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GEOLOGY AND MINERAL EVALUATION OF THE WADI BIDAH DISTRICT, SOUTHERN HIJAZ QUADRANGLE, KINGDOM OF SAUDI ARABIA

by

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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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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.

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ABSTRACT

The Wadi Bidah district in southwest Saudi Arabia contains several ancient mines and mineral prospects. The Precambrian rocks of the district are steeply dipping and highly folded and faulted. They are divided into three major units: (1) older metavolcanic rocks, (2) metasedimentary rocks, and (3) younger metavolcanic rocks. Massive sulfide-type deposits show stratigraphic control and are found in metasedimentary rocks and in the younger metavolcanic rocks. There appears to be a close genetic relationship between the sulfide deposits and volcanism. Deposits containing copper, zinc, gold, and silver are indicated by geologic mapping and by shallow diamond drill holes in two of the ancient mine localities. The ore estimate for the district is 2.55 million short tons computed to depths that range from 79 to 150 meters. It seems probable that deeper drilling of the indicated deposits and drilling of other outlined target areas would add substantially to the ore reserves.

INTRODUCTION

Description and objectives

The Wadi Bidah district covers approximately 400 square kilometers in the southern Hijaz region of Saudi Arabia, and it contains five ancient mine localities (fig.1). The boundaries of the district are not geologically or physiographically definitive. The district is named after the major wadi (dry river valley) that drains the area.

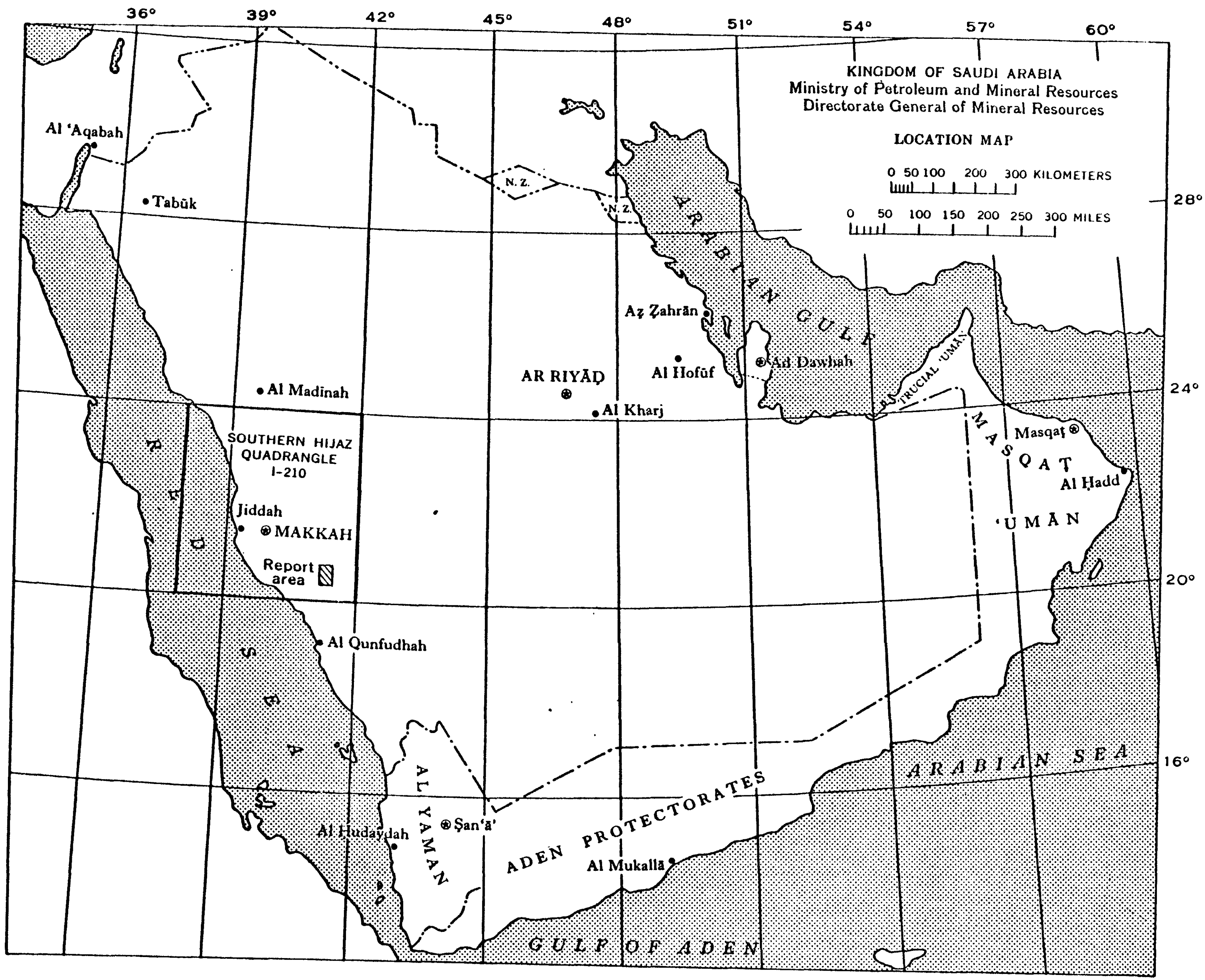

Figure 1.—Index map of the Arabian Peninsula.

The primary objectives of the investigations were to evaluate the mineral potential of the ancient mine localities, to locate exploration target areas to resolve geology of the district, and to determine the geologic controls related to mineral deposits of the district that might have practical application in the exploration approach for ore bodies in other parts of Saudi Arabia where geologic conditions are similar.

The investigations were carried out by the U.S. Geological Survey as part of its agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

Location and accessibility

The Wadi Bidah district (fig. 2) lies between latitudes 20°22'N. and 20°48'N. and longitudes 41°20'E. and 41°27'E. The north boundary is about 325 kilometers by road east-southeast from Jiddah, a major port city on the Red Sea coast. The road is a paved (two and four-lane highway) for about 165 kilometers between Jiddah and At Ta'if and a paved road extending east-southeast from At Ta'if toward the Wadi Bidah district is under construction. During the present investigations, the district was reached by a normally good and well traveled unpaved road from At Ta'if. The trip from Jiddah to the Wadi Bidah district takes about 7 hours by car or truck. Drill access roads connect four of the ancient mine localities with the main road in the middle of Wadi Bidah.

