagioclase at 320 feet.
324.1	344.3	20.2	16.0	Coarse-grained pyroxenite; diorite 328 to 330 feet.
344.3	364.6	20.3	15.1	Coarse-grained pyroxenite, partly pegmatitic; 1 foot diorite at 361 feet.
364.6	383.6	19.0	15.4	Coarse-grained pyroxenite; 1 inch diorite at 364 feet, much schist-like flow structure.
383.6	397.2	13.6	15.4	Coarse-grained pyroxenite.
397.2	419.0	21.8	15.4	Coarse-grained pyroxenite; some plagioclase at 407 feet.
419.0	437.2	18.2	15.3	Coarse-grained pyroxenite, hornblende 423-424 feet, augite 428-429 feet.
437.2	456.3	19.1	15.3	Coarse-grained pyroxenite, some pegmatitic; 3 feet diorite at 440 feet.
456.3	477.2	20.9	16.4	Coarse pyroxenite, partly pegmatitic.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

From-	To-	Feet	Total iron, percent	Description
477.2	495.9	18.7	16.4	Coarse pyroxenite, partly pegmatitic.
495.9	504.0	8.1	16.0	Do.
504.0	506.2	2.2	33.3	Magnetite and pyroxenite.
506.2	510.2	4.0	12.8	Coarse-grained pyroxenite, with little magnetite.
510.2	520.6	10.4	16.5	Coarse-grained pyroxenite, partly pegmatitic.
520.6	534.3	13.7	19.2	Same as 510.2-520.6 feet, with an increase in magnetite.
534.3	553.0	18.7	16.1	Coarse-grained pyroxenite.
553.0	561.6	8.6	15.7	Do.
561.6	572.0	10.4	17.8	Same as 534.3-553.0 feet, with slight increase in magnetite.
572.0	582.6	10.6	16.2	Coarse pyroxenite, partly pegmatitic.
582.6	599.2	16.6	14.0	Coarse pyroxenite, diorite, and breccia, 587-593 feet.
599.2	618.8	19.6	15.7	Coarse pyroxenite, diorite, and breccia, 615-618 feet.
618.8	638.3	19.5	15.7	Coarse pyroxenite, partly pegmatitic; 6 inches diorite at 630 feet.
638.3	659.2	20.9	14.2	Coarse pyroxenite.
659.2	679.7	20.5	14.0	Do.
679.7	698.0	18.3	14.3	Do.
698.0	717.6	19.6	14.9	Same as 638.3-659.2 feet, but 700-703 feet diorite with flow structure.
717.6	737.0	19.4	15.4	Coarse pyroxenite, partly pegmatitic.
737.0	755.8	18.8	14.9	Do.
755.8	772.1	16.3	13.9	Coarse-grained pyroxenite, some felsic areas.
772.1	790.0	17.9	16.3	Do.
790.0	811.6	21.6	14.6	Do.
811.6	830.8	19.2	16.3	Pyroxenite, partly pegmatitic.
830.8	852.6	21.8	16.3	Same as 811.6-830.8 feet, with 1/4 inch epidote, plagioclase stringer 837-838 feet.

HOLE 2

Location: Lat. 4,095.6, Dep. 6,085.4 — Bearing: S. 58° 04'E.
Elevation: 312 ft. — Inclination: -29°
Depth: 742.0 ft.

From-	To-	Feet	Total iron, percent	Description
0	15.0	15.0		Moss and soil plus overburden.
15.0	37.6	22.6	18.6	Pyroxenite, with some magnetite, biotite, and traces of pyrite.
37.6	58.0	20.4	22.2	Do.
58.0	75.0	17.0	16.8	Do.
75.0	95.8	20.8	18.2	Same as 15.0-37.6 feet, but 1 inch plagioclase at 89 feet.
95.8	116.2	20.4	18.1	Pyroxenite, with some magnetite; felsic spots.
116.2	136.3	20.1	18.8	Pyroxenite, with some magnetite.
136.3	159.7	23.4	18.4	Do.
159.7	179.5	19.8	18.8	Do.
179.5	203.6	24.1	17.7	Same as 116.2-136.3 feet, but 2 small felsic spots.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

From-	To-	Feet	Total iron, percent	Description
203.6	222.7	19.1	17.3	Same as 116.2-136.3 feet, but 3 small felsic spots.
222.7	243.0	20.3	16.7	Pyroxenite, with 3 felsic spots and patches of hornblende.
243.0	262.8	19.8	18.4	Pyroxenite, some hornblende, and some better magnetite.
262.8	276.0	13.2	18.0	Same as 243.0-262.8 feet, with minor amount of pyrite.
276.0	282.4	6.4	23.1	Pyroxenite, a felsic spot, and some better magnetite.
282.4	298.8	16.4	18.9	Pyroxenite, with hornblende and some better magnetite.
298.8	309.0	10.2	22.3	Do.
309.0	328.2	19.2	19.4	Pyroxenite, with small felsic spots, good magnetite 320-321 feet.
328.2	350.0	21.8	17.8	Pyroxenite, with some better magnetite.
350.0	386.0	36.0	19.4	Do.
386.0	401.2	15.2	17.7	Same as 328.2-350.0 feet, but containing some diorite phases.
401.2	428.0	26.8	19.1	Same as 328.2-350.0 feet, but solid diorite 406-408 feet.
428.0	448.0	20.0	18.9	Pyroxenite, with some flow structure, some better magnetite.
448.0	469.0	21.0	16.8	Pyroxenite, with some better magnetite.
469.0	491.0	22.0	18.6	Same as 448.0-469.0 feet, but diorite 481.5-483.5 feet.
491.0	496.7	5.7	41.8	Coarse-grained pyroxenite, with heavy magnetite.
496.7	511.6	14.9	25.5	Pyroxenite, with flow structure, masses of magnetite.
511.6	532.0	20.4	15.9	Same as 496.7-511.6 feet, but less magnetite.
532.0	552.2	20.2	17.7	Coarse-grained pyroxenite, with some magnetite.
552.2	572.7	20.5	19.3	Same as 532.0-552.2 feet, but better magnetite.
572.7	593.0	20.3	20.1	Do.
593.0	603.3	10.3	25.4	Coarse-grained pyroxenite, with better magnetite.
603.3	613.7	10.4	45.1	Magnetite, with some pyroxenite.
613.7	624.4	10.7	37.0	Coarse-grained pyroxenite and magnetite.
624.4	638.9	14.5	15.9	Coarse-grained pyroxenite, with some magnetite.
638.9	659.2	20.2	18.1	Do.
659.2	679.4	20.2	16.7	Do.
679.4	701.3	21.9	17.0	Do.
701.3	722.1	20.8	16.0	Do.
722.1	742.0	19.9	15.3	Coarse-grained pyroxenite, with traces of diorite at 725 and 727 feet.

HOLE 3

Location: Lat. 3,679.9, Dep. 5,703.6
Elevation: 530 ft.
Depth: 742.0 ft.

Bearing: S. 26° 55' E.
Inclination: -35°

From-	To-	Feet	Total iron, percent	Description
0	3.0	3.0		Overburden, soil, and moss.
3.0	10.0	7.0	15.4	Coarse pyroxenite, possibly boulders.
10.0	19.8	9.8	26.6	1 foot pyroxenite, 1 foot diorite, 4 feet better magnetite, then pegmatitic pyroxenite.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

From-	To-	Feet	Total iron, percent	Description
19.8	39.7	19.9	17.5	Coarse pyroxenite partly pegmatitic. Pyroxenite is slightly more than half clinopyroxene, with some associated hornblende and disseminated magnetite, plus small amounts of biotite, apatite, and sphene and very small amounts of clinozoisite, ilmenite, pyrrhotite, and chalcopyrite.
39.7	59.7	20.0	17.2	Same as 19.8-39.7 feet, except for patch of pyrite at 41 feet.
59.7	79.7	20.0	17.5	Coarse pyroxenite, pegmatitic in sections.
79.7	99.8	20.1	18.7	Do.
99.8	126.4	26.6	17.3	Do.
126.4	150.1	23.7	19.0	Same as 99.8-126.4 feet, but felsic spots and some flow structure.
150.1	171.0	20.9	17.8	Coarse pyroxenite, pegmatitic in sections.
171.0	186.3	15.3	18.6	0.8 foot of diorite, followed by coarse pyroxenite.
186.3	264.3	78.0	17.2	Coarse pyroxenite, pegmatitic in sections.
264.3	281.5	17.2	23.7	Same as 186.3-264.3 feet, but more magnetite.
281.5	400.1	118.6	16.9	Coarse pyroxenite, partly pegmatitic.
400.1	420.3	20.2	16.3	Same as 281.5-400.1 feet, but banded with diorite.
420.3	461.0	40.7	14.0	Mostly diorite, some coarse-grained pyroxenite.
461.0	621.5	160.5	15.3	Coarse pyroxenite, partly pegmatitic.
621.5	640.7	18.7	12.4	Same as 461.0-621.5 feet, but diorite 624-625 feet.
640.7	742.0	101.3	16.3	Coarse pyroxenite, partly pegmatitic, some epidote at 675 feet.

HOLE 4

Location: Lat. 3,706, Dep. 5,686
Elevation: 528 ft.
Depth: 505.5 ft.

Bearing: N. 25° 21' W.
Inclination: -60°

0	5.0			Moss and soil.
5.0	48.4	43.4	18.3	Pyroxenite, partly coarse grained; some pyrrhotite and chalcopyrite.
48.4	72.8	24.4	19.1	Pyroxenite, with diorite 56-58 feet, and magnetite, with epidote 64-65 feet.
72.8	93.0	20.2	15.5	Flow structure poor in magnetite 73-77 feet, then interspersed with normal pyroxenite.
93.0	210.7	117.7	19.6	Coarse-grained pyroxenite, with intermittent magnetite enrichment.
210.7	230.8	20.1	26.3	Coarse-grained pyroxenite, with moderate to heavy magnetite enrichment.
230.8	251.0	20.2	20.2	Do.
251.0	270.9	19.9	39.1	Do.
270.9	287.0	16.1	36.0	Do.
287.0	303.8	16.8	21.4	Do.
303.8	323.8	20.0	34.4	Do.
323.8	344.0	20.2	31.1	Do.
344.0	362.9	18.9	28.6	Do.
362.9	380.4	17.5	35.5	Do.
380.4	400.0	19.6	24.9	Do.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

From-	To-	Feet	Total iron, percent	Description
400.0	418.9	18.9	22.5	Pyroxenite, with marked reduction in magnetite.
418.9	458.0	39.1	19.4	Pyroxenite containing considerable biotite, with some spotted magnetite and 4 inches felsic core at 420 feet.
458.0	505.5	47.5	16.7	Coarse-grained pyroxenite, felsic at 470 and 483 feet and with 3 inches diorite at 501 feet.

HOLE 5

Location: Lat. 3,708, Dep. 5,686 — Bearing: N. 18° 04' E.
Elevation: 529 ft. — Inclination: -50°
Depth: 549.0 ft.

From-	To-	Feet	Total iron, percent	Description
0	5.0	5.0		Moss and soil.
5.0	27.4	22.4	17.6	Pyroxenite, with felsic spots and sulfides at 24 feet.
27.4	50.5	23.1	17.5	Pyroxenite, with biotite, some epidote 45-46 feet.
50.5	123.7	73.2	16.4	Pyroxenite, felsic spots at 80 and 95 feet.
123.7	133.8	10.1	28.0	Pyroxenite, with moderate to heavy magnetite enrichment.
133.8	151.9	18.1	19.4	Pyroxenite, with biotite; weak magnetite enrichment.
151.9	172.4	20.5	19.3	Coarse pyroxenite, with some magnetite enrichment.
172.4	208.5	36.1	17.3	Pyroxenite, with biotite and some flow structure.
208.5	233.4	24.9	16.2	Coarse pyroxenite, with spot of magnetite at 230 feet.
233.4	270.2	36.8	16.2	Pyroxenite, with biotite and some felsic spots.
270.2	293.0	22.8	11.4	Dark, hornblende diorite, with flow structure parallel to core.
293.0	316.0	23.0	10.9	Coarse pyroxenite, with some magnetite.
316.0	353.4	37.4	15.9	Pyroxenite, with biotite, hornblende, and some magnetite.
353.4	452.1	98.7	15.6	Coarse pyroxenite, with biotite, hornblende, and some magnetite.
452.1	493.7	41.6	14.7	Same as 353.4-452.1 feet, but epidote with pyrite at 467-469 feet and 480-485 feet, diorite 472-473 feet.
493.7	549.0	55.3	15.8	Coarse augite pyroxenite, with some weak magnetite enrichment.

HOLE 6

Location: Lat. 3,706, Dep. 5,685 — Bearing: N. 64° 25' W.
Elevation: 529 ft. — Inclination: -50°
Depth: 440.4 ft.

From-	To-	Feet	Total iron, percent	Description
0	5.0	5.0		Moss and soil.
5.0	46.0	41.0	18.2	Coarse pyroxenite, with biotite between 14-26 feet, 6 inches magnetite enrichment at 21 feet, felsic spot at 41 feet.
46.0	103.5	57.5	19.5	Coarse pyroxenite, with biotite, some hornblende, and magnetite.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

From-	To-	Feet	Total iron, percent	Description
103.5	123.2	19.7	26.1	Spotted magnetic enrichment begins at 106 feet in a gray-green pyroxenite.
123.2	165.2	42.0	24.1	Pyroxenite, with spotted magnetic enrichment; diorite at 133 and 140 feet.
165.2	189.1	23.9	34.4	Pyroxenite, with good magnetite enrichment.
189.1	230.4	41.3	20.9	Partly coarse pyroxenite, with dispersed magnetite.
230.4	250.7	20.3	32.0	Pyroxenite, with moderate to heavy magnetite enrichment.
250.7	270.9	20.2	25.4	Partly coarse pyroxenite; considerable magnetite felsic spots.
270.9	307.5	36.6	32.5	Partly coarse pyroxenite, with erratically distributed magnetite masses.
307.5	368.7	61.2	21.9	Coarse pyroxenite felsic spots with epidote in spots and variable magnetite enrichment.
368.7	386.3	17.6	19.4	Same as 307.5-368.7 feet, but 6 inches of diorite at 377 feet.
386.3	430.4	44.1	17.4	Same as 307.5-368.7 feet, with spots of diorite or felsic spots and some pyrite from 422 to 424 feet.
430.4	440.4	10.0	22.0	Pyroxenite, with better magnetite enrichment 436 feet to end of hole.

HOLE 7

Location: Lat. 3,707, Dep. 5,683 Bearing: N. 64° 25' W.
Elevation: 528 ft. Inclination: -30°
Depth: 401.0 ft.

From-	To-	Feet	Total iron, percent	Description
0	10.0	10.0		Moss, soil, and overburden.
10.0	24.7	14.7	18.7	Coarse pyroxenite, with some epidote and magnetite.
24.7	45.0	20.3	23.4	Coarse pyroxenite, with spots of diorite and moderate magnetite enrichment.
45.0	87.2	42.2	17.8	Coarse pyroxenite, with some biotite and from 71 feet spotted magnetite enrichment.
87.2	109.1	21.9	22.0	Coarse pyroxenite, with some magnetite enrichment.
109.1	129.7	20.6	28.6	Same as 87.2-109.1 feet, with more magnetite.
129.7	150.8	21.1	37.0	Same as 87.2-109.1 feet, but magnetite dominant mineral.
150.8	185.0	34.2	32.8	Do.
185.0	204.3	19.3	20.2	Same as 87.2-109.1 feet, but with little magnetite.
204.3	244.0	39.7	36.0	Same as 87.2-109.1 feet, more magnetite, 6 inches felsic at 227 feet.
244.0	264.9	20.9	30.7	Same as 87.2-109.1 feet, with good magnetite enrichment.
264.9	283.3	18.4	20.4	Same as 87.2-109.1 feet, but weak in magnetite.
283.3	323.6	40.3	25.7	Same as 87.2-109.1 feet, with moderate magnetite enrichment.
323.6	401.0	77.4	18.2	Coarse pyroxenite, with some magnetite. Spot of diorite at 368 feet and biotite in pyroxenite 392-401 feet.

TABLE 2. - Core sample descriptions and total iron analyses (Con.)

HOLE 8

Location: Lat. 3,704, Dep. 5,688
Elevation: 529 ft.
Depth: 496.1 ft.

Bearing: S. 19° 51' W.
Inclination: -30°

From-	To-	Feet	Total iron, percent	Description
0	5.0	5.0		Soil and moss overburden.
5.0	51.9	46.9	16.8	Coarse pyroxenite, with some magnetite; felsic spots at 14-15 feet, spot at 17 and 28 feet; diorite 9-10 feet and 40-41 feet.
51.9	153.2	101.3	20.5	Coarse pyroxenite, felsic spots in some sections and others with biotite; weak magnetite enrichment.
153.2	233.8	80.6	17.5	Dominantly coarse pyroxenite, containing some magnetite and in spots biotite, epidote, and, rarely, small areas of diorite.
233.8	253.9	20.1	24.0	Coarse pyroxenite, with moderate magnetite enrichment.
253.9	314.8	60.9	18.0	Same as 233.8-253.9 feet, but containing biotite and weaker in magnetite.
314.8	436.1	121.3	18.2	Fine-grained pyroxenite, with some short, coarse sections, disseminated magnetite mineralization, 1 inch of diorite at 370 feet.
436.1	475.5	39.4	16.8	Coarse pyroxenite, with some biotite and magnetite, some epidote at 460-465 feet.
475.5	496.1	20.6	17.2	Coarse pyroxenite, with biotite, hornblende, and some pyrite to 485 feet, then coarse hornblende, epidote, plagioclase, biotite, with moderate magnetite enrichment at 495-496 feet.

HOLE 9

Location: Lat. 3,168, Dep. 6,036
Elevation: 762 ft.
Depth: 719.6 ft.

Bearing: S. 26° 59' E.
Inclination: -30°

From-	To-	Feet	Total iron, percent	Description
0	6.0	6.0		Moss and soil overburden.
6.0	112.5	106.5	15.5	Coarse pyroxenite (clinopyroxene), with sections containing biotite and others hornblende, disseminated magnetite, minor pyrite, epidote, and felsic spots.
112.5	226.7	114.2	15.0	Coarse pyroxenite with biotite, minor magnetite, and felsic spots; diorite, 203-205 feet.
226.7	247.4	20.7	14.2	Dioritic phase 230-242 feet, with calcite at 235 and 238 feet and siderite at 239 feet.
247.4	311.4	64.0	13.9	Hornblende, biotite, and clinopyroxene, with felsitic or dioritic intergrowths; weak in magnetite and containing very minor pyrite.
311.4	377.1	65.7	15.3	Coarse pyroxenite, with hornblende, biotite, felsic spots with pyrite, some disseminated magnetite.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

From-	To-	Feet	Total iron, percent	Description
377.1	398.3	21.2	15.3	Diorite or plain felsic 380-388.2 feet, then coarse pyroxenite.
398.3	418.9	20.6	26.1	Coarse-grained pyroxenite, with epidote, felsic spots, and some magnetite enrichment.
418.9	554.8	135.9	15.4	Coarse pyroxenite, with hornblende, biotite, and minor magnetite, felsic spots sometimes with pyrite, pyrrhotite, and epidote at 476, 481, 500, 509, 513 feet, etc.
554.8	615.0	60.2	14.7	Largely clinopyroxene, felsic spots 561-562 feet, diorite 569-576 feet, and felsic spots with pyrite bands 576-580 feet, diorite 594-595 feet, some disseminated magnetite throughout.
615.0	672.4	57.4	15.2	Pyroxenite, with hornblende, biotite, and disseminated magnetite; at 655 feet rock changes to gabbro and at 671 feet changes from dark amphibole, epidote felsic mixture to diorite.
672.4	719.6	47.2	8.9	Diorite to 685 feet, pyroxenite to 688 feet, then diorite with accessory hornblende and magnetite; 697-700 feet long fracture partly filled with pyrite, 700-701 feet flow structure, 712 feet watercourse, 715 feet to bottom partly felsic with fine pyrite mixed with the diorite.

HOLE 10

Location: Lat. 3,394, Dep. 5,889 Bearing: N. 63° 35' E.
Elevation: 643 ft. Inclination: -45°
Depth: 500.2 ft.

0	9.5	9.5		Moss, soil, and overburden.
9.5	93.7	84.2	18.4	Light-gray, coarse-grained pyroxenite, with disseminated magnetite, in sections some biotite, epidote, felsic spots, and banded structure, spots of diorite 84-86 feet, traces of pyrite.
93.7	159.3	65.6	17.8	Same as 9.5-93.7 feet, with diorite at 104 and 125 feet, banded with pyrite at 110 feet.
159.3	179.4	20.1	16.9	Light-gray pyroxenite, with diorite 167.5-169.5 feet and 1/2 inch at 179 feet.
179.4	259.9	80.5	17.2	Light-gray pyroxenite (augite-pigeonite), with felsic spots, and some pyrite in felsic stringers.
259.9	300.5	40.6	17.1	Gray pyroxenite, with some biotite, and felsic bands.
300.5	363.8	63.3	16.9	Pyroxenite (clinopyroxene), with disseminated magnetite, and felsic spots.
363.8	404.5	40.7	16.3	Light-gray pyroxenite containing disseminated magnetite, with felsic spots and some epidote, hornblende, and pyrite.
404.5	449.6	45.1	17.4	Same as 363.8-404.5 feet, but pyrite only from 436-436.7 feet.
449.6	500.2	50.6	19.1	Gray pyroxenite with disseminated magnetite, some biotite, and massive magnetite 469-469.6 feet.

TABLE 2. - Core-sample descriptions and total iron analyses (Con.)

HOLE 11

Location: Lat. 3,385, Dep. 5,869
Elevation: 641 ft.
Depth: 598.0 ft.

Bearing: S. 62° 55' W.
Inclination: -45°

From-	To-	Feet	Total iron, percent	Description
0	8.0	8.0		Moss, soil, and overburden.
8.0	93.0	85.0	16.7	Coarse-grained, pale-green pyroxenite, with some enrichment, some diorite at 15 and 30 feet, calcite at 89 feet.
93.0	214.2	121.2	16.7	Coarse-grained, gray pyroxenite, with disseminated magnetite, biotite, and felsic spots.
214.2	254.5	40.3	17.3	Coarse-grained pyroxenite, with disseminated magnetite and biotite, also magnetite epidote, calcite, and pyrite at 222 and 234 feet and diorite banding at 233, 234, 248, and 251 feet.
254.5	275.0	20.5	10.5	Diorite, with some fine-grained pyroxenite, banded irregular contacts with pyroxenite inclusions.
275.0	301.4	26.4	15.2	Fine-grained mafic, containing some magnetite, biotite, felsic spots at 290 feet, and banded pyroxenite at 295 feet.
301.4	367.4	66.0	16.0	Coarse-grained pyroxenite, with disseminated magnetite and felsic spots, magnetite at 367 feet.
367.4	440.7	73.3	15.6	Fine-grained pyroxenite, with biotite and some magnetite, felsic spots at 407 and 409 feet, diorite 413 and 420 feet.
440.7	501.0	60.3	16.9	Coarse-grained pyroxenite, with disseminated magnetite and some felsic spots, dioritic and banded 493-495 feet.
501.0	598.0	97.0	16.5	Fine-grained pyroxenite containing biotite, occasional hornblende and disseminated magnetite; spots of diorite at 524 and 552 feet.

LABORATORY STUDIES

Samples

Laboratory beneficiation testing was conducted on composite samples prepared from diamond-drill cores obtained during the Bureau of Mines drilling campaign at the Snettisham deposit during 1953 and 1954. The investigation was executed in two distinct parts. Phase 1 consisted of a series of wet magnetic separation tests made on 17 samples composited to represent definite sections of the deposit. Phase 2 was a more intensive testing program on a sample composited to be representative, as nearly as possible, of the entire portion of the ore body covered by the investigation.

All samples were roll crushed to minus-10-mesh and mixed thoroughly to assure representative splits for testing and analysis.

Character of the Ore

Detailed physical and chemical studies were made on only the general composite sample representative of the portion of the Snettisham ore body included in the field examinations.

Physical

The sample essentially contains augite, hornblende, less magnetite, and relatively small amounts of calcite, epidote, chlorite, apatite, alkali-calcic plagioclase, and biotite. Also present are very small amounts of chalcopyrite, pyrrhotite, quartz, and pyrite.

The magnetite is partly liberated in the minus-200-mesh fraction; because of intimate association of ferromagnesian minerals, however, much of the magnetite remains locked.

Chemical

Representative head samples, carefully prepared from the general composite, were analyzed both chemically and spectrographically. Partial chemical analysis of the ore is shown in table 3. Semiquantitative spectrographic analysis revealed the presence and approximate quantities of the metal listed in table 4. Any other elements, if present, are in amounts lower than the minimum detectable by the routine technique employed.

TABLE 3. - Chemical analysis

Assay, percent									Oz. per ton	
Fe	TiO_2	S	P	V	Al_2O_3	SiO_2	MgO	CaO	Au	Ag
18.9	2.6	0.29	0.32	0.05	7.8	33.9	9.3	15.4	Nil	0.2

Ni, As, Mn, and Cu are present in amounts of less than 0.05 percent. Co was reported to be less than 0.01 percent.

TABLE 4. - Spectrographic analysis

Al	Ca	Cu	Mg	Fe	Mn	Ni	Si	Ti	V	B
C+	A	E	C	A	D	E	A	D+	E	F

Legend:
- A - over 10 percent.
- B - 5 to 10 percent.
- C - 1 to 5 percent.
- D - 0.1 to 1 percent.
- E - 0.01 to 0.1 percent.
- F - 0.001 to 0.01 percent.
- G - less than 0.001 percent.

Magnetic iron, magnetite, or recoverable iron assays are empirical analyses, usually based on the percentage of total iron recovered in a concentrate made by wet low-intensity, magnetic separation at a selected grind. Thus, based on treatment of minus-100-mesh ore, the Snettisham general composite contains approximately 12.2 percent magnetic iron.

Tests described later show that both the grade of the concentrate and the percentage of iron remaining in the tailing depend, to a large extent, on the degree of fineness of the feed. For this reason, all recoveries given in this paper have been reported in terms of total rather than magnetic iron.

Beneficiation Studies

Methods of Concentration

Because iron ore is a low-priced commodity, beneficiation treatment is limited to comparatively simple concentration methods.

Magnetic separation of magnetite-bearing ore usually is effective, but grinding costs are often high. Gravity-concentration methods or magnetic concentration in stages can sometimes be employed to minimize the amount of material requiring fine grinding. Laboratory studies of Snettisham ore included sizing and gravity-concentration tests. Because most of the magnetite in the ore occurs as relatively fine grains the bulk of the test work was directed toward developing a feasible magnetic treatment method.

Specifications for an iron concentrate vary widely, depending upon the purpose for which it is to be used and the process employed to yield the finished metal. The specifications imposed upon magnetite ores often require an iron content of over 60 percent. Similarly, the restrictions placed on sulfur, phosphorus, and titanium contents of an iron ore vary with the smelting method to be employed.

For simplicity, therefore, arbitrary specifications were adopted for this investigation, and the laboratory testing was directed toward producing a concentrate that assayed over 60 percent Fe but only trace amounts of P and S. Titania and vanadium contents have been reported without an attempt to evaluate their effect on the product.

Fine magnetite concentrates require sintering or nodulizing before use as a blast-furnace feed. For this investigation, concentrates were sintered only to show the reduction in sulfur content that may be obtained by this treatment. Studies pertaining to fuel requirements, to moisture content of sinter feed, and to reducibility and strength of sinter were considered to be beyond the scope of this paper.

Preliminary Magnetic-Separation Tests

To determine if ores from various sections of the deposit were alike in their response to magnetic separation treatment drill-core samples from 11 holes were composited in accordance with instructions of the project engineer to yield 17 samples, each of which was treated separately. A portion of each sample was roll crushed and ground in a laboratory pebble mill to pass a 100-mesh sieve. The ground material was treated on a wet, low-intensity, magnetic separator, after which each of the magnetic and nonmagnetic fractions was analyzed for iron, titania, sulfur, phosphorus, and vanadium. Results are summarized in table 5.

Based on the premise that the feed to a concentration plant would approximate equal parts of ore as represented by the samples tested, results obtained by treatment following minus-100-mesh grinding would be similar to those shown in table 6.

A study of the data in table 5 shows that the trend of concentration is similar for all samples and that recovery of iron and rejection of impurities vary directly as the grade of the head samples. As summarized in table 6 the results indicated that magnetic separation of Snettisham ore ground to minus-100-mesh would recover about 65 percent of the total iron in a product assaying over 60 percent Fe, about 4 percent TiO_2, 0.5 percent S, 0.02 percent P, and 0.3 percent V. The high sulfur content is due to the magnetic sulfide, pyrrhotite; consequently, the final concentrate probably would require flotation or sintering for removal of sulfur.

TABLE 5. - Preliminary magnetic separation

Sample	Feed, assay, percent					Concentrate										
						Weight, percent	Grade, assay, percent					Distribution, percent				
	Fe	TiO_2	S	P	V		Fe	TiO_2	S	P	V	Fe	TiO_2	S	P	V
1	16.3	2.6	0.43	0.82	0.12	15.24	62.1	4.1	1.27	0.06	0.31	58.0	24.3	45.0	1.1	40.9
2	19.7	2.6	.10	.04	.07	20.72	65.0	3.5	.13	.01	.31	68.5	27.6	27.6	4.8	88.9
3	17.1	2.5	.23	.04	.06	18.28	60.5	3.9	.68	.02	.29	64.6	28.4	53.9	10.8	86.9
4	23.6	3.2	.12	.10	.11	28.93	63.5	4.8	.17	1/ .01	.29	77.7	43.9	40.8	1.0	80.0
5A	16.8	2.7	.41	.48	.04	15.64	64.0	3.5	1.03	.02	.20	59.7	20.6	38.9	.7	79.5
5B	29.4	3.7	.16	.20	.10	37.29	65.3	3.9	.20	.02	.26	82.9	39.2	47.8	3.6	94.2
6A	18.7	2.6	.16	.26	.06	20.37	63.0	3.7	.50	.03	.24	68.5	29.2	61.4	2.3	86.0
6B	26.3	3.6	.06	.09	.11	33.74	64.5	4.5	.07	1/ .01	.29	82.6	42.1	41.1	2.3	93.3
7A	18.8	2.7	.19	.18	.06	20.60	61.6	4.2	.44	.03	.22	67.5	32.6	48.9	3.3	86.0
7B	27.8	3.6	.07	.11	.10	36.19	63.0	5.0	.09	.01	.26	82.1	49.9	50.8	3.6	94.0
8A	17.5	2.7	.20	.21	.05	17.86	62.5	3.5	.50	.02	.26	63.8	22.7	45.4	1.9	85.2
8B	21.8	3.3	.33	.49	.07	24.16	65.0	3.9	.61	.02	.24	72.1	28.6	44.7	1.0	87.9
9A	15.3	2.4	.46	.33	.03	11.55	62.5	2.4	.77	.05	.17	47.3	11.3	19.3	1.8	69.0
9B	14.6	2.2	.22	.21	.03	11.07	64.1	1.8	.26	.01	.20	48.7	8.9	13.4	.5	71.0
9C	8.9	1.7	.25	.24	1/ .02	1.03	66.2	1.1	1.52	.09		7.7	0.6	6.3	.4	
10	17.9	2.6	.41	.06	.05	19.23	62.4	4.0	1.32	1/ .01	.24	67.1	29.5	61.7	1.7	85.2
11	16.1	2.6	.16	.73	.04	15.09	62.5	3.4	.40	.01	.24	58.7	20.1	37.0	.3	81.8

1/ Less than.

TABLE 6. - Wet magnetic separation, average feed

Product	Weight, percent	Assay, percent					Distribution, percent				
		Fe	TiO_2	S	P	V	Fe	TiO_2	S	P	V
Magnetic	20.41	62.4	3.95	0.45	0.015	0.26	67.1	28.8	41.2	2.2	81.5
Nonmagnetic	79.59	7.85	2.5	.18	.33	.015	32.9	71.2	58.8	97.8	18.5
Calculated head ..	100.00	19.0	2.8	.24	.27	.065	100.0	100.0	100.0	100.0	100.0
Average assay head		19.0	2.8	.23	.27	.045					

Sizing

A portion of the general composite sample was roll crushed to minus-10-mesh and screen sized wet using standard Tyler sieves. The results are shown in table 7.

TABLE 7. - Screen analysis

Product	Weight, percent	Assay, percent		Distribution, percent	
		Fe	TiO_2	Fe	TiO_2
Plus-20-mesh	26.36	18.5	2.7	26.0	26.1
20/35-mesh	23.21	18.5	2.6	22.9	22.2
35/48-mesh	10.40	18.4	2.5	10.2	9.5
48/65-mesh	9.05	20.0	2.8	9.6	9.3
65/100-mesh	8.34	20.0	2.8	9.0	8.6
100/200-mesh	11.32	20.4	2.8	12.3	11.6
Minus-200-mesh sand	8.11	18.7	3.0	8.1	8.9
Slime	3.21	9.7	2.8	1.9	3.8
Calculated head ...	100.00	18.8	2.7	100.0	100.0

The screen analysis showed no marked concentration of iron in any of the sized fractions. A slight increase in grade of iron is noted below 48-mesh, indicating partial liberation of magnetite from the gangue at that size.

Wet Magnetic Separation

Portions of the general composite were ground with a porcelain mortar and pestle to pass 20-, 35-, 48-, 65-, 100-, 150-, 200-, and 325-mesh sieves. Each portion was treated on a low-intensity, wet magnetic separator to produce a magnetic concentrate and a nonmagnetic reject. Results are summarized in table 8.

The results in table 8 show that the grade of iron in the final product is inversely proportional to particle size. Elimination of titania and phosphorus is increasingly improved with finer grinding, but nearly 40 percent of the sulfur remains in the magnetic concentrate, even in the minus-325-mesh size range.

The data indicate that grinding to minus-100-mesh is adequate for producing plus-60-percent Fe concentrate. Minus-150-mesh grinding, however, is necessary to reduce the phosphorus content of the magnetic concentrate to less than 0.01 percent P. At this grind 64.3 percent of the iron was recovered in a product that assayed 64.4 percent Fe, 3.7 percent TiO_2, 0.62 percent S, and less than 0.01 percent P.

Figures 16 and 17 illustrate the effect of fine grinding on grade of iron and phosphorus in the final concentrate.

TABLE 8. - Wet magnetic separation

Grind (mesh)	Product	Weight, percent	Assay, percent					Distribution, percent			
			Fe	TiO_2	S	P	SiO_2	Fe	TiO_2	S	P
Minus-20	Magnetic	33.89	41.2	3.9	0.42	0.10	20.3	71.1	47.6	49.5	9.9
	Nonmag.	66.11	9.5	2.2	.22	.47		28.9	52.4	50.5	90.1
	Calc. head	100.00	18.8	2.6	.29	.32		100.0	100.0	100.0	100.0
Minus-35	Magnetic	26.84	47.3	4.6	.50	.06	13.9	68.4	43.4	47.9	4.9
	Nonmag.	73.16	8.0	2.2	.20	.45		31.6	56.6	52.1	95.1
	Calc. head	100.00	18.6	2.8	.28	.34		100.0	100.0	100.0	100.0
Minus-48	Magnetic	22.95	54.0	4.6	.51	.04	8.6	66.8	37.3	45.7	2.6
	Nonmag.	77.05	8.0	2.3	.18	.43		33.2	62.7	54.3	97.4
	Calc. head	100.00	18.6	2.8	.26	.34		100.0	100.0	100.0	100.0
Minus-65	Magnetic	20.60	58.3	4.4	.56	.02	5.7	65.4	34.2	46.0	1.2
	Nonmag.	79.40	8.0	2.2	.17	.42		34.6	65.8	54.0	98.8
	Calc. head	100.00	18.1	2.7	.25	.34		100.0	100.0	100.0	100.0
Minus-100	Magnetic	19.20	61.9	4.1	.60	.01	2.6	64.8	28.0	47.1	.6
	Nonmag.	80.80	8.0	2.5	.16	.42		35.2	72.0	52.9	99.4
	Calc. head	100.00	18.4	2.8	.24	.34		100.0	100.0	100.0	100.0
Minus-150	Magnetic	18.34	64.4	3.7	.62	1/ .01	2.0	64.3	24.2	41.2	.3
	Nonmag.	81.66	8.0	2.6	.20	.42		35.7	75.8	58.8	99.7
	Calc. head	100.00	18.4	2.8	.28	.34		100.0	100.0	100.0	100.0
Minus-200	Magnetic	18.08	65.0	3.3	.58	1/ .01	1/ .05	63.9	22.6	40.2	.3
	Nonmag.	81.92	8.1	2.5	.19	.37		36.1	77.4	59.8	99.7
	Calc. head	100.00	18.4	2.7	.26	.30		100.0	100.0	100.0	100.0
Minus-325	Magnetic	17.60	66.1	2.9	.50	1/ .01	1/ .05	63.8	15.8	37.3	.3
	Nonmag.	82.40	8.0	3.3	.18	.42		36.2	84.2	62.7	99.7
	Calc. head	100.00	18.2	3.2	.24	.35		100.0	100.0	100.0	100.0

1/ Less than.

Gravity Concentration

In an attempt to eliminate a portion of the fine grinding, a study was made of the possibility of employing spiral or table concentration methods at relatively coarse sizes to produce a rough concentrate that could be reground and cleaned by magnetic separation.

Three tests were made with a laboratory spiral concentrator unit on ore ground to minus-10-, minus-20-, and minus-35-mesh. The results were unsatisfactory. Although up to 80 percent of the iron was recovered in the concentrate, the grade was low, and only 30 percent of the total weight was rejected as tailing.

No table test was satisfactory on material coarser than 48-mesh. By tabling minus-48-mesh ore, 83 percent of the total iron was recovered in a product containing 64.7 percent of the original weight and assaying 23.8 percent Fe. Regrinding the concentrate to minus-150-mesh and treating the ground material by wet magnetic separation produced a concentrate that assayed 64.0 percent Fe, 3.4 percent TiO_2,

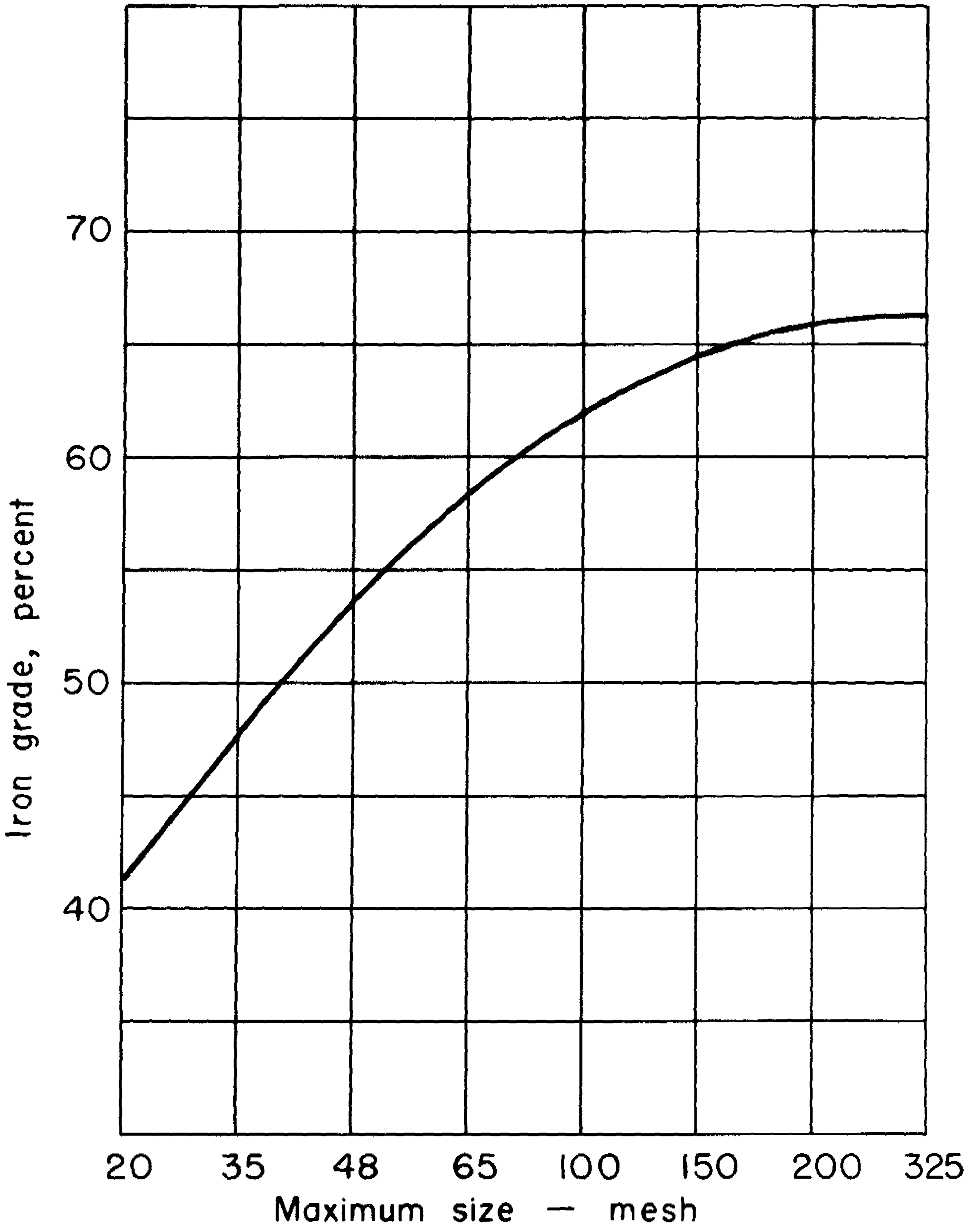

Figure 16. - Iron grade vs. particle size.

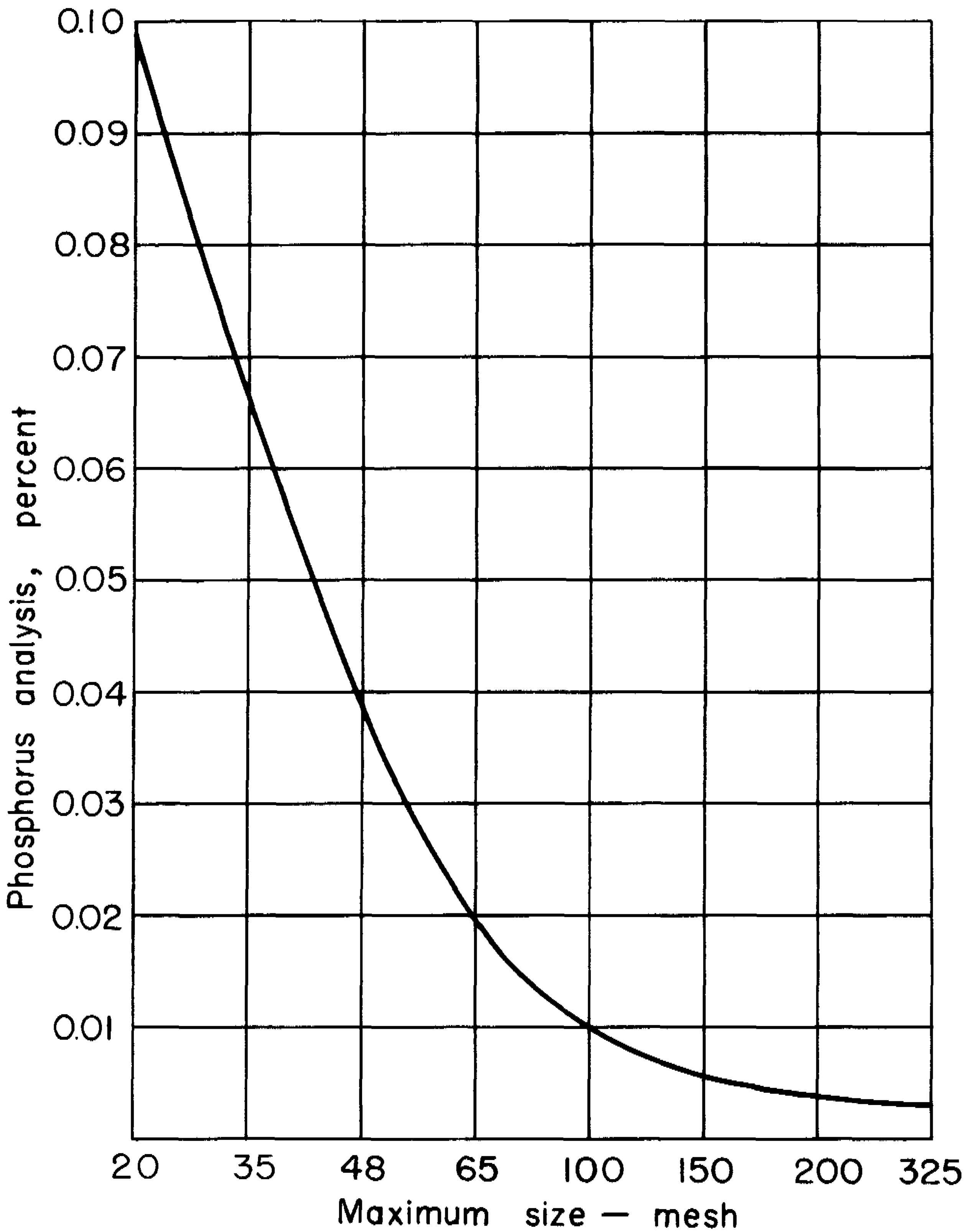

Figure 17. - Phosphorus grade vs. particle size.

0.52 percent S, 0.32 percent V, and 0.03 percent P. This represented an over-all recovery of 61.4 percent of the total iron.

Dry Magnetic Separation

Magnetic separation, using a Wetherill-type high-intensity separator, was tried for the preliminary concentration step. For this test ore was roll crushed to minus-20-mesh and screen sized on 35-, 65-, and 200-mesh sieves. Each fraction was treated separately to produce a magnetic concentrate and a reject. Like products were combined for assay. The combined concentrate was reground to minus-150-mesh and treated by wet magnetic separation. Results are shown in table 9.

TABLE 9. - Dry and wet magnetic separation

Product	Weight, percent	Assay, percent					Distribution, percent	
		Fe	TiO_2	S	P	V	Fe	TiO_2
Magnetic	19.38	66.1	2.85	0.41	1/0.01	0.37	65.6	21.7
Wet reject	22.03	8.7	3.90	.33	.28	1/.02	9.8	34.3
Dry reject	58.59	8.2	1.90				24.6	44.0
Calc. head	100.00	19.5	2.5				100.0	100.0
Dry magnetic	41.41	35.6	3.4				75.4	56.0

1/ Less than.

By combined dry and wet magnetic separation, 58.59 percent of the original weight was rejected after only minus-20-mesh grinding. The final concentrate contained 65.6 percent of the total iron and assayed 66.1 percent Fe, 2.85 percent TiO_2, 0.41 percent S, 0.37 percent V, and less than 0.01 percent P.

Staged Wet Magnetic Separation

Review of the foregoing tests showed that by dry magnetic separation approximately 59 percent of the original weight of ore was rejected without further grinding, whereas by wet magnetic separation 73 percent of the ore could be rejected without further treatment. A study was made, therefore, of wet magnetic separation of minus-35-mesh material followed by regrinding the magnetic portion to minus-150-mesh and re-treatment. Results are given in table 10.

TABLE 10. - Staged wet magnetic separation

Product	Weight, percent	Assay, percent						Distribution, percent				
		Fe	TiO_2	S	P	V	SiO_2	Fe	TiO_2	S	P	V
Magnetic...	17.40	64.5	3.1	0.47	1/0.01	0.34	1/0.05	61.9	21.2	43.2	0.6	50.0
Regrind reject...	8.28	10.8	6.3	.31	.20	.08		4.9	20.5	13.6	4.4	5.9
Coarse reject...	74.32	8.1	2.0	.11	.49	.07		33.2	58.3	43.2	95.0	44.1
Calc. head.	100.00	18.1	2.5	.19	.38	.12		100.0	100.0	100.0	100.0	100.0

1/ Less than.

By staged wet magnetic separation treatment 61.9 percent of the total iron was recovered in a magnetic product that assayed 64.5 percent Fe, 3.1 percent TiO_2, 0.47 percent S, 0.34 percent V, and less than 0.01 percent P. The recovery is slightly less than was made by direct wet magnetic treatment of minus-150-mesh ore, but the 2-stage treatment method eliminated fine grinding of 74 percent of the total material. Half of the total vanadium in the ore reported in the magnetic concentrate. Although the grade is only 0.3 to 0.4 percent V, a portion of the vanadium might be recoverable during subsequent smelting treatment.

Sulfide Flotation

Several tests employing standard sulfide flotation techniques were run on high-grade iron concentrates in the attempt to eliminate a portion of the sulfur. Results were unsatisfactory; in no test was the sulfur content reduced below 0.4 percent. These results indicated that the pyrrhotite is in extremely intimate association with magnetite and that sintering of the magnetic concentrate would be required for sulfur elimination.

Sintering

Samples of concentrate containing 64.3 percent Fe and 0.4 percent S were treated by laboratory methods to yield sinter that assayed only 0.07 percent S. Although no effort was made to determine fuel requirements or strength and reducibility of the sintered material, the results of the tests indicated that sulfur rejection can be effected by standard sintering procedures.

Recommended Flowsheet

Based on the results of laboratory testing, the beneficiation method apparently most feasible for the treatment of Snettisham ore involves staged wet magnetic separation and sintering. This could be accomplished in a plant by a simple arrangement of equipment similar to that in the flowsheet shown as figure 18.

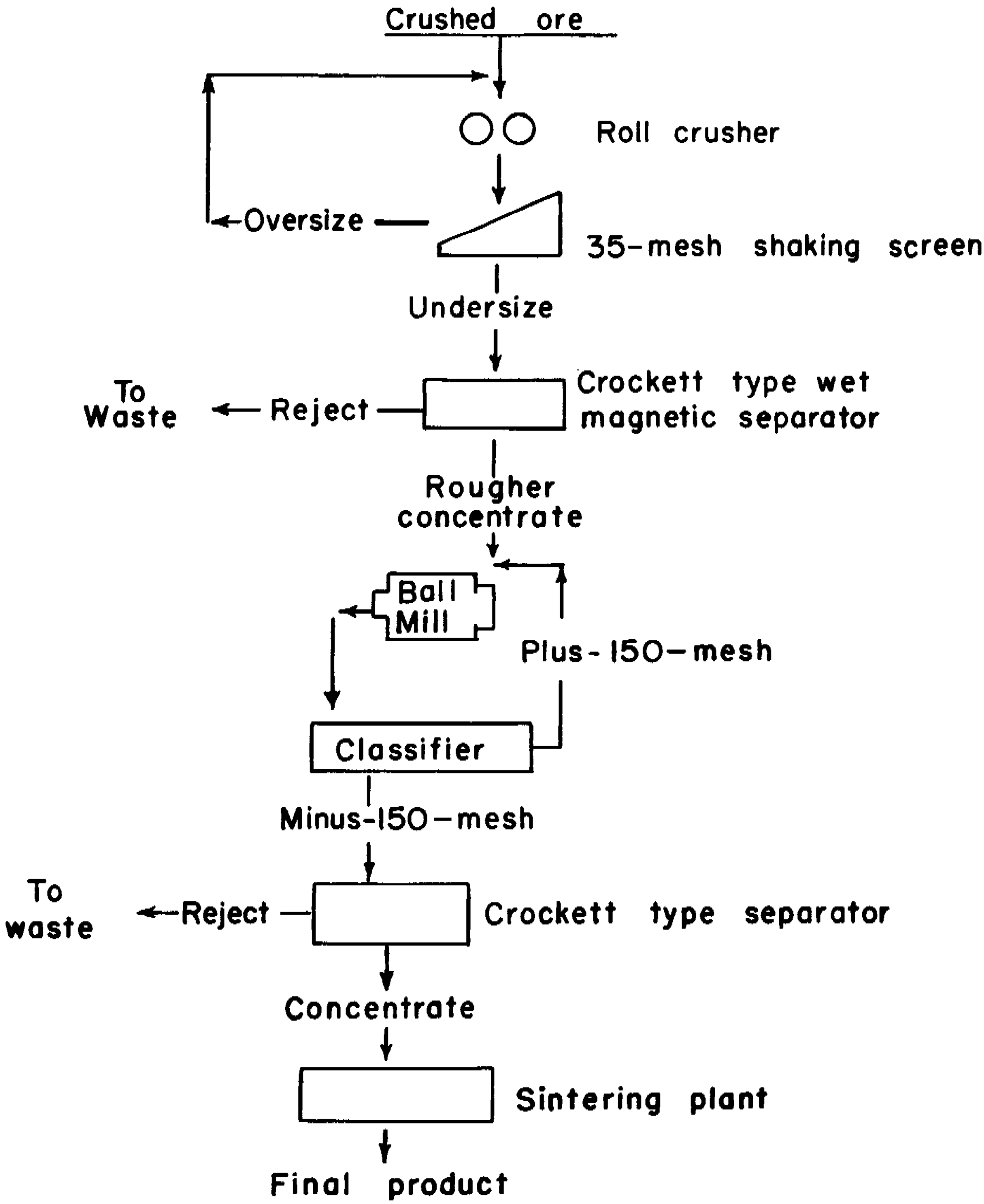

Figure 18. - Proposed flowsheet, Snettisham.