U. S. Geological Survey.

[REPORTS-OPEN FILE SERIES], no. 1496: 1970.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Saudi Arabia Investigation Report
(IR) SA-111

AN APPRAISAL OF THE JABAL IDSAS MAGNETITE MINERALIZATION BASED ON DIAMOND DRILL HOLE N40A

by

Conrad Martin
U. S. Geological Survey

1970

(o-)
Weld - Int. 2905
496

111

U.S. GEOLOGICAL SURVEY
WASHINGTON, D.C.
20242
[Reports - Open file series]

For release NOVEMBER 6, 1970

The U.S. Geological Survey is releasing in open files the following reports. Copies are available for inspection in the Geological Survey Libraries, 1033 GSA Bldg., Washington, D. C. 20242; Bldg. 25, Federal Center, Denver, Colo. 80225; and 345 Middlefield Rd., Menlo Park, Calif. 94025:

1. Schmidt hammer test method for field determination of physical properties of zeolitized tuff, by John R. Ege, Danny R. Miller, and Walter Danilchik. 37 p., including 19 figs., 1 table. (*)

2. A geochemical evaluation of the Ash Sha'ib mineral prospect, Asir quadrangle, Kingdom of Saudi Arabia, by Glenn H. Allcott. 38 p., 6 pl., 3 figs., 6 tables.

3. Preliminary geophysical investigation of the Esh Qay'ib (Esh Sha'ib) mine area, Saudi Arabia, by Willard E. Davis and Hisham Kazzaz. 10 p., 6 figs.

4. Recommended geophysical investigations of mineral occurrences at Jabal Samran, Al Marasia, and Wutaileh, by D. H. Hase, V. J. Flanigan, and M. N. Akhrass. 5 p., 1 map, scale 1:500,000.

5. Qualitative analysis of airborne magnetometer data: The Arabian Shield, Kingdom of Saudi Arabia, by Donald H. Hase. 44 p., 1 pl.

6. Preliminary investigation of cement materials in the Taif area, Saudi Arabia, by Conrad Martin. 18 p., 1 fig., 1 table.

7. An appraisal of the Jabal Idsas magnetite mineralization based on diamond drill hole N40A, by Conrad Martin. 29 p., 4 figs., 1 table.

8. Geological reconnaissance of the western part of the Wadi Ar Rimah quadrangle, Saudi Arabia, by James W. Mytton. 3 p.

9. Reconnaissance ~~of~~ for mineral deposits in the Precambrian rocks of the Wadi Ar Rimah quadrangle, Kingdom of Saudi Arabia, by James W. Mytton. 76 p., 1 pl., 3 figs., 3 tables.

10. Preliminary report on the Dawadami district, Saudi Arabia, by Paul K. Theobald, Jr. 4 p.

(*) Note: Item 1, above, is also available for inspection at 504 Custom House, San Francisco, Calif. 94111; 7638 Federal Bldg., Los Angeles, Calif. 90012; 1012 Federal Bldg., Denver, Colo. 80202; 8102 Federal Office Bldg., Salt Lake City, Utah; and in the Library, Mackay School of Mines, University of Nevada, Reno, Nev. 89507.

AN APPRAISAL OF THE JABAL IDSAS MAGNETITE MINERALIZATION BASED ON DIAMOND DRILL HOLE N40A

by

Conrad Martin
U. S. Geological Survey

PREFACE

In 1963, in response to a request from the Ministry of Petroleum and Mineral Resources, the Saudi Arabian Government and the U. S. Geological Survey, U. S. Department of the Interior, with the approval of the U. S. Department of State, undertook a joint and cooperative effort to map and evaluate the mineral potential of central and western Saudi Arabia. The results of this program are being released in USGS open files in the United States and are also available in the Library of the Ministry of Petroleum and Mineral Resources. Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government agencies. The Government of Saudi Arabia makes this information available to interested persons, and has set up a liberal mining code which is included in "Mineral Resources of Saudi Arabia, a Guide for Investment and Development," published in 1965 as Bulletin 1 of the Ministry of Petroleum and Mineral Resources, Directorate General of Mineral Resources, Jiddah, Saudi Arabia.

CONTENTS

ILLUSTRATIONS

TABLE

U. S. GEOLOGICAL SURVEY
SAUDI ARABIAN MINERAL EXPLORATION PROJECT
INTERAGENCY REPORT NO. 111

AN APPRAISAL OF THE JABAL IDSAS MAGNETITE MINERALIZATION BASED ON DIAMOND DRILL HOLE N40A

by

Conrad Martin

ABSTRACT

Diamond Drill Hole N40, intended to test the magnetite mineralization at Jabal Idsas, was aborted because of technical difficulties and a new hole, N40A, was drilled at the same site in February of 1968 to an inclined down-the-hole depth of 445.7 meters. Disseminated magnetite and locally massive lenses, veins, and breccia fillings of magnetite were encountered along most of this length, but more consistently between the depths of 82 and 435 meters. The average iron content of this section in the form of magnetite was 16.4 percent. Several sections, each about 20 meters in length, contained from 22.4 to 31 percent iron.

Extrapolation of costs from current taconite iron ore operations in the United States, beneficiating ores averaging 23 percent iron, suggests that ore of similar or possibly lower iron content from Jabal Idsas could be mined and processed at comparable if not at somewhat lower costs. The beneficiation product, containing about 64 percent iron, would have a current value of $16.00 per long ton at the point of use. On the basis of information presently available there is a reasonable expectation that reserves of the order of 75 to 125 million tons could be developed at Jabal Idsas to sustain a similar operation.

Tin, not previously reported from this district, was found in the cores in small but widely distributed amounts averaging perhaps .01 percent. Although the amount is anomalous it is probably not of economic significance in the magnetite area, but one should not at this stage discount the possibility of finding higher concentrations of tin elsewhere in the district.

The origin of the magnetite in this geologic setting is attributed largely to the uralitization of high-iron pyroxene. It is believed that this interpretation is a more useful guide to further exploration than other explanations previously adduced.

INTRODUCTION

Magnetite at Jabal Idsas, lying near the eastern boundary of the Arabian Shield, about 190 kilometers airlines southwest of Riyad, has been under recurrent investigation since 1955. The complete history of the investigations, consisting of regional and, locally, detailed geologic mapping, ground and airborne geophysical surveying, and diamond drilling, need not be recounted here as this has already been ably set out in previous reports (Kahr 1965; Davis, Allen, and Akhrass, 1970; Rocroi 1966).

Drill Hole N40 was begun under U. S. Geological Survey supervision in 1964 on the basis of an airborne magnetometer survey which was further verified by a ground check. Due to technical difficulties the hole was aborted at 247 meters in massive magnetite after penetrating 195 meters of sporatic magnetite mineralization. Subsequently, Bureau de Recherches Geologiques et Minieres (B.R.G.M.) undertook to continue the exploration on behalf of the Directorate General of Mineral Resources with further geophysical work, geologic mapping, and diamond drilling which was to include the completion of Drill Hole N40. However, after completing the additional geophysical and geologic work and two holes, ID-1 and ID-2 (fig.1), B.R.G.M. concluded that the completion of Drill Hole N40 was not essential to a proper assessment of the mineralization and to an explanation of the magnetic anomaly (Vincent, 1967) and that the mineralization was in any case uneconomic and hence did not warrant further work.

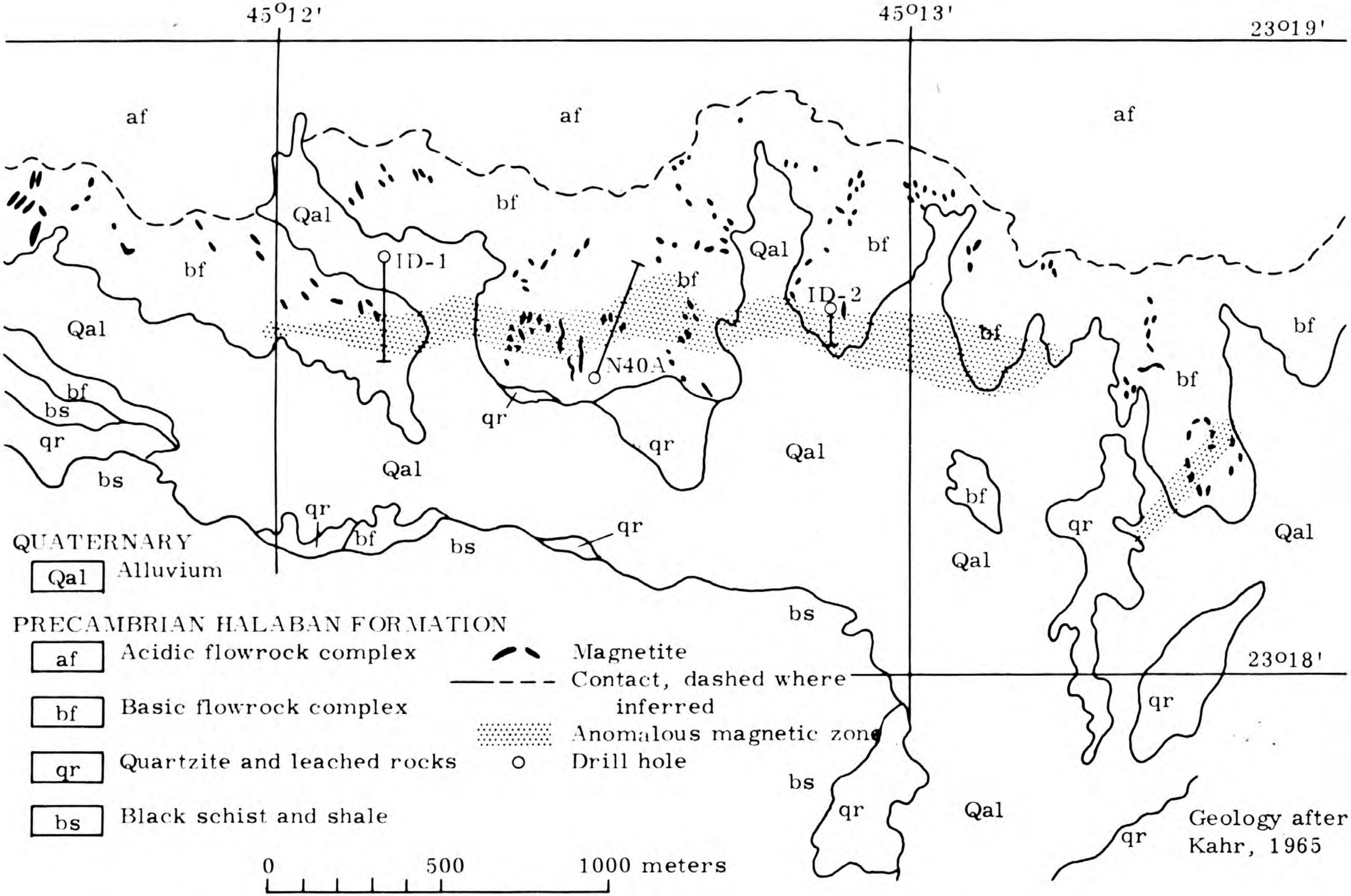

FIGURE 1. - Geologic sketch map of the Jabal Idsas magnetite prospect showing the location of diamond drill holes ID-1, ID-2, and N40A.

1. If the geophysical work has any significance Drill Hole N40 is located at the most favorable site (fig. 2). Not to complete it would leave a gap in the investigation which, in spite of other negative assessments, it was desirable to close if for no other reasons than to support these assessments in the face of possible future questions and doubts which were otherwise bound to arise.
2. The additional information, even though it only corroborated that from other sources, would be useful in evaluating other magnetic anomalies in similar geologic settings and thus enhance the chances of making a better assessment at less cost in the future.
3. The drilling had a predominantly geophysical orientation in that the major object was to drill for information that would explain the anomaly. It should be pointed out that this is not necessarily the same as drilling to test for an orebody. A case in point is Hole ID-1. From the form of the magnetic anomaly it was concluded that the body mainly responsible for it would lie at some depth (Rocroi 1966, p. 42; Vincent 1966, p. 43). Accordingly, Hole ID-1 was located and oriented so as to intercept this hypothetical body in the shortest possible distance. The hole was drilled nearly vertically. From a geophysical point of view this made sense. However, if the structure in the area has been interpreted correctly (Vincent 1966, pp. 16 & 18), this hole was drilled essentially down dip and thus cut across but a small part of the magnetic zone.
4. Hole ID-2 (Vincent 1966, p. 44) traverses the magnetite zone but in an area that, from the geophysical data, seems to be less favorable than the location at Hole N40 (fig. 2; Davis, 1970, p. 2). B.R.G.M. concluded, however, that in spite of its more favorable location completing Hole N40 would not materially change the

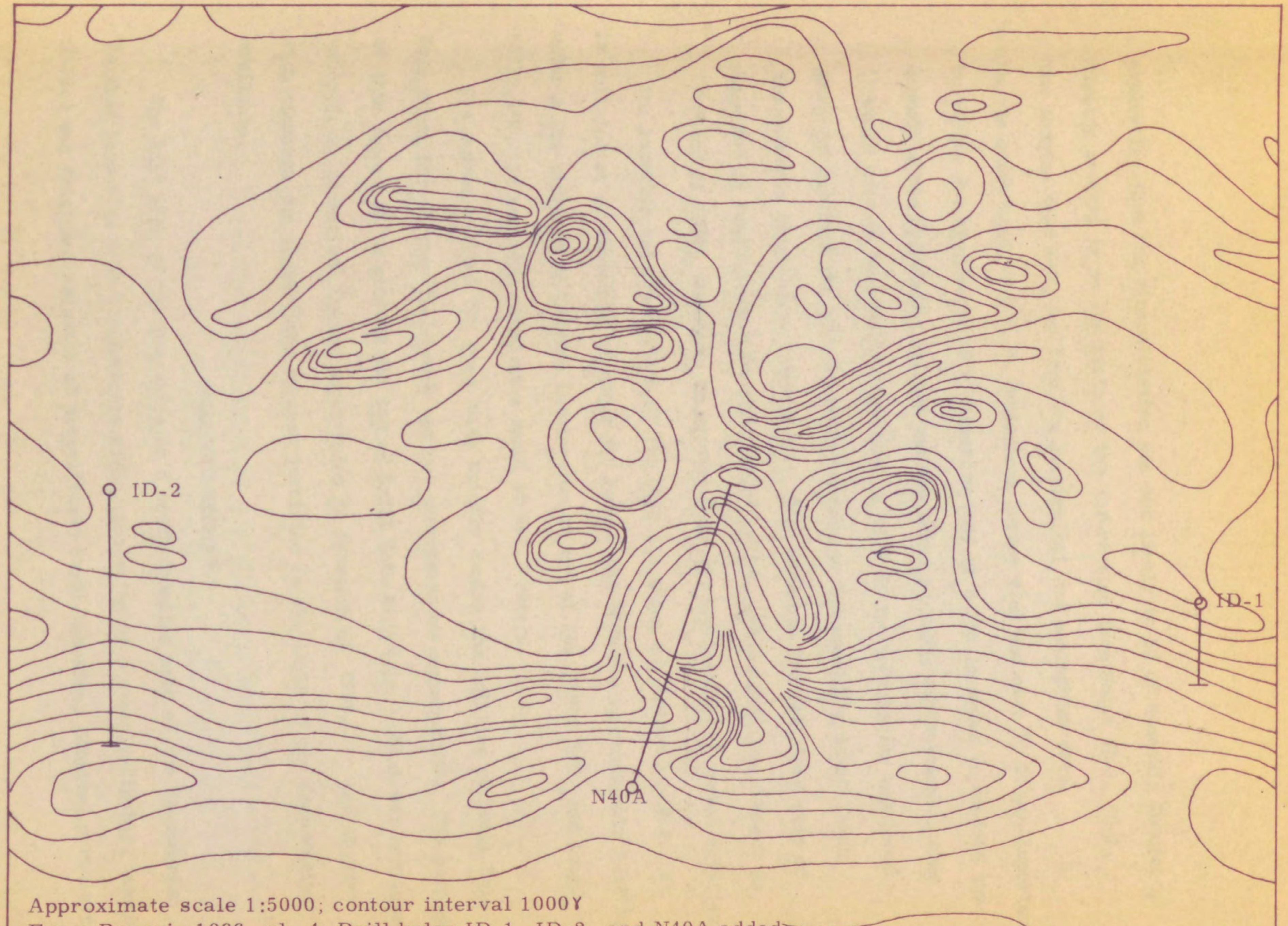

FIGURE 2.- Magnetic (total field) map of the Jabal Idsas magnetite prospect.

evaluation that the mineralization was not likely to be of economic interest, already arrived at on the basis of the information from Holes ID-1, ID-2, the aborted Hole N40, and from the geophysical and geological data.

5. On the other hand, the U. S. Geological Survey view was that if it was important to verify the hypothesis of a magnetite body at depth in order to explain the anomaly (this hypotheses did not exclude other possible explanations), then it would seem to be equally important in view of the ambiguities mentioned above to continue the work in order to resolve the remaining doubt about the economic assessment. Accordingly, Hole N40A was drilled along side of Hole N40 at roughly the same orientation by the Arabian Drilling Company in February of 1968. Attempts to recover Hole N40 had previously proved fruitless.

The location and orientation of the hole are shown on Figures 1 and 2. It is collared at an elevation of about 850 meters and directed approximately N.18°E. under a low ridge at an initial inclination of 45° at lat. 23°19.5'N. and long. 45°12.5'E. It was terminated at a depth of 445.7 meters.

The writer visited the area twice briefly during the drilling of Drill Hole Hole N40A, but further field work was not undertaken or contemplated. The purpose of this report is to present the log of Drill Hole N40A (app.) which was completed under U. S. Geological Survey supervision in February of 1969, and to make such comments and suggestions as seem justified in the light of the information available.

GEOLOGIC SETTING

The host rock of the magnetite is a north-trending belt of the Precambrian Halaban Formation 1 to 5 kilometers wide, consisting of a steeply-dipping, intensely folded and fractured sequence of propylitized basic andesite, diorite, pyroclastic rocks, and minor intercalated dolomite and clastic sediments. These lie in the upper plate of the major thrust, directed from the northeast, which over rides a thick section of metamorphosed sedimentary rocks. Toward the east the complex is overlain by diorite, and microdiorite dikes are common in the area. Farther to the east as well as to the west lie granitic rocks, intrusive as well as antecedent, of several ages and diverse compositions.

The magnetite-bearing rocks have been widely uralitized and saussuritized. Some pyroxenes have been converted to serpentine, others to green hornblende plus magnetite and fiberous actinolite; more complete alteration at a lower facies has produced chlorite. Feldspar rocks gave rise to fine-grained mixtures of sodic plagioclase, epidote, and ziosite veined with minor calcite and quartz. The rock can be characterized as ophiolitic or spilitic.

MINERALIZATION

The major magnetite mineralization lies in a zone about 3 kilometers long and from 300 to 400 meters wide as coarse- and fine-grained disseminations which, concentrated in bands, grade into tabular bodies of massive magnetite sometimes several meters across and a few hundred meters long. It is also found as breccia filling and as veinlets in the fractured areas. Where the magnetite forms the replacing matrix, the partly rounded remnants of the saussuratized host rock give the impression of a coarsely porphyritic texture. The coalescing blebs of magnetite, surrounding remnant saussurite, produce a mottled effect or "leopard ore".

Drilling indicates that mineralization persists undiminished to a depth of at least 500 meters, and no doubt for some distance beyond. While the average magnetite content in Drill Hole ID-1 is somewhat higher than in Drill Hole ID-2 it is not yet possible to say how the average tenor of the mineralization changes along the strike because these holes do not penetrate comparable widths of the magnetite zone. Drill Hole N40A, which lies about one half of the way between the other two, and which traversed most of the magnetite zone, might thus be taken to represent the average over this distance. Here, over a width of 250 meters, corresponding to the interval from 82 to 435 meters along the drill hole, the iron content in the form of magnetite was a little over 16 percent corresponding to a magnetite content of 14 percent by volume. The better part of this section, 150 meters wide, represented by the interval from 82 to 296 meters, averaged 19 percent iron corresponding to a magnetite content by volume of a little under 17 percent. Narrower sections, about 20 meters in width, contained up to 30 percent iron. The distribution of the magnetite content along the hole, graphed in terms of percent magnetite by volume, is shown on Figure 3.

Copper mineralization is sparsely and widely dispersed over the area, but it is rarely found in significant quantities. Small amounts of chalcopyrite and bornite were noted in the core of the Drill Hole N40A which, from the sections of core analyzed, would average a little over .01 percent in copper (table 1).

Table 1 shows that a small but persistent amount of tin is present ranging up to .015 percent for the sections of core analyzed. Tin has not been mentioned in previous reports of this district and its significance remains to be evaluated. The form in which the tin is found has not as yet been definitely determined. The geologic setting and the prevalence of copper would suggest stannite ($Cu_2Fe\,Sn\,S_4$) as well as cassiterite, the average of the samples analyzed is .01 percent Sn.

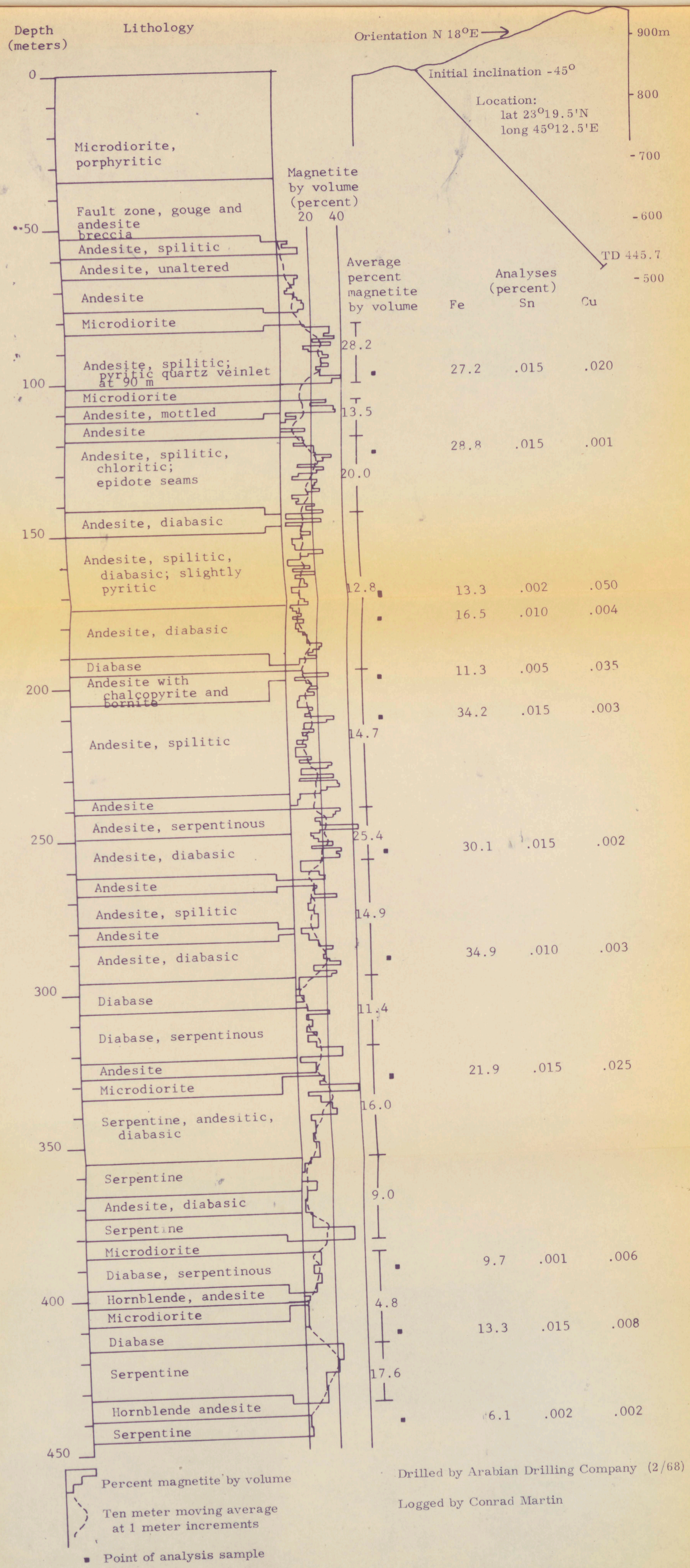

FIGURE 3.- Graphic log of Drill Hole N40A showing magnetite content.

Table 1. Chemical analyses of some randomly selected segments of core from Drill Hole N40A

Interval Represented (meters)	Sp. Gr.	% Fe from Sp. Gr.	Analysis (percent)					
			Fe	Sn*	Cu	Zn	Ti	P
98-99	3.46	28.3	27.2	.015	.020	.01	.10	.08
124-125	3.40	25.9	28.8	.015	.001			
170-172	3.07	11.4	13.3	.002	.050			
179-180	3.14	14.8	16.5	.010	.004	.01	.23	.01
198-199	3.00	8.0	11.3	.005	.035			
211-212	3.59	33.1	34.2	.015	.003	.01	.32	.16
255-256	3.55	31.7	30.1	.015	.002	.01	.21	.24
291-292	3.58	32.7	34.9	.010	.003			
328-330	3.27	20.6	21.9	.015	.025	.01	.17	.06
390-393	3.00	8.0	9.7	.001	.006			
410-416	2.88	1.6	13.3	.015	.008	.005	.32	.02
439-443	2.88	1.6	6.1	.002	.002			
Numerical Average		17.5	20.6	.010	.013			

* By spectrographic analysis reading the 3262 A° line

Its presence does suggest, however, that it might occur in higher concentrations elsewhere in the district, particularly in the more siliceous, rhyolitic facies of mineralized rocks as at Al Amar.

Zinc is present to the extent of .01 percent, lower than would be expected from the geologic setting and mineral association. It substitutes for some of the ferrous iron in magnetite. Tungsten was tested for but not detected. Sulfur, while undoubtedly present, lay below the limits of quantitative determination by the analytical methods employed. The amounts of phosphorous and titanium lie within tolerable limits for an iron ore.

ORIGIN OF THE MAGNETITE MINERALIZATION

All who have investigated the magnetite deposits at Jabal Idsas and have speculated about their origin have explained them as segregations from a magma. This follows the convential geological wisdom which holds that such minerals as magnetite, cassiterite, bornite, pyrrhotite, etc., are high temperature minerals and thus linked with magmatic processes. A considerable body of evidence, however, points in quite a different direction.

The occurrence of authigenic magnetite, for instance in chert, dolomite, clastic, and other sedimentary rocks, hardly needs further documentation. Magnetite is presently forming in the sediments of some parts of the ocean floor (Harrison and Peterson, 1965). It has been found as colloform masses deposited from colloidol solutions or iron gels (Stevenson and Jeffery, 1964). It forms part of the dentition of some marine organisms, and it has been deposited from meteoric waters and synthesized in solutions at ordinary temperature and pressures (Spiroff, 1938). Other instances could be cited. What has been said above in this regard about magnetite applies as well to cassiterite and most of the high-temperature minerals. Wing-Easton (1937, p.21) describes enrichments of cassiterite in parts of the Malay Archipelago that resulted from the concentration of percolating rain water.

As mentioned earlier, the magnetite at Jabal Idsas occurs in a complex of highly altered flow and pyroclastic rocks, including metamorphosed sediments. Their origin would hardly be conducive to magmatic segregation. Their spilitic aspect suggests, but does not necessarily require, a subaqueous environment in which they were emplaced. The occurrence of magnetite in fractures and breccia zones would indicate that the mineralization was post-magmatic. The uralitization and saussuritization, which accompany the mineralization, also support this view. Furthermore, magnetite is often a product of these processes (Hatch, Wells, A. K., and Wells, M. K., 1949, p. 293).

These low-grade metamorphic transformations are largely isochemical. The iron for the magnetite, if its origin is indeed to be attributed to them, must have been already present in the rocks involved. The logical carriers would be olivine and the high-iron pyroxenes - augite, bronzite, hedenbergite, and perhaps acmite. Their high-iron content would also make them especially susceptible to uralitization (Barth, 1962, p. 272).

It is suggested, then, that the magnetite at Jabal Idsas may have resulted from the uralitization of the high-iron pyroxenes promoted by the tectonism that has affected the host rocks and facilitated by interstitial fluids probably inherited from their earlier aqueous environment. The process may have continued after tectonism had subsided, the magnetite filling fractures and replacing breccia zones thus created. Seeds of accessory magnetite, originally present in the rock, acted as centers of crystallization. As these centers grew and coalesced they formed the more massive, roughly accordant tabular bodies. Where seeds were sparse, small dispersed new centers of crystallization arose.

The explanation given above accords more nearly with all of the essential facts. There are, however, further implications which it may not be amiss to consider here. Highly magnetic, hornblende-rich rocks, containing at times lenses of magnetite, are sometimes found bordering granitic intrusions. Lenses, even dikes of magnetite may also be found in the intrusive itself. These have generally been interpreted as magmatic segregations, and the magnetite in the bordering rocks as emanations from the intruding magma. However, in the light of what has been said above concerning the origin of the magnetite at Jabal Idsas, a similar explanation might apply here. The source of the magnetite would be the bordering rocks themselves whose high-iron silicates would in this instance be uralitized by the temperature and pressure gradients set up and the tectonism and fluid movements attending the intrusion. As intrusion progressed magnetite bodies previously formed in the enclosing rocks would be engulfed. These then should be more properly spoken of as xenoliths or pendants. Otherwise, it would be difficult to explain how a granitic rock, which may be essentially free of iron, could have given rise to these high-iron segregations. It is clear that such relationships are not at all unusual. Callaghan (1935) describes dikes supposedly intruding granodiorite in which apophyses of the latter ramified through the dikes and filled the spaces between separated segments, demonstrating clearly that the dikes were older than the granodiorite they ostensibly intruded.

While the foregoing considerations might not be crucial in any particular set of circumstances concerning magnetite exploration they might nevertheless be kept in mind as possible guides in any such further exploration.

POSSIBLE RESERVES AND GRADES

In order to arrive at some approximation of the magnetite content encountered in Drill Hole N40A a representative section, 6 to 10 centimeters long, was taken from each meter or less of core and its specific gravity determined. Where the core contained only a small amount of visible magnetite or appeared to be relatively homogeneous the selected specimen might represent a longer interval. The magnetite content (by volume) was read from a graph prepared for this purpose. The specific gravity of pure magnetite was taken as 5.18. The average specific gravity of the essentially magnetite-free host rock, as determined by the lack of response of the specimen to the pull of small, strong magnet, was taken as 2.85. Such specimens, however, were not complete non-magnetic as they would still affect a compass needle. The conversion of specific gravity to magnetite content by volume rather than by weight was used because the former relationship is a straight line function and was therefore simpler to graph. Also, for the parameters used in the magnetite content by volume would always lie within a percentage point or two of the corresponding iron content by weight and thus served as an approximation of the latter. The relevant relationships are the following:

$$\text{Percentage magnetite by volume} = \frac{\text{sp.gr} - 2.85}{5.18 - 2.85} \times 100$$

$$\text{Percent iron content by weight} = \frac{5.18}{5.18 - 2.85}\left(1 - \frac{2.85}{\text{sp.gr}}\right) \times 100$$

Percent iron content by weight = percent magnetite content by weight x .723

where sp.gr. is the specific gravity of the specimen.

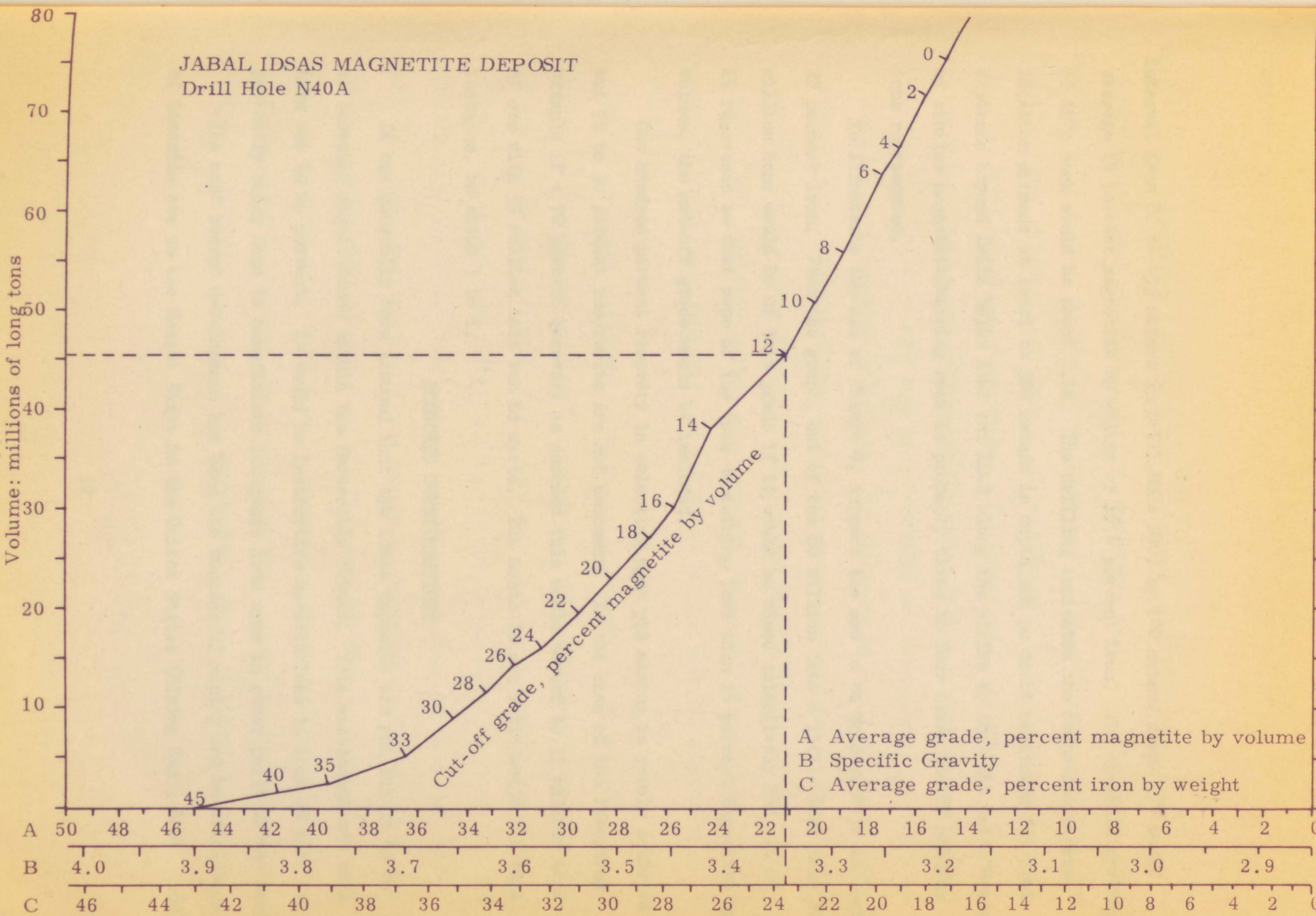

FIGURE 4.- Cumulative grade distribution

The magnetite content by volume, as determined from the specific gravity is plotted along the length of Drill Hole N40A as a bar graph on Figure 3. Each of the succession of dots, also shown on the graph, represents the average magnetite content of a 10-meter interval of which the dot is also the midpoint. This is a convenient device for arriving at the average of any longer interval by combining a number of these 10-meter sections and adjusting for any partial sections by adding or subtracting the individual values represented by bar graph extending over the partial section.

Analyses of some of the specimens of core, more or less randomly selected, are given in Table 1. These show that the iron content as approximated from the specific gravity are in reasonable agreement with the iron content as determined by analysis. The differences are not of such magnitude as to vitiate the conclusions set out later on.

The graph of Figure 4 shows the cumulative distribution of the various grades of material encountered in Drill Hole N40A, as determined by the method outlined above, in the interval from 82 to 435 meters. The graph is constructed by the step-wise additions of the volumes of successively lower grade material, regardless of where this may be located in the interval, and computing the average magnetite content of the summed volume or tonnage, at each step. For convenience, scales of iron content and specific gravity have been added.

The total volume of magnetite-bearing rock represented by Figure 4 amounts to 80 million tons. It would be contained in a block 1000 meters long (a little less than the distance between Drill Holes ID-1 and ID-2) and, taking the average dip of the magnetite to be close to vertical, 250 meters wide (represented by the interval from 82 to 435 meters in Drill Hole N40) by 100 meters deep. It would average 14 percent magnetite by volume or 16.4 percent iron. The specific gravity of this rock would be about 3.18. The drilling indicates the magnetite mineralization extends at least to 500 meters in depth and no doubt continues for some distance beyond Drill Holes ID-1 and ID-2 along the strike so that the total volume of similar magnetite-bearing rock is probably three to four times the 80 million tons represented.

To illustrate the use of Figure 4, suppose the ore to be processed is to contain 28 percent iron. From the graph, out of the 80 million tons a little less than 30 million tons would be of this grade if it could be mined selectively and all of it recovered so that none of the rock containing less than 16 percent magnetite by volume, the cut-off grade, would be included.

One hundred percent recovery in selective open pit mining is rarely achieved but 70 to 90 percent recoveries are not uncommon. In the case of the foregoing example if a 70 percent recovery is assumed this would amount to 21 million tons of ore with 59 million tons run to waste. The waste to ore ratio would, in this instance, be about 3 to 1.

ECONOMIC CONSIDERATIONS

It has generally been assumed that the Idsas deposits are not likely to be of economic significance within the forseeable future. This assessment may well turn out to be correct. It would be instructive nevertheless to look at what is presently being done to beneficiate low-grade iron ores in other parts of the world.

The most recent development has been the successful mining and beneficiation of taconite ore on the Mesabi Range in the United States (Mining Eng., Sept. 1968).

Taconite is a ferruginous chert or jasper containing about 20 to 30 percent iron in the form of dispersed hematite, maghemite, and magnetite. It is a difficult ore to mine and beneficiate. Mining requires special drilling techniques - actually "jet flame piercing" rather than drilling - and beneficiating takes fine grinding and multistage hydro and magnetic separation. The concentrate, containing 63 to 64 percent iron, is pelletized and usually sintered. Costs for open pit operations, processing 2 to 4 million long tons of ore annually and averaging 23 percent iron, are about $10.00 per longton of pellets. The treatment of even lower grade ores is contemplated. Underground mining operations are also envisaged on ore averaging 27 percent iron at a cost of about $11.00 per long ton of pellets (Pfleider and Scofield, 1967). Sintered pellets are currently quoted at 25¢ per longton unit of contained iron at Lower Lake Ports or $16.00 per ton for material containing 64 percent iron.

Open pit taconite operations in the United States are now fairly well standardized and cost data are readily available. Mangetite operations on the other hand are more diverse and usually on a much smaller scale so that the available costs are not readily comparable. But they would, in any event, be lower than for a similar, but inevitably, more complex, taconite operation. It is a reasonable assumption, then, that the $10.00 cost per ton of pellets quoted above for a typical open pit taconite operation would at least be equal and probably lower for a magnetite operation of comparable scale, processing ores of similar iron content at comparable waste to ore and concentration ratios. It remains then to examine how the cost per ton of pellets would change with a change in these factors.

The typical operation would be one of mining and processing 2 to 5 million long tons of ore a year containing 23 percent iron at a concentration ratio of 3:1, a waste to ore ratio of 0:1 that is, little or no waste would be mined, and producing pellets containing 63 to 64 percent iron at a total cost of $10.00 per ton of pellets. Unit costs, taken with some modifications from the literature cited above, are 45¢ per ton for mining waste, 65¢ per ton for mining ore, and 72¢ per ton for beneficiation. All other costs would change little either with the scale of the operation or with a change in the reference conditions.

Taking then the grade distribution shown in Figure 4 as reasonably representative of the Idsas magnetite body, then the volume of rock averaging 23 percent iron, or perhaps a little more, would amount to 45.5 million tons out of each 80 million tons. It would include all of the material containing more than 12 percent magnetite by volume, the cut-off grade, or 14 percent iron in the form of magnetite. Again, as in our previous example, we assume that because of dilution and the exigencies of pit designs only 70 percent or 32 million tons of the specified grade will actually be recovered in mining. The other 48 million tons would be run to waste giving a waste to ore ratio of 1.5 to 1. With a concentration ratio 3 tons of ore to produce 1 ton of pellets containing 64 percent iron, this means that 4.5 tons of waste would be mined for each ton of pellets produced. The cost of this waste removal would add $2.25 to the cost of each ton of pellets bringing the total to $12.25 per ton.

However an inspection of Figure 3 shows that much of this waste need not be mined at all if only that part of the orebody represented by the interval from 82 to 296 meters is considered. The block would now be 150 meters wide rather than 250 meters and would contain 49 million tons averaging 19.2 percent iron, arrived at by subtracting from the total iron content the iron content of the part represented by the interval from 296 to 435 meters. If, instead of mining this material selectively to a better grade as was done in the previous example, all of it were to be processed then there would be little or no waste. However, because the ore to be beneficiated would be of lower grade than in the previous example and because of this there would also be some drop in beneficiation efficiency it would now take about 4.2 tons of ore to produce one ton of pellets instead of 3 as before. To mine and to beneficiate the additional 1.2 tons of ore would add $1.65 to the cost of a ton of pellets bringing the total of this case to $11.65 per ton. The 49 million tons of 19.2 percent ore would yield 11.7 million tons of pellets as compared to 10.7 million ton from 32 million tons of the higher grade ore of the previous example at a cost 60¢ per ton of pellets lower. Within limits these costs might be reduced still further by a combination of proper pit design, and judicious choice of cut-off grade and other factors. It is expected that they would, in any event be lower, as stated at the outset, for a magnetite operation as compared to the taconite operation upon which the foregoing is based. To these, cost of transportation from the point of production to the point of use would have to be added. In Saudi Arabia this could amount to as much as $5.00 per ton. Nevertheless the analysis carried out above indicates that should the need arise the mining and beneficiation of the Jabal Idsas magnetite bodies would not lie beyond the realm of possibility.

In order to justify the investment in mine and processing plant, power capacity, water development, and townsite amounting to perhaps 30 million dollars it would be desirable to have an ore reserve yielding from 25 to 30 million tons of concentrate over a 20 to 30 year period, which would have a current value at the point of use from 400 to 480 million dollars. This reserve would be contained in a block 1250 meters long 200 meters deep and 150 meters wide that is, equal to the width represented by the interval from 82 to 296 meters in Drill Hole N40A and having the grade distribution of this interval. Such a block would contain about 125 million tons of ore averaging 19 percent iron in the form of magnetite. In view of what has been said earlier, the development of such a reserve is a reasonable expectation. But it must be emphasized that with the work done up to now it is no more than an expectation. However should the reserves turn out to be only one half of what above has been considered desirable it would add at most $1.50 to the cost of a ton of concentrate in depreciation charges. This applies also to any of the other major elements of cost: mining, processing, capital investment, and transportation.

CONCLUSIONS

The magnetite bodies at Jabal Idsas could turn out to be a substantial national asset. Extrapolation of costs from taconite mining and beneficiation involving a much more recalcitrant ore than would be the case of Jabal Idsas indicate the economic feasibility of exploiting these deposits at comparable if not lower costs.

Investigations support the reasonable expectation that a well-coordinated development program would establish reserves sufficient to sustain such an operation. These would amount to 75 to 125 million tons containing between 18 and 30 percent iron in the form of magnetite which upon beneficiation would yield from 20 to 30 million tons of pellets containing 63 to 64 percent iron whose current value at the point of use would be between 320 and 480 million dollars. An initial capital investment of about 30 million dollars would be required.

Spectrographic analyses of the core from Drill Hole N40A indicate the presence of a small amount of tin to the extent of .01 percent. Tin has not been previously reported from this area so this occurrence needs to be verified in other parts of the district where it might well occur in higher concentrations.

The origin of the magnetite deposits is conceived of as resulting from the wide spread uralitization of the host rocks. This conception seems to accord better with the geologic setting, mineralization, alteration, and form of the deposits. It could thus serve as a more meaningful guide to further exploration than the hypothesis of magmatic segregation usually invoked to account for their origin.

RECOMMENDATIONS

Further investigations of the Jabal Idsas magnetite deposits seem warranted regardless of what a more detailed analysis may indicate about the economic feasibility of their exploition.

1. Additional segments of core, and perhaps all of the cores, should be analyzed for iron and tin.
2. If the presence of tin is verified a field check should be made to determine its distribution in the various lithologies, the form in which the tin occurs, and the amount.
3. It would not be amiss to test for tin in some of the more promising wadis.
4. Laboratory beneficiation test might be carried out on the present drill cores. Test samples should be made up to represent at least four different grades of ore. For instance, the core of Drill Hole N40A might be divided as follows:

   A. The section from 82 to 282 meters might be segregated into two samples one made up of all the material containing more than 20 percent magnetite, the other consisting of the remainder.

B. The section from 282 meters to 435 meters might be similarly made up into two samples: one composed of all the material containing more than 15 percent magnetite, the other made up of the remainder.

These four samples would represent a range of grades and a variety of lithologies and textures. It is essential that tests be made on the low-grade material. The results from these would later be crucial in determining what the optimum cut-off grade should be in an actual operation.

The beneficiation studies suggested above might be carried out in conjunction with a broader investigation looking forward to beneficiating iron ores from a number of sources. It should be anticipated that the concentrates might be used in one of several "direct reduction" processes which have recently been developed and the tests conducted accordingly.

5. If the foregoing tests prove the technical feasibility of beneficiating the Jabal Idsas ore a more detailed economic analysis might be made which would establish the scale of the operation, minimum reserves, cut-off grade, and other variables. Again, the studies would look beyond these immediate objectives to include possible operations involving iron ores from other areas.

6. If the studies to this stage point to a possible operation then, when the need arises, a detailed development program might be undertaken aimed at establishing the minimum reserves upon which to launch such an enterprise and to gather the data for an optimum pit design. A further objective would be to outline the ultimate boundary of the ore body and to determine its probable tenor. This would involve surface trenching, diamond drilling, and possibly underground development.

7. A small surface pit should be started at this stage on one of the more conveniently located magnetite showings. The purpose would be to determine what the actual mining conditions would be and thus to anticipate some of the problems, to investigate the extent to which mining could be selective, and to stockpile some ore for a pilot plant run.

8. These activities would generate a great deal of technical and financial information. A system of cost-accounting should be established from the beginning so that a body of reliable cost data would be assembled to guide future assessments of similar projects. The lack of such data for Saudi Arabia at the present time is one of the principal deterrents to the influx of venture capital. It is important also that any such development program have the best technical direction so that the cost data will be an accurate reflection of the operating conditions.

REFERENCES

Barth, T. F. W., 1962, Theoretical petrology, 2nd ed., John Wiley & Sons, Inc., New York, 416 p.

Callaghan, Eugene, 1935, Pre-granodiorite dikes in granodiorite: Am. Geophys. Union Trans., 17th Ann. Mtg., pt. 1, National Research Council, August 1935, p. 302-307.

Davis, W. E., Allen, R. V., and Akhrass, M. N., 1970, Magnetometer survey in the Jebel Idsas area: U. S. Geol. Survey open file rept. (IR) SA-18.

Hammes, J., 1966, The economics of production and delivery of ore pellets from North American taconite-type resources: Proc. of the 27th Ann. Mining Symposium, Univ. of Minnesota, Jan. 1966, p. 9-16.

Harrison, C. G. A., and Peterson, M. N. A., 1965, Magnetic minerals from the Indian Ocean: Am. Mineralogist, v. 50, no. 5/6, 1965, p. 704-712.

Hatch, F. H., Wells, A. K., and Wells, M. K., 1949, The petrology of the igneous rocks: Thomas Murley and Co., London, 469 p.

Kahr, V. P., 1965, Jabal Idsas area, geology and mineralization: Saudi Arabia Directorate Gen. Min. Resources open file rept. 3/212/6013, 26 p.

Mining Eng., Sept. 1968, Taconite build-up on the Mesabi: Mining Eng., v. 20, no. 9, p. 81-84.

Pfleider, E. P., and Scofield, J., 1967, A preliminary economic analysis of the underground mining of Minnesota taconite: Mining Eng., v. 19, no. 9, p. 107-112.

Rocroi, J. P., 1966, Ground magnetic survey at Jabal Idsas: Bureau de Recherches Geologiques et Minieres, Report to Directorate Gen. of Mineral Resources.

Spiroff, Kiril, 1938, Magnetite crystals from meteoric solutions: Econ. Geology, v. 33, no. 8, p. 808-828.

Steveson, J. S., and Jeffery, W. G., 1964, Calloform magnetite in contact metasomatic iron deposits, Vancouver Island, British Columbia: Econ. Geology, v. 59, no. 7, p. 1298-1305.

Vincent, G., 1966, The magnetite occurrences at Jabal Idsas, in Eijkelboom, G., 1966, The mineral resources and geology of the Idsas-Wadi Jifr region: Bureau de Recherches Geologiques et Minieres, Report SG. Jed 66A15, App. 5.

__________, 1967, Completion report of Drill Holes ID-1 and ID-2 Jabal Idsas: Bureau de Recherches Geologiques et Minieres, Report SG. JED 67 A6.

Wing-Easton, Micolas, 1937, The tin ores of Banca, Billiton and Singkep, Malay Archipelago: Econ. Geology, v. 32, no. 1, p. 1-30.

APPENDIX
LOG OF DRILL HOLE N40A

Location: lat. 23°19.5'N.; long. 45°12.5'E.
Elevation: approximately 850 meters
Orientation: N. 18°E.; minus 45
Total depth: 445.7 meters

Hole size:

NX	0	-	55 meters	
BX	55	-	282	
AX	282	-	445.7	

Core recovery:

58%	0	-	34.5 meters
14%	34.5	-	55
100%	55	-	445.7

Driller: Arabian Drilling Company, Jiddah, Saudi Arabia
Date of drilling: February 1968
Tro-Pari survey:

Depth	Inclination	Direction
50 meters	45°	N.18°E.
100	47°	N.18°E.
150	47°	N.18°E.
200	48°	N.19°E.
250	49°	N.18°E.
300	49°	N.18°E.
350	50°	N.18°E.

Log:

Depth	
0	Microdiorite porphyry
34.7	Fault zone: indurated, locally limonitic gouge and andesite breccia with finely dispersed magnetite; andesite 51-54 m.
55	Andesite, chlorite with dispersed coarse- to medium-grained magnetite
59	Andesite, dark-gray
66	Andesite, dark-green to black, chlorite, fine epidote seams; dispersed locally coarse magnetite
78	Microdiorite, light-gray. Contact at 45° to axis of core
82	Andesite, dark-green to black, hard fine-grained locally chloritic and serpentinous; largely replaced by coarse magnetite. Pyrite quartz veinlet at 89.5 m.
101.3	Microdiorite, light-gray; uneven contact at 45° to axis of core
106.9	Andesite, fine, hard, gray to black; largely replaced by magnetite, locally massive.

APPENDIX
LOG OF DRILL HOLE N40A (cont'd.)

Depth	
111	Andesite, dark-gray, fine to dense, diabasic in part, locally dispersed magnetite
119	Andesite, dark-green to black, locally chloritic, with porous calcite-epidote seams; abundant magnetite
144	Diabase, dark-greenish-gray, hard, some epidote; magnetite 146-147 m.
148	Andesite, diabasic, non-porphyritic, fine even granular; chloritic and in part serpentinous; locally sparsely pyrite; variable magnetite
174	Diabase, andesite, chloritic, serpentinous, some epidote seams; variable magnetite
194	Diabase dike(?), gray, fine, hard
196	Andesite, chloritic, with magnetite and traces of chalcopyrite and bornite
199	Andesite, coarsely porphyritic with pale green rounded phenocrysts of saussurite 1.5 cm. dia. Interstitial magnetite, hornblende, and chlorite; spilitic, appears to be replaced and indurated breccia zone. Calcite and epidote seams 235-236 m.
236	Andesite, greenish-gray, diabasic, porphyritic, sparse magnetite
241	Serpentine, greenish-black, soft, massive, with veinlets of massive magnetite
249	Andesite, diabasic, locally serpentinous and mottled; seams, dispersed, and locally massive magnetite
264	Andesite, gray, fine porphyritic
266	Andesite, greenish-black, soft chloritic, locally mottled and serpentinous, variable magnetite
280	Andesite, hard, greenish-gray, porphyritic
282	Andesite, veined with magnetite, locally massive
296	Diabase, hard, fine, dark-gray; sparse magnetite
307	Serpentinous diabase, greenish-black, with increasing magnetite
322	Andesite, coarsely porphyritic sparse variable magnetite
327	Microdiorite, dark-pinkish-gray, fine-grained
328	Serpentine, diabasic, with dispersed and veined magnetite; locally massive
355	Serpentine, andesite, and diabase; variable magnetite

APPENDIX
LOG OF DRILL HOLE N40A (cont'd.)

Depth	
382	Microdiorite, dark pinkish-gray
386	Diabase, dark-greenish-gray, fine, hard; serpentinous; sparse magnetite; traces of chalcopyrite
399	Hornblende andesite, pink
400	Dark, aphanitic, diabase - andesite
402	Microdiorite
403	Diabase, dark greenish-gray, aphanitic
416	Serpentine, massive; dispersed magnetite
435	Hornblende andesite, pink
439	Serpentine
445.7	Bottom of hole.