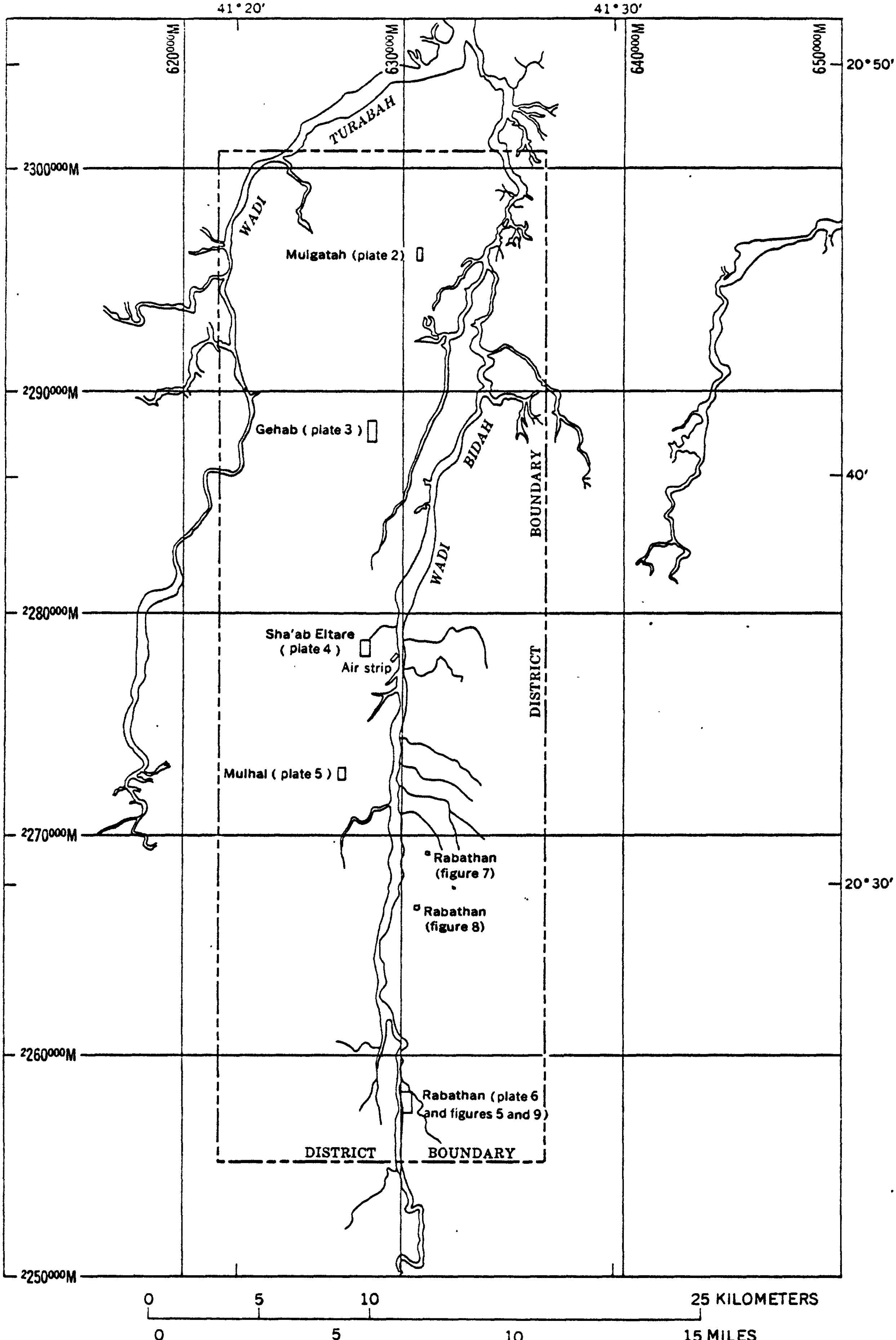

Figure 2.—Index map of the Wadi Bidah district, showing detailed map areas.

An airstrip suitable for light aircraft is located near the center of the district at 1318 meters elevation. The airstrip is 235 kilometers from Jiddah on a bearing of 114°.

Geography and geomorphology

The Wadi Bidah district is in a region of moderate to rugged relief. The north-south axis of the district is subparallel to the course of Wadi Bidah which forms an undulating valley floor about 2 kilometers wide. Wadi Bidah flows northerly and empties into Wadi Turabah a short distance north of the district. The valley walls are steep sided, and the relief is rugged to the east and west of the valley. Secondary wadis in Wadi Bidah provide access to parts of the rugged areas. Elevations in the district range from 1215 meters in the north part of the district to 1686 meters in the southwest part, so that the maximum relief is 471 meters. Mountain peaks a short distance south of the district rise to 1816 meters.

The topography of the district is in the intermediate stage of youthful development. In the northern part of the district, flat-lying lava flows, which are probably of Miocene age or younger cover an irregular erosion surface of Precambrian rocks. The lavas rest on a Tertiary erosion surface which is about 45 meters above the present valley floor. A northeasterly tilted peneplane surface is suggestive by the low angular accordance of peaks in the western part of the district.

Normally the wadis of the district have intermittent flow; however, the present study was conducted in a year of abnormal rainfall and Wadi Bidah maintained perennial flow. The region receives frequent showers in winter and spring, and occasional late afternoon showers in summer and fall. Rainfall is usually of short duration. Because of the topographic configuration, the valleys in the district are subject to frequent flashfloods, and occasionally the floods cause considerable damage to crops and homes.

The water table in the district is highly fluctuating; however, water-wells are of adequate depth to assure a perennial source of water. All wells are located in the Wadi Bidah valley and are concentrated in the southern part of the district. Water is used for irrigation as well as for human and animal consumption.

The principal industry of the district is the grazing of sheep and goats. Small orchards of pomegranate and apricots and fields of millet can be observed in the main valley in the southern part of the district. A few grapes and lemons are also cultivated.

The district does not include any villages and the population is sparse. Most inhabitants live in the southern part of the Wadi Bidah valley near the water wells. Nearly all are permanent settlers, although a few nomads are generally present. Judging from the large number of ruins that may date back to the Ottoman Empire of the fourteenth century or possibly later, the population of the district must have been far more dense at the time than it is today.

The Ottoman ruins are located in the central and southern part of the district near the main valley. They mostly consist of large fortress-like structures built on low but steep crests and ridges that contain the best grade building stone in the district. The location of the structures as evidently determined by their defensive characteristics and by the availability of good building materials. Ancient quarries are commonly found near the ruins.

Ruins that probably date back to the eighth and ninth centuries of the Abbasid caliphate are in less accessible parts of the district, near ancient mines. The most extensive and best preserved of the older ruins were observed at the Mulgatah and Mulhal ancient mine localities.

Wild life in the district includes fox, wolf, rabbits, baboons, a small variety of birds, rodents, small reptiles, and insects. The insect population includes the malarial infected anopheles mosquito. Temperatures in the district have a maximum variation from 5°C. in the winter months to 46°C. in the summer months.

Previous investigations

The Wadi Bidah district is included in the Southern Hijaz Quadrangle map (Brown and others, 1962). In 1964 C. W. Smith, formally with the Directorate General of Mineral Resources, compiled an unpublished map of the geology of the Mulhal ancient mine which is located near the center of the district. Electromagnetic surveys were conducted by Davis and Allen (1970) in the Mulhal and Mulgatah ancient mine areas.

The negative results of these surveys indicates that the depth of oxidation exceeded the effective depth of penetration of the geophysical method used.

Anomalous amounts of gold and silver were found in the alluvium near the Mulgatah and Rabathan ancient mine areas by Gonzalez (1970).

A general description of the geology and mineral resources of the Wadi Bidah district is in a geologic report on the Southern Hijaz quadrangle (Goldsmith, in press). He assigned sub-district status to Wadi Bidah which included a more extensive area than the Wadi Bidah district as defined in this report. Goldsmith (in press) collectively grouped the rocks of the Wadi Bidah district into the Schist Series; a thick and extensive series of metavolcanic and metasedimentary rocks. He suggested that the regional structure, in which the Wadi Bidah district is included, may be anticlinal and that the Schist Series forms the west limb of the anticline. The present investigations lend support to this observation. Goldsmith (in press) also included brief descriptions of the Mulgatah and Rabathan ancient mines areas in his report.

Acknowledgements

Acknowledgement is due to the Minister of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia and his staff for providing the logistical support and encouragement that made the work possible.

The advice and guidance of A. E. Weissenborn, research geologist, G. F. Brown, Project Chief, Saudi Arabia, and J. A. Reinemund, Chief of Foreign Geology Branch all of the U. S. Geological Survey, all of whom visited the district during the investigations, was utilized in the planning and execution of the work. Diamond drilling operations were directed by E. W. Raisanen, U.S. Geological Survey, and topographic surveys were conducted under the field direction of K. S. McLean of the U. S. Geological Survey. Core samples were analyzed by the Ministry of Petroleum and Mineral Resources laboratory in Jiddah and U. S. Geological Survey laboratories in Washington D.C. and Denver, Colorado. Mr. Ghanem Geri, prospector-guide, employed by the U. S. Geological Survey also made important contributions to the work.

PRESENT INVESTIGATIONS

Introduction

The present investigations are an outgrowth of the helicopter-borne mineral reconnaissance survey which covered extensive regions in the Southern Hijaz and Tihamat ash Sham quadrangles in Southern Saudi Arabia. The reconnaissance was conducted by a U. S. Geological Survey team directed by G. H. Allcott and R. L. Earhart during the spring and summer of 1967. This work resulted in the location of numerous mineralized localities, and visits to known mineral localities within the district were included in the investigations.

Numerous grab and select samples were collected during the reconnaissance survey. A partial list of analytical results of samples collected from old mine localities in the Wadi Bidah district are included in table 1. These results, along with the presence of ancient mines, and of geologic conditions favorable for sulfide mineralization, suggested the possibility that ore deposits are in the district. Therefore, an exploration program involving geological, geochemical, and geophysical studies was proposed. The present geological studies included geological mapping and diamond drilling which required topographic and laboratory support.

Geochemical studies by Allcott and geophysical studies by Flanigan and Gazzaz are currently in progress or are being compiled. A helicopter-borne electromagnetic-magnetometer survey was conducted under a contract agreement between the U.S. Geological Survey and Sanders Geophysics Limited in February 1968. In preparing the geologic report, the authors have frequently consulted with those persons involved in the geochemical and geophysical aspects of the work.

Geologic mapping

Geologic mapping of five ancient mine localities was at a scale of 1:1000 (pls. 2-6), whereas mapping of the district was at a scale of 1:50,000 (pl. 1). Parts of the Rabathan area in the southern part

TABLE 1. A PARTIAL LIST OF ANALYTICAL RESULTS FROM GRAB AND SELECTED SAMPLES COLLECTED DURING RECONNAISSANCE INVESTIGATIONS, WADI BIDAH DISTRICT. Au and Ag in ounces per ton; Cu, Pb, and Zn weight percent; and Mo in parts per million.

Locality - Mulgatah Ancient Mine

Sample No.	Description	Au	Ag	Cu	Pb	Zn
37348	Quartz-sericite schist	Nil	0.57	3.0	1.0	1.5
37349	Gossan	Nil	1.13	4.5	1.5	2.5
37350	Siliceous gossan	Nil	0.75	2.3	1.5	1.0
37351	" "	Nil	6.58	1.2	0.3	1.0
37352	Slag	Nil	0.16	4.5	0.3	1.5

Locality - Gehab Ancient Mine

Sample No.	Description	Au	Ag	Cu	Pb	Zn
37336	Gossan	0.10	Nil	0.03	0.15	0.005
37337	Limonitic, sheared rhyolite	0.58	0.34	0.004	0.075	0.0025
37338	" " "	0.19	0.15	0.025	0.02	0.0025
44115	Gossan	0.51	0.52	0.03	-	0.050
44105	Gossan	0.12	1.32	0.08	-	0.125

Locality - Sha'ab Eltare Ancient Mine

Sample No.	Description	Ag	Cu	Pb	Zn	Mo (ppm)
45828	Rhyolite	Tr	0.05	<.05	0.05	<5
45722	Sericite schist	Tr	0.10	<.05	<0.02	<2
45826	Gossan	Tr	0.25	<.05	0.07	50
45677	Gossan	Tr	0.05	<.05	0.02	5
54860	Chlorite schist	-	0.07	<.05	0.03	<2

TABLE 1. A PARTIAL LIST OF ANALYTICAL RESULTS FROM GRAB AND SELECTED SAMPLES COLLECTED DURING RECONNAISSANCE INVESTIGATIONS, WADI BIDAH DISTRICT. Au and Ag in ounces per ton; Cu, Pb, and Zn in weight percent; and Mo in parts per million. (cont'd.)

Locality - Mulhal Ancient Mine

Sample No.	Description	Au	Ag	Cu	Zn
37270	Siliceous gossan	0.30	10.51	0.24	0.10
37271	Slag	0.69	2.57	15.50	0.25
37272	Siliceous gossan	0.38	0.43	2.30	0.30
37274	Quartz-sericite schist	1.24	0.75	1.50	0.20
37277	Barite-quartz vein	0.46	2.44	0.16	0.10

Locality - Rabathan Ancient Mine

Sample No.	Description	Au	Ag	Cu	Pb	Zn	Mo(p
37342	Slag	Nil	0.23	1.20	0.005	0.005	-
37344	Gossan	0.23	0.46	0.03	0.0025	0.0025	-
37346	Chlorite schist	Nil	0.14	6.0	0.0025	0.01	-
49082	Gossan	-	<.06	0.03	<0.05	0.03	<2
49136	Greenstone	-	<.06	0.03	<0.05	0.05	<2

Samples collected by R. Earhart, G. Allcott and G. Geri.

Analysis by the laboratories of the Ministry of Petroleum and Mineral Resource, Jiddah, Saudi Arabia.

of the district were mapped at a scale of 1:2000 (figs. 5, 7, and 8).

The detailed maps at a scale of 1:1000 were made by the plane-table and alidade method of four of the five ancient mine localities. The other ancient mine locality, the Mulhal, was mapped by the pace and compass method along geochemical survey lines of 50 meter spacings from stations established on 20 meter intervals. The Mulhal ancient mine locality was mapped at a scale of 1:1200, but was enlarged to 1:1000 to conform with the maps of the other ancient mine localities.

The district was mapped on aerial photographs at a scale of 1:50,000, and later plotted on a semi-controlled photo mosaic. After the field work was completed, recent photography at a scale of about 1:12,000 was made available and stereoscopic study of these photographs permitted further refinement of the geology.

Selected parts of the Rabathan area, which were diamond drilled but not included on the plane table maps, were mapped on an enlarged photographic base at a scale of 1:2000.

Diamond drilling

The objectives of the diamond drilling program were to as many ore-grade mineral deposits as possible, and to supplement surface geologic data. No attempt was made to block out orebodies nor to determine the approximate limits of such bodies by diamond drill hole information. Consequently, target areas were penetrated by only one drill hole regardless of the results of that hole. This procedure was necessary because of the large number of targets in the district, several of which have not been tested by drilling.

Eighteen diamond drill holes were completed for a total of 2,199.2 meters by the U. S. Geological Survey drilling team and by the Arabian Drilling Company (table 2). The Arabian Drilling Company drilled four of the holes for a total of 513.0 meters. The overall average core recovery, excluding overburden, was 74.7 percent and core recovery in ore-grade material averaged 72.2 percent. The diamond drill hole data is given in table 2, and a further breakdown of core recovery in the mineralized zones is presented on table 3. Three of the holes were lost or abandoned before completion due to drilling difficulties or to insufficient core recovery.

Topographic surveys

The locations and elevations of 15 prominent points in or near the district were established by an electronic method of triangulation. Five of the stations were purposely established near ancient mine localities and a secondary control station was surveyed in all but one of the mine localities. The base elevation used for vertical control was taken from the average altimeter ground readings of aircraft at the airstrip in the central part of the district. The locations of all points were calculated in terms of latitude and longitude, and were converted to the International Spheroid grid system so that locations of individual detailed map areas can be easily interrelated in terms of meters.

Table 2.—Diamond drill hole data.

Drill hole number	Locality	Intended Inclination	Bearing	Depth, in meters	Core recovery, in percent	Rock types	Remarks
M-1	Mulgatah	-65°	N. 80° E.	123.5	69.4	Pyritic quartz-sericite schist, chlorite schist, greenstone.	Undercut ancient mine workings.
G-1	Gehab	-45°	N. 76° E.	145.6	93.0	Rhyolite, quartz-sericite schist, chlorite schist, amphibolite.	Undercut ancient mine workings.
G-2A	do.	-90°	Vertical	29.98	59.3	Siliceous gossan.	Hole lost.
G-2B	do.	-90°	Vertical	142.5	84.3	Siliceous gossan, pyritic quartz-sericite schist, chlorite schist.	Drilled same location as G-2a, near ancient mine workings.
G-3	do.	-65°	S. 73° W.	216.9	96.7	Mafic and siliceous volcanic rock, quartz-sericite schist, massive to richly disseminated sulfides.	12.2 meters of ore-grade copper.
G-4	do.	-45°	N. 77° E.	175.6	88.6	Quartz-sericite schist,metarhyolite, richly disseminated to massive sulfides, amphibolite, chlorite schist.	42.5 meters of low grade copper, narrow zone ore- grade copper
G-5	do.	-65°	S. 30° W.	97.1	85.0	Chlorite schist, iron formation, pyritic metarhyolite, amphibolite.	Undercut ancient mine workings.
S-1	Sha'ab Eltare	-45°	N. 83° W.	42.5	7.4	Siliceous gossan, gouge.	Hole abandoned.
S-1A	do.	-60°	N. 83° W.	41.8	13.8	Siliceous gossan, gouge.	Same location as S-1, hole abandoned.
S-2	do.	-45°	S. 85° E.	144.2	58.4	Quartz-sericite schist, chlorite schist, disseminated to massive sulfides.	10.8 meters of low-grade copper, rocks highly fractured.
R-1	Rabathan	-45°	S. 88° E.	122.0	97.5	Siliceous pyroclastic rock, siliceous carbonate rock, pyritic graphite schist.	Undercut ancient mine workings.
R-2	do.	-45°	S. 73° W.	106.7	97.7	Siliceous pyroclastic rock, chlorite schist, oxidized iron and copper sulfides, graphite schist.	5.3 meters of ore-grade copper.
R-3	do.	-45°	S. 88° E.	102.5	73.3	Gossan, graphite schist, siliceous pyroclastic rock, disseminated to massive sulfides.	4.3 meters of ore-grade copper.
R-4	do.	-45°	N. 70° E.	205.6	83.4	Graphite schist, siliceous pyroclastic rock, massive sulfides, greenstone.	10.4 meters of ore-grade copper.
R-5	do.	-45°	N. 75° W.	103.6	61.6	Siliceous carbonate rock, siliceous pyroclastic rock, quartz-sericite schist, graphite schist.	North Rabathan area.
R-6	do.	-55°	S. 52° E.	121.7	91.5	Siliceous carbonate rock, siliceous pyroclastic rock, graphite schist, greenstone.	Rocks highly fractured.
R-7	do.	-50°	N. 68° W.	92.2	87.2	Chlorite schist, siliceous carbonate rock, siliceous pyroclastic rock.	North Rabathan area.
R-8	do.	-70°	N. 60° W.	105.2	95.8	Siliceous pyroclastic rock, graphite schist, siliceous carbonate rock.	North Rabathan area.
Totals				2119.18	74.7		

TABLE 3, CORE RECOVERY IN ORE ZONES

Hole No.	Ore interval in meters	Percent core recovery
Gehab # 3	12.2	88.7
Gehab # 4	3.1	100.0
Rabathan # 2	5.3	28.0
Rabathan # 3	4.3	100.0
Rabathan # 4	10.4	100.0
Sha'ab Eltare # 2	10.7*	29.9

* Submarginal material

Analysis of drill cores

A total of 593 drill core samples were analyzed during the study. All sample pulps were prepared by the laboratory of the Ministry of Petroleum and Mineral Resources in Jiddah, and most samples were analyzed by them. The pulps were prepared from split AX and BX size cores and the unused split was retained. A total of 191 sample pulps were analyzed by U. S. Geological Survey laboratories in the United States. Most pulps were from samples that were also analyzed in the Jiddah laboratory; the results are given in table 4. With few exceptions, all samples were analyzed for copper, lead, zinc, gold, and silver. Molybdenum was determined on a few of the samples. The analytical results indicate that some samples contain highly significant amounts of copper, zinc, gold, and silver, but none of the samples contain appreciable amounts of lead or molybdenum.

GEOLOGIC SETTING

The Wadi Bidah district (pl. 1) is part of an extensive orogen of Precambrian volcanic and sedimentary rocks, the limits of which are not well defined. An anticlinorium is the dominant regional structure, and its axis lies east of the district and strikes northerly so that the rocks in the district comprise part of the west limb.

The rocks consist of two series of volcanic rocks which are separated by a comparatively narrow succession of sedimentary rocks. Regional metamorphism has advanced to the upper greenschist facies.

TABLE 4.—*Analytical results of mineralized core samples analysed by laboratories in Saudi Arabia and the United States.*

Sample no.	Drill hole no. and sample interval, in meters	Assay results											
		Cu%			Zn%			Au oz/ton			Ag oz/ton		
		1	2	3	1	2	3	1	2	3	1	2	3
	G-3												
46055	G-3 160.5-162.6	0.2	0.21	—	3.0	2.8	—	0.001	0.017	—	0.19	0.114	—
46056	G-3 162.6-163.8	2.26	2.3	—	6.0	5.0	—	.002	.029	—	.17	.166	—
46057	G-3 163.8-164.9	5.0	5.0	—	2.5	1.6	—	.002	.034	—	.19	.2	—
46058	G-3 164.9-166.1	2.08	2.4	—	0.5	0.35	—	.004	.08	—	.35	.25	—
46059	G-3 166.1-168.0	2.0	2.1	—	.3	.07	—	.003	.068	—	.39	.25	—
46060	G-3 168.0-169.3	1.0	1.1	—	.15	.06	—	.04	.046	—	.21	.189	—
46061	G-3 169.3-171.0	0.8	0.57	—	.125	.044	—	.02	.049	—	.14	.08	—
46062	G-3 171.0-172.7	.5	.45	—	.1	.052	—	.02	.0086	—	.15	.114	—
	G-4												
46214	G-4 66.2- 67.7	.6	.94	—	.2	.003	—	.008	.0029	—	.1	.074	—
46215	G-4 67.7- 69.3	1.93	2.3	—	.015	.028	—	.008	.0029	—	.29	.274	—
	R-2												
46111	R-2 12.8- 14.0	4.00	2.8	—	.125	.008	—	.001	—	—	.05	.017	—
46112	R-2 14.0- 18.1	3.03	3.4	—	.075	.01	—	.001	.006	—	<.04	<.006	—
	R-3												
46093	R-3 79.9- 81.4	3.33	2.9	—	4.0	3.9	—	.04	.37	—	.68	.4	—
46094	R-3 81.4- 82.0	2.7	3.3	—	3.5	0.5	—	.004	.006	—	.19	.11	—
46095	R-3 82.0- 82.3	0.6	0.55	—	0.15	.077	—	.002	.0023	—	.08	.034	—
46096	R-3 82.3- 82.6	2.55	2.6	—	.20	.1	—	<.001	.006	—	.14	.029	—
46097	R-3 82.6- 83.4	0.02	0.026	—	.0125	.018	—	.002	.0011	—	.04	<.006	—
46098	R-3 83.4- 84.2	3.65	2.7	—	.8	.34	—	.006	.0086	—	.19	.97	—
	R-4												
46522	R-4 96.9- 97.4	0.75	0.32	—	.025	.006	—	.001	.0006	—	.074	<.006	—
40523	R-4 97.4- 97.8	6.1	6.3	—	.0875	.0032	—		.0029	—	.108	.029	—
46524	R-4 97.8- 98.8	5.0	5.0	—	.2	.0083	—		.006	—	.11	.4	—
46525	R-4 98.8- 99.5	3.5	3.4	—	.45	.0084	—	.004	.006	—	.094	.023	—
46526	R-4 99.5- 99.9	1.8	3.7	—	.05	.0074	—	.003	.0029	—	.055	.011	—
46527	R-4 99.9-100.4	3.2	3.5	—	.125	.0046	—	.002	.0029	—	.077	.011	—
46528	R-4 100.4-100.9	8.3	7.8	—	.15	.012	—		.006	—	.132	.051	—
46529	R-4 100.9-101.8	7.5	6.1	—	.15	.007	—		.006	—	.138	.06	—
46530	R-4 101.8-102.6	7.6	5.8	—	.2	.001	—	.004	.006	—	.125	.046	—
46531	R-4 102.6-103.3	2.5	2.0	—	.1	.007	—	.004	.0029	—	.083	.006	—
46532	R-4 103.3-104.2	4.9	4.8	—	.1	.013	—		.0029	—	.091	.023	—
46533	R-4 104.2-104.9	5.6	5.8	—	.125	.0064	—		.0086	—	.133	.4	—
46534	R-4 104.9-106.0	0.4	0.27	—	.03	.0084	—		.0086	—	.052	<.006	—
46535	R-4 106.0-107.3	.02	.29	—	.0025	.0076	—		.0011	—	.054	<.006	—
	S-2												
46297	S-2 62.3- 62.9	3.18	—	4.7	.3	—	0.071	.02	—	0.029	.09	—	0.1666
46298	S-2 62.9- 64.0	0.5	—	0.53	.2	—	.15	.001	—	.0029	<.04	—	.066
46299	S-2 64.0- 66.1	.7	—	.67	.075	—	.051	.001	—	.0029	<.04	—	.056
46300	S-2 70.1- 72.8	.5	—	.48	.16	—	.12	.005	—	.0057	<.04	—	.066
46301	S-2 72.8- 73.0	.7	—	.62	.126	—	.075	.035	—	.0029	.11	—	.114

1.—Ministry of Petroleum and Mineral Resources Laboratory, Jeddah, Saudi Arabia.
2.—U.S.G.S. Laboratories, Denver.
3.—U.S.G.S. Laboratories, Washington, D. C.

Au and Ag in oz per ton & Cu and Zn in weight percent

The extensively folded and faulted rocks strike northerly and dip steeply to the west and east. They are intruded by plutonic rocks, and are locally overlain by Tertiary basalt.

STRATIGRAPHY

The rocks of the Wadi Bidah district are mostly metamorphosed volcanic and sedimentary rocks of Precambrian age (table 5). The metamorphosed rocks are divided into three major units as follows: (1) older metavolcanic rocks, (2) metasedimentary rocks, and (3) younger metavolcanic rocks. Granitic and dioritic plutons and related dike rocks intruded the metamorphosed rocks, and Tertiary basalt flows cover large areas in the northeast part of the district.

Older metavolcanic rocks

The oldest rocks consist of a thick sequence of chloritic metavolcanic rocks of basaltic to andesitic composition and equivalent pyroclastic rocks. The lavas include amygdaloidal metabasalt that is otherwise lacking in volcanic structures or textures. The abundance of vesicules and lack of pillow structures suggest that the mafic volcanic rocks were deposited in a sub-aerial or shallow water environment. The mafic lavas are metamorphosed to the chlorite-epidote subfacies and are intruded by quartz-hornblende diorite. They crop out in the eastern part of the district, and a fault contact separates them from younger metasedimentary rocks to the west.

Table 5.—Stratigraphic column, Wadi Bidah district.

System	Rock units		Approximate thickness, in meters	Character & distribution
HOLOCENE	Unconsolidated sediments		0-25	Colluvial and fluvial; occurs locally throughout the district.
	unconformity			
TERTIARY	Volcanic rocks		0-40	Basaltic lava flows; flat lying, covers broad areas in northeast part of district.
	Angular unconformity			
PRE-CAMBRIAN?	Younger granite		?	Peralkaline granite and related dike rocks; small areas of exposure in north part of district.
	Diorite quartz-diorite		?	Quartz diorite; diorite border facies, related dike rocks, in central and southeast part of district.
PRE-CAMBRIAN	Older granite		?	Calc-alkalic granite; in southwest part of district.
	Younger volcanic rocks	Upper	2000-3000?	Greenstone and intercalated felsic and mafic metavolcanic and metapyroclastic rocks; exposed throughout western part of district.
		Middle	0-100	Metarhyolite and related quartz-sericite schist; host to sulfide mineralization, local chlorite schist, iron formation at lower contact locally in north and west parts of district.
		local unconformity		
		Lower	2000	Mafic metavolcanic and metapyroclastic rocks; includes pillowed amphibolite, marble marker bed near base, in north-central and west-central part of district.
	unconformity			
	Meta-sedimentary rocks	Upper	0-300	Quartzite and phyllitic quartz-chlorite sericite schist; in south-central part of district.
		Middle	0-700	Metapyroclastic rocks; iron formation, greenstone, in central and south-central part of district.
		Lower	0-600	Siliceous, limey, and dolomitic metasedimentary rocks; pyritic graphite schist, iron formation, lenticular sulfide masses, cherty tuff; in east-central and south part of district.
	Fault contact			
	Older volcanic rocks		2000	Mafic metavolcanic and metapyroclastic rocks; in east and southeast part of district.
	disconformity			
	Basement gneiss		?	Granite gneiss; comprises core of anticlinorium about 2 kilometers east of Wadi Bidah district.

 (PAGE 23 FOLLOWS)

Metasedimentary rocks

Metasedimentary rocks occupy the valley formed by Wadi Bidah in the central and southern parts of the district. They are mostly of pyroclastic origin, although some metasedimentary rocks are of non-volcanic origin. The metasedimentary rock unit is divided into lower, middle, and upper parts.

The lower part of the metasedimentary rock unit is highly sheared and contorted due to its close proximity to the East fault which separates the metasedimentary rocks from older metavolcanic rocks. Pyritic quartz-graphite schist, fine-grained siliceous tuff, and chlorite schist are the dominant rocks. Lenses of cherty tuff, iron formation, bedded siliceous carbonate rock, and massive sulfides are in the quartz-graphite schist and tuff.

Quartz-graphite schist is altered to limey quartz schist near the surface so that graphite is rarely discernible in outcrop. Cores from drill holes show a transition from limey quartz schist to quartz-graphite schist within the zone of oxidation, and the empirical data suggest that the alteration to limey quartz schist is due to a weathering process.

The rocks that form lenses in the schist and tuff are erratically distributed. The lenses are commonly asymmetric and highly variable in size. Siliceous carbonate rock forms the largest lens, and it has an average composition of silica magnesium limestone. It forms prominent outcrops that weather tan or buff.

Massive sulfide lenses in the lower rock unit are more abundant in the extreme southern part of the district and especially in the locality shown on plate 6. They rarely have a strike length exceeding 100 meters. The lenses are discernible by a hydrous ferric oxide outcrop and locally some siliceous material.

Lenses of iron formation are most abundant in the area shown in figure 7. They were not observed in the extreme southern part of the district where massive sulfide lenses are most common.

Lenses of cherty tuff were observed at several localities but are most abundant in the locality shown in figure 7. Individual lenses of cherty tuff are too small to be mapped at the present scale.

Foliated siliceous and chloritic pyroclastic rocks comprise most of the middle part of the metasedimentary rock unit. Some intermediate to acidic flow rocks are locally present, and narrow bands of iron formation are near the top of the middle part of the unit.

In the southern half of the district, the siliceous and chloritic pyroclastic rocks locally contain volcanic ejectamenta of lappili size and occasionally larger. Weakly foliated and highly chloritic greenstone is interstratified in the pyroclastic rocks in the central part of the district. One or two-meter wide bands of siliceous hematitic iron formation, near the top of the coarse textured pyroclastic rocks, decreases in abundance to the north.

The upper part of the metasedimentary rock unit consists of a poorly exposed phyllitic quartz-sericite-chlorite schist and quartzite. The phyllitic schist appears to be of uniform composition and texture. It is overlain by light-gray quartzite that forms prominent outcrops on the west side of the Wadi Bidah valley in the central and southern parts of the district. A large number of the ancient ruins are located on knolls and ridges of quartzite.

Younger metavolcanic rocks

The younger metavolcanic rocks overlie quartzite in the southern part of the district, but in the northern part of the district the lower contact is not exposed. They range in composition from mafic to acidic and because of repetition by folding and faulting they are exposed over a broad area that extends beyond the western boundary of the district. This rock unit can be divided into three parts.

The lower part of the unit consists of meta-andesite, chlorite schist, and amphibolite. A marble band 1 to 3 meters thick crops out fairly persistently from the north to the south-central part of the district. In the central and south-central parts of the district the marble appears to be concordant above the base of the meta-andesite. The origin of the marble is not known.

Amphibolite is exposed in the vicinity of the Gehab ancient mine and the adjacent area. It is medium to coarse grained and the amphibole is chloritized hornblende. At the Gehab ancient mine, the weakly vesicular amphibolite contains well developed pillow structures, chilled flow tops with columnar jointing, and volcanic detritus overlying flow tops. Amphibolite is exposed about 1 kilometer north of the Gehab mine. It appears to be mineralogically and texturally similar to that at the Gehab ancient mine, but lacks volcanic structures. It may be the hypabyssal equivalent to amphibolite derived from mafic extrusive rocks at the mine. Chilled flow tops and well developed pillow structures indicate that the volcanic rocks of the lower part of the younger metavolcanic rock unit were deposited in an aqueous environment. Siliceous iron formation is locally at the contact between the lower and middle parts of the younger metavolcanic rock unit.

The middle part of the younger metavolcanic rock unit consists of metarhyolite and narrow interbands of chlorite schist. Metarhyolite is in all of the ancient mine areas located in the younger metavolcanic rocks, but it is locally absent beyond the limits of those areas. The contact between the mafic and acidic volcanic rocks is always sharp, and iron formation is locally along the contact in the Gehab mine locality.

The metarhyolite is fine to medium grained and contains flow banding. In most places it is weakly sericitized, and it is completely altered to quartz-sericite schist in zones that have been intensely sheared. Some quartz phenocrysts are elongated in the direction of regional foliation or local shearing. The phenocrysts are the only discernible original feature of the rock where the metarhyolite has been altered to quartz-sericite schist.

Although pyrite is almost always present in minor amounts in the metarhyolite, it is locally concentrated in large amounts with associated economic sulfide minerals. Rarely sulfide minerals constitute about 95 percent of the rock and form massive sulfide bodies. The large concentrations of sulfide minerals are in localities where the metarhyolite is tightly folded or faulted, commonly sites of ancient mining activity.

The upper part of the younger metavolcanic rock unit consists of greenstone and intercalated heterogeneous lavas. The more mafic intercalations are similar in appearance to meta-andesite of the lower part and the acidic intercalations resemble metarhyolite of the middle part. The contact between the upper and middle parts is sharp at some localities, but gradational and obscure at others. Poorly developed pillow structures were observed in the basic lavas. Pyroclastic rocks of composition equivalent to the flow rocks are probably in the upper part of the younger metavolcanic rock unit.

Intrusive rocks

The intrusive rocks of the district are calc-alkalic granite, diorite, peralkaline granite, and related dike rocks. A few quartz veins and dolerite dikes are present, but show no apparent relationship to the intrusive masses.

The oldest intrusive is a gray to pink, medium-grained granite that contains abundant blue-gray quartz and strongly resembles the calc-alkalic granite identified by Brown and others (1962) in the Southern Hijaz Quadrangle. They (1962) report that rubidium-strontium isotope ratios of calc-alkalic granite indicate an age of 700 to 750 million years. Calc-alkalic granite is in a north-south elongate exposure in the southwest part of the district. It is younger than regional metamorphism and older than the north-northwest striking faults. The contact between the granite and the intruded metamorphosed rocks is sharp.

Diorite intrudes the older metavolcanic and metasedimentary rock units. It is a hornblende diorite near the border facies and a quartz-hornblende diorite in the core. The top of the diorite intrusive crops out as a long tongue in the center of the Wadi Bidah valley in the central and southern parts of the district. In the central part the diorite is overlain by greenstone roof pendants. The core is exposed over broad areas east of the East fault. The diorite is chilled, bleached, and completely void of quartz along the contact near the upper margin of the pluton. The core is coarse grained and unaltered except for slight chloritization of hornblende and weak saussaritization of plagioclase. The age of the diorite is not known. It appears to be younger than the northwesterly striking fault system, and therefore younger than the calc-alkalic granite and older than the East fault.

Pink to gray pegmatitic granite is exposed in two small localities in the north part of the district. One locality is 1.7 kilometers west of the Gehab ancient mine, and the other is in the northwest corner of the district. The granite is similar in appearance to peralkaline granite described by Brown and others (1962) elsewhere in the Southern Hijaz quadrangle. They (1962) report that rubidium-strontium ratios indicate an age of about 535 million years for the granite. The relative ages of the diorite and the peralkaline granite are not clear in the Wadi Bidah district; however, Goldsmith (in press) observed that similar diorite is older than peralkaline granite in other parts of the Southern Hijaz quadrangle. In the northwest corner of the district, the granite contact is partly controlled by pre-existing faults that belong to a northeast striking fault system. In the vicinity of the Gehab ancient mine, these faults were intruded by felsic dikes that may be related to the peralkaline granite.

Locally there are dolerite dikes and quartz veins. The dikes form straight-line linear patterns, and are apparently unrelated to the plutonic rocks.

Tertiary and younger rocks

A series of flat-lying basaltic lava flows cover broad areas in the northeast part of the district. They are columnar jointed and attain an aggregate maximum thickness of about 12 meters. Where the flows are breached by erosion, the underlying rocks consist of steeply dipping metamorphic rocks. The flows are inferred to be of Tertiary age. Goldsmith (in press) noted basalt flows of probable Holocene age at other localities in the Southern Hijaz quadrangle. However, the extensive erosion of the flows in the Wadi Bidah district indicates that they are older than Holocene.

Partly compacted and stratified mudstone and mudstone conglomerate of recent age are in small isolated patches on the Wadi Bidah flood plain. The wadis of the district contain unconsolidated fluvial material.

STRUCTURE

Regional

The rocks of the Wadi Bidah district are in the west limb of an anticlinorium, the main regional structure. The gneissic granite core of the anticlinorium is 2 to 4 kilometers east of the district. The axis strikes northerly, parallel to regional foliation. Rocks forming the west limb are highly folded and faulted for an undetermined distance beyond the north, west, and south boundaries of the district.

Folds

There are numerous anticlines and synclines in the Wadi Bidah district. The folds are most evident in the younger metavolcanic rock unit in the western part where there is repetition of the strata. Tight folding is common, and the folds are locally overturned and isoclinal. Most fold axes plunge to the south, some plunge both north and south. The foliation in the rocks is parallel to the northerly strike of the folds. Axial planes dip steeply to the east or west, some are vertical. The primary folds and related shearing appear to be the oldest structural features in the district. Their alignment with the regional foliation indicates that they are closely related to a compressive orogenic activity that resulted in regional metamorphism.

Locally broad open folds are associated with plutonic rocks in or near the district. They are associated also with the calc-alkalic granite intrusive in the southwest part of the district. Gentle arcuate folds in the north and west parts of the district are associated with peralkaline granite intrusives exposed outside the district.

Drag folds are superimposed on the primary folds and reflect the direction of movement of fault systems. These folds are most common in the incompetent schist near the East fault on the east side of the Wadi Bidah valley.

Faults

The rocks in the Wadi Bidah district are transected by four fault systems. The oldest faults are strike faults and shears associated with regional metamorphism. Chloritization and seritization alteration associated with these faults are evident in localities of tightly folded rocks, and near the geologic contacts of highly contrasting rock types. Displacement associated with this fault system is distributed over broad areas, therefore the faults are not shown on the geologic maps. The evidence for the fault system is mostly near the porphyritic metarhyolite where it is converted to quartz-sericite schist as a result of shearing. Round quartz phenocrysts of the rhyolite are retained in the schist, but are commonly elongated with the long axis parallel to shearing and foliation.

The next oldest faults form prominent linear features and belong to a north to northwest striking fault system that has apparent left lateral displacement. The fault planes dip nearly vertical except for local variations, and the maximum apparent displacement is 750 meters. Brecciation, mylonitization, and sympathetic drag folding is locally extensive in the rocks at or near the fault zones.

A transverse fault system with an average strike of N. 40 E. transects the rocks in the north part of the district. These faults are most numerous near the Gehab ancient mine locality where they displace northwesterly striking faults. The fault planes are nearly vertical and show apparent vertical displacement. Maximum displacement along the faults is probably less than 100 meters. Faults of this system form a small graben a short distance east of the Gehab ancient mine locality. Felsic dikes, which are probably related to the peralkaline granite, commonly occupy pre-existing fractures related to this fault system. The north and south contacts of a small peralkaline granite mass, in the extreme northwest part of the district, are controlled by faults of this system.

The north striking East fault, along the east side of the Wadi Bidah valley in the south half of the district, is the youngest and most prominent fault in the district (pl. 1). It forms a southerly trending escarpment which increases in height toward the south. At the extreme south end of the district the escarpment is 330 meters high. The fault plane dips steeply east to vertical. Metasedimentary rocks west of the fault are intensely sheared and drag folded for about 300 meters west of the fault plane. The drag folds indicate that the last movement along the fault was nearly horizontal in a left lateral sense. Earlier movement of the fault, as indicated by displacement of the diorite and by drag folds, was mostly vertical and of major proportion. The top of a diorite pluton is exposed west of the fault at an approximate elevation of 1350 meters, and the core of possibly the same pluton is exposed east of the fault at an elevation of 1584 meters. The diorite is a discordant body so cannot be used for determining minimum vertical displacement, but it does indicate the general magnitude of that displacement. North to north-northwest striking faults in the eastern part of plate 1 are probably related to the East fault.

A fault near the center of the Wadi Bidah valley in the southern part of the district strikes parallel to the East fault and may be related to it. Drag folding along this fault indicates a vertical movement. The fault was evidently formed during early movement along the East fault but was not affected by the later, left-lateral movement. It provides further evidence that there were two distinct periods of movement of the East fault.

In addition to the four fault systems described above, a low angle fault which may be a tilted thrust fault was observed in the vicinity of the Gehab ancient mine. Similar faults were not recognized in the other parts of the district. The low angle fault appears to be older than the northwesterly striking faults.

SULFIDE MINERALIZATION

Gossans

Numerous gossan outcrops in the Wadi Bidah district indicate the presence of sulfide deposits. The gossan material is massive to abundant disseminated limonite* and locally it has differing amounts of quartz and micaceous minerals. The gossans are in the middle part of the younger metavolcanic rocks and in the lower part of the metasedimentary rocks. The depth of oxidation ranges from 22 to 35 meters, which is determined by differences in the topographic configuration of the sulfide bodies and in the degree of shearing from one locality to another.

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* The term "limonite" as used in this report refers to hydrous iron oxides that have not been specifically identified.

Gossans derived from sulfide minerals in metarhyolite have contrasting colors of maroon, brown, tan, and yellow that commonly show a layering effect which results in a banded appearance. The minerals of the gossan have been tentatively identified in hand specimens as goethite, jarosite, red and black hematite, and a black manganese oxide mineral. Smithsonite and malachite are rarely present in minor amounts, and barite is in the gossan at one locality. Although malachite is rarely present in the gossans, a minor amount of transported malachite is commonly in the rock adjacent to the gossans. The gossans are dense and rarely contain well-defined boxwork. Their outcrops are elongate in the direction of strike of the surrounding rocks. The gossans in the middle part of the younger metavolcanic rocks are restricted to the metarhyolite rock unit, and they change abruptly to unmineralized rock at lithologic boundaries. Where highly mineralized rock is completely surrounded by metarhyolite, the gossan contact is commonly gradational.

Most gossans derived from the weathering of sulfide minerals of the lower part of the metasedimentary rocks do not have the bright, contrasting colors observed in gossans in the metarhyolite. The gossan from the sulfide minerals are brown, maroon and black with some yellow tints. However, in the vicinity of Rabathan drill hole R-4 the gossan is brightly varicolored. Goethite and hematite are probably the main constituents of the gossan, and differing amounts of fine-grained quartz and micaceous minerals are commonly in the gossan material. In many places transported malachite is in the rocks adjacent to the gossan. The shape of the gossans in the metasedimentary rocks is irregularly lenticular.

Stratigraphic position

Geologic mapping, diamond drilling, and the analysis of samples suggest that the sulfide bodies with significant amounts of economic sulfide minerals are restricted to two stratigraphic positions. These are, (1) the lower part of the metasedimentary rock unit, spatially related to pyritic graphite schist and siliceous pyroclastic rocks, and (2) metarhyolite of the middle part of the younger metavolcanic rocks. The pyrite with associated economic sulfides appear to be entirely restricted to the two stratigraphic positions.

Small amounts of disseminated pyrite are in a variety of rocks that have a wide range of stratigraphic positions. Graphite-quartz schist locally contains about 25 percent pyrite. It is interesting to note that samples from highly pyritic quartz-graphite schist, even those with a close spatial relationship to cupriferous massive sulfides, consistently contain less than 100 ppm copper and less than 25 ppm zinc.

Disseminated pyrite, which is apparently lacking in significant amounts of associated economic sulfide minerals, is abundant in metarhyolite near some massive cupriferous sulfide deposits. Sulfide exposures of this type are especially abundant in the vicinity of the Mulgatah ancient mine in the north part of the district, and at several other metarhyolite localities elsewhere in the district.

Intercalations of metarhyolite in the upper part of the younger metavolcanic rocks commonly contain disseminated pyrite. Although associated economic sulfides have not been observed in these rocks in the Wadi Bidah district, metarhyolite in this stratigraphic position may warrant close scrutiny in future regional mineral surveys.

Size and shape of the sulfide bodies

The interpretation of the size and shape of the sulfide bodies is based on the planar outline formed by gossan outcrops, rock foliation attitudes, and a minimal amount of diamond drill hole data.

Sulfide bodies associated with the lower part of the metasedimentary rocks tend to be irregularly lenticular. The lenses are near vertical and commonly range from a few meters to 100 meters along the long axis in planar view. Rarely, does the length of a lens exceed 200 meters. The width is generally between 2 to 20 meters; locally it may exceed 20 meters. The long axes in the planar view of each lens approximately parallels the strike of the surrounding rocks, and the lens asymmetry reflects local folding and shearing. The asymmetry makes it difficult to ascertain what part of the original lens is being viewed in outcrop, and poses a problem in attempting to estimate the shape and volume of a sulfide body underlying lenticular-shaped gossan outcrops. The problem has been only partly resolved by a minimal amount of diamond drilling. More drilling is required to provide adequate information on the sizes and shapes of the lenses and the volume of material their outcrops represent. A comparison of the position and size of lenticular gossan outcrops with detailed topographic data may be helpful as an exploration guide and in the determination of the physical characteristics of the sulfide lenses.

The sulfide deposits associated with metarhyolite are elongate, tabular, steeply dipping bodies that parallel the strike of the surrounding rocks and fold trends. They are as much as 500 meters long, but are not necessarily massive over that length. Concentrations of massive sulfides are as much as 8 meters thick and some of the them are included in an envelope of disseminated sulfides that generally contain sub-marginal base and precious metal values. The tabular sulfide bodies are locally displaced by faults and in some places show pinching and swelling.

<u>Structural controls</u>

Folding and faulting are important structural controls for localization of sulfide deposits in the Wadi Bidah district. Remobilization of the sulfide minerals is evident in both gross and minute detail. Apparently the sulfide minerals have not been remobilized beyond the stratigraphic boundaries in which they were deposited; they appear to have migrated laterally and have concentrated in dilatant zones caused by folding and faulting.

All sulfides that contain significant amounts of economic minerals are located near the crests or noses of tight folds or in highly faulted localities and these structural controls determine their configuration. At the Mulgatah and Gehab ancient mine localities folding has mostly controlled the present position and concentration of the sulfide minerals. The shape of the ore zones at the Gehab essentially corresponds to the shape of the major fold structure of that locality. Folding and faulting may be of equal importance as structural controls at the Mulhal ancient mine locality, whereas faulting is the important structural control at the Sha'ab Eltare.

Structural control by faulting is evident in the Rabathan ancient mine locality where lenses of sulfide bodies are near the East fault zone. Sulfide lenses are a more competent rock type than the surrounding soft, plastically deformed schists. The lenticular habit of the sulfide deposits is due to intense shearing of one or more tabular sulfide bodies that were relatively competent as compared to the surrounding rock. This conclusion is supported by the fact that all of the competent metasedimentary rocks in this locality have this same habit while the incompetent rocks do not.

Composition and texture

The sulfide mineralogy of the deposits appears to be simple. Pyrite is the main sulfide in all deposits and subordinate amounts of chalcopyrite are always present except in zones containing sparsely disseminated pyrite. Minor to moderate amounts of marmatitic sphalerite are commonly in the hanging wall part of a deposit. There are also trace amounts of a blue-black unidentified copper sulfide mineral. The principal non-metallic gangue mineral is quartz, locally with minor amounts of micaceous minerals. Sulfides associated with metarhyolite are mineralogically and texturally similar to sulfides associated with the metasedimentary rocks, except that the latter commonly has a higher chalcopyrite to pyrite ratio.

Seven polished sections were prepared from sulfide-bearing drill cores of all deposits that contain mineralization of economic grade. All sections show a dense, medium-to coarse-grained, cataclastic texture that is more or less typical of the Canadian massive sulfide ores. The pyrite is brecciated and commonly shows good separation. The breccia fragments are angular and matching fragments are close together. Chalcopyrite has undergone plastic deformation and occupies the groundmass and microscopic fractures in the pyrite. Marmatitic sphalerite is either closely associated with the chalcopyrite or it is alone in minute cavities. Pyrite boundaries are sharp and without indication of replacement by other sulfide minerals. The polished sections in places show thin banding due to layered differences in concentrations of gangue pyrite and chalcopyrite. Bands of this type are megascopically discernible in some drill cores and are as much as 1 cm wide. The massive specimens commonly contain about 95 percent sulfide minerals and 5 percent non-metallic gangue.

The cataclastic texture which resulted from mechanical breakdown of pyrite and plastic flow of the less competent sulfide minerals is interpreted to reflect sulfide remobilization (Lindgren, 1933). Paragenesis is obscured by remobilization, but the lack of replacement by other sulfides along the pyrite boundaries suggests the possibility of mutual crystallization.

The attitude of the sulfide bodies and the topographic configuration of the mineralized localities are not conducive to the formation of an extensive zone of supergene minerals. Copper and zinc that have been leached from sulfide minerals in the zone of oxidation have been precipitated as native copper, oxides, and carbonates over a fairly broad area in the footwall rocks near the base of oxidation. A microfilm of chalcocite over pyrite and chalcopyrite is in the sulfides transected by drilling a short distance below the base of oxidation. Chalcocite was also observed in microscopic fractures in pyrite near the base of oxidation.

Wall-rock alteration

The wall-rock alteration effects caused by emplacement of the sulfide bodies are obscured by regional metamorphism and to a lesser degree by later faulting. Where the wall rocks are comprised of siliceous volcanic rocks, they are commonly altered to quartz-sericite schist near the ore bodies; however, this same alteration of siliceous volcanic rocks was observed in many localities without significant amounts of sulfide minerals. Seritization and silicification appear to be more closely related to regional metamorphism than to sulfide mineralization.

The mafic volcanic rock adjacent to sulfide mineralization is the same as similar rocks elsewhere in the area. However, near the sulfide bodies they locally contain more euhedral pyrite. The pyrite in the wall rock is commonly unfractured.

AGE OF SULFIDE MINERALIZATION AND GENETIC CONSIDERATIONS

The age of sulfide mineralization in the younger metavolcanic rocks, relative to geologic events in the Wadi Bidah district, can be reasonably established on the basis of structural relationships and sulfide textures. The oldest recognizable structural features are folds and faults associated with regional metamorphism. Sulfide deposits in these folds show the same general configuration as the folds, and the highest concentrations of sulfide minerals are near the crests and noses of the folds. Thus the sulfides may have been emplaced prior to folding and were remobilized into dilatant zones during folding, or that the dilatant zones which resulted from folding and, to a lesser degree, from faulting were recepticals for ore solutions. However, textural characteristics of the sulfide deposits suggest that the sulfides were emplaced prior to these older structural features.

Sulfide textures are cataclastic in all deposits regardless of the structural feature with which they are associated. In some deposits, minor deformation by folding or faulting is younger than regional metamorphism. The cataclasis in these deposits is probably associated with compressive stresses related to regional metamorphism. The great similarity in the geologic setting and character of the sulfide deposits from one locality to another in the younger metavolcanic rocks suggests a common origin and an approximate equivalent age. It seems probable, therefore, that the emplacement of all the sulfide deposits in the younger metavolcanic rocks preceeded the regional metamorphic event.

The sulfide bodies in the lower part of the metasedimentary rock unit have been highly deformed by the youngest fault recognized in the district. Consequently, the age of these deposits cannot be established as being older than regional metamorphism on the basis of structural and textural features, even though the sulfide minerals in the metasedimentary rocks show about the same degree of cataclasis as those in the younger metavolcanic rocks. The present position and configurations of the sulfide bodies in the metasedimentary rocks are apparently the result of sulfide remobilization and displacements caused by stresses and movement along the East fault zone, however the genetic implications discused in the following paragraphs suggests that sulfide emplacement probably preceded the regional metamorphic event.

There is no apparent genetic or spacial relationship between sulfide mineralization and the plutonic rocks of the district. The plutonic rocks are younger than regional metamorphism, and granite gneiss exposed to the east of the district is far removed from all of the sulfide bodies. The Mulgatah and Gehab ancient mine areas are about 4.5 km and 1 km respectively from the nearest peralkaline granite outcrop, and both localities are many kilometers from exposures of calc-alkalic granite and diorite. The Sha'ab Eltare ancient mine locality is about 2 kilometers from diorite, 5 kilometers from calc-alkalic granite, and 8 kilometers peralkaline granite. The Mulhal ancient mine locality is about 3 kilometers from diorite, 2 kilometers from calc-alkalic granite, and many kilometers from peralkaline granite. The Rabathan ancient mine locality is about 2 kilometers from diorite and many kilometers from either calc-alkalic or peralkaline granite. There is no evidence indicating that the sulfide bodies show a close spatial relationship with any one of the plutonic rocks at depth, and it seems unlikely that three different types of plutonic rocks in the district caused almost identical type ore bodies. Heat and energy associated with the intrusive rocks could have contributed to remobilization of the sulfide bodies to their present positions, but no evidence was found to suggest this.

The mechanism by which the sulfide minerals were emplaced is speculative, but the close association of the sulfide deposits with volcanic and pyroclastic rocks suggests a genetic relationship to volcanism. The lower part of the metasedimentary rock unit is mostly graphite schist with interstratified siliceous tuff. These rocks are interpreted to have been deposited during the culminative phase of volcanism represented by the older metavolcanic rocks. Experimental data by Holland (1962) shows that at hydrogen pressures greater than 5-5.25 atm, CO and H_2 will react to form graphite and water. A slow shower of graphite may have been associated with volcanic gaseous emissions (Holland, 1962). Barth (1952) has also noted the formation of graphite by ascending hydrocarbons or carbonyl-bearing gases. It seems probable that graphite schist in the lower metasedimentary rock unit was deposited from quiet, fumarolic, gaseous emissions. The presence of interstratified siliceous tuff would indicated occasional explosive-type volcanism during the culminative phase. The nearly complete exclusion of chalcophile èlements in the graphite schist and their common occurrence in the tuff suggests that the chalcophile elements were introduced during the highly explosive phases.

Copper-bearing and zinc-bearing sulfide minerals in the younger metavolcanic rocks are almost entirely restricted to the siliceous volcanic rocks. These rocks may be, at least in part, derived from pyroclastic material. Extrusions of acidic composition are sudden, violent, and explosive as compared to the quiet effusion of basic lavas. The presence of bedded, magnesium-rich, siliceous carbonate rocks in the lower part of the metasedimentary rock unit, and of well-developed pillow structures in the lavas underlying the metarhyolite of the younger metavolcanic rocks are indications of a subaqueous environment in both of these geologic settings. Thus the sulfide deposits in both the metasedimentary and younger metavolcanic rock units are included with rocks which were formed under violent, subaqueous, volcanic conditions. It is therefore possible that the mechanism by which the sulfide minerals were emplaced is the same in both of these geologic settings. Oftedahl (1958) has suggested that, under submarine conditions, volcanic gaseous emissions can precipitate metals on the sea floor, or the metals will be dissolved in sea water giving birth to widespread sedimentary ores. In the Wadi Bidah district, the fumarolic vapors which resulted in the formation of graphite contained high concentrations of iron and sulfur, but very low concentrations of base metals. Apparently the base metal deposits were formed under more highly explosive conditions than that suggested by Oftedahl (1958). Fluids and volcanic ejectamenta as well as gases were probably released during the highly explosive emissions. Anderson (1969) has pointed out that recent discoveries of metal-bearing hot brine solutions in the Red Sea and Salton Sea have added importance to the role of alkali chloride solutions in sulfide ore gneisis. Most thermal waters associated with volcanism contain base metals only in the parts-per-billion range (White, 1967), but thermal alkali chloride solutions are an effective media of base metal transport (Anderson (1969). If metaliferous alkali chlorite solutions were emitted during highly explosive volcanism, the sudden release of pressure and the dilution of the solutions by sea water could have permitted direct precipitation of the metals on the sea floor, or the dense brine solutions could have been ponded by topographic depressions and displaced interstitial sea water in permeable pyritic tuffaceous rocks, resulting in the formation of massive sulfide base metal deposits. The hot brine solutions may have been of magmatic origin and collected their heavy metal content from early metal concentrations in the volcanic piles. The exclusion of base metals in the pyritic graphite schist could be due to the absence of hot brine solutions during graphite deposition and to the low permeability of the graphite. The evidence linking sulfide ore genesis with hot brine solutions is circumstantial, but this genetic theory seems to be compatible with the interpretation of geologic events in the district.

QUARTZ VEINS

Quartz veins crop out locally but are not abundant in the Wadi Bidah district. The veins consist of white, milky, massive quartz and, with rare exception, are barren of sulfide minerals. Some quartz veins are folded and reflect fold structures in the surrounding rocks; others cross-cut fold structures.

DESCRIPTION OF ANCIENT MINE LOCALITIES

Introduction

There are five known ancient mine localities in the Wadi Bidah district. The localities in geographic order from north to south are Mulgatah, Gehab, Sha'ab Eltare, Mulhal, and Rabathan. In addition to the ancient mines, several prospect pits with mineral showings and a few small rock quarries of ancient origin were located. The ancient mine localities are discussed in the above order. The Gehab and Rabathan localities are more extensively discussed than the others because of their potential economic interest.

Mulgatah ancient mine locality

Location and description

The Mulgatah ancient mine locality (pl.2) is in the vicinity of 2,296,000 N and 630,700 E. It is accessible via the drill access road which connects with the At Ta'if-Bishah road 4.5 kilometers south of Wadi Turabah.

The mine is on the east side of a small, steep-sloped valley and consists of a trench 165 meters long that parallels the valley. The trench is 3 to 5 meters wide and 2 to 3 meters deep, and is partly filled with slump and wash material. At least nine shafts or stopes extend downward from the bottom of the trench, but these are now filled with cave, slump and windblown sediment. A 3000 square meter area west of the trench is covered with mine dump material and an ancient townsite covers a 4000 square meter area in the valley below the mine. Apparently, a sizable community once inhabited this locality. Slag piles, which are partially covered with talus and windblown sediment, extend southward for several tens of meters from the south end of the townsite.

Geology

The rocks of the Mulgatah locality consist of greenstone, chlorite schist, quartz-chlorite schist, metarhyolite and related quartz-sericite schist of the younger metavolcanic rock unit (pl.2)..

Metarhyolite and related quartz-sericite schist are the oldest rocks and they are poorly exposed in the core of a tightly folded, doubly plunging anticline (pl.2). The axis of the anticline is in the approximate center of the valley and strikes northerly. To the north of the mine workings, the anticline is locally overturned to the east. The rocks on the east and west limbs of the anticline consist of greenstone and chlorite schist and locally siliceous volcanic rocks are intercalated in the greenstone near the contact. The rocks are highly sheared as a result of tight folding. They contain round to elongate quartz phenocrysts and differing amounts of limonite.

Sulfide mineralization and drill hole results

Sulfide mineralization in the Mulgatah locality consists of disseminated pyrite in siliceous metavolcanic rocks. Pods of massive sulfides with copper, zinc, lead and silver are along the contact between siliceous and mafic volcanic rocks. The pods appear to be highly localized; however, the ore zone is exposed in only a few places. Samples from the ancient workings contained from 1.2 to 4.5 percent copper, 1.0 to 2.5 percent zinc, 0.3 to 1.5 percent lead, and 0.57 to 6.58 ounces of silver per ton. Gold was not detected in any of the samples (table 1).

As a result of folding, metarhyolite is exposed over a large area about 0.5 kilometers west of the mine and is moderately to a highly limonitic after pyrite. However, no indications of economic sulfide minerals were observed.

One drill hole, M-1, tested the mineralized metarhyolite and undercut the mine workings. It was terminated in the mafic volcanic rocks east of the workings. The metarhyolite contained 15 to 30 percent pyrite throughout but did not contain associated economic sulfides. The host rock was highly sheared and the pyrite was medium-to coarse-grained and cataclastic. There is an abrupt change in the intensity of mineralization at the contact between the mafic and siliceous metavolcanic rocks; however, minor pyrite persists in the mafic volcanic rocks.

Fifteen core samples from drill hole M-1 were selected for chemical analysis of copper, zinc, gold and silver (table 4). Eleven samples from pyritic metarhyolite contain 20 to 250 ppm copper and

50 ppm or less zinc, except for two samples near the greenstone contact that have 3,000 and 12,000 ppm zinc. Three samples of greenstone contain 75 to 100 ppm copper and 50 to 150 ppm zinc. One sample from a fracture zone in the greenstone contain 6,000 ppm copper, 150 ppm zinc, and the only detectable amounts of gold and silver.

Conclusions

The results indicate that mineralization in the metarhyolite consist almost entirely of pyrite. Localized pods of massive cupriferous sulfides along the metarhyolite-greenstone contact appear too small and erratic to be of economic interest. However, in most places a covering of debris prevented close inspection of the ancient workings.

Gehab ancient mine locality

Location and description

The Gehab ancient mine locality (pl.3), in the vicinity of 2,228,000 N and 628,700 E, is accessible via a drill access road that join the At Ta'if-Bishah road 15.0 kilometers south of Wadi Turabah.

The Gehab ancient mine is in an area of moderate to rugged relief. The mine workings consist of five small trenches and stopes distributed over a 600 meter strike length on the east and west limbs of an anticline. The foundations of ancient dwellings and a small amount of slag were observed in the west-central part of the locality. All ancient mine workings are located in massive gossan material. Many of the surface samples collected during reconnaissance investigations were anomalous in gold (table 1). The ancients very likely worked the highly oxidized rock for gold. The stopes are partially caved and unsafe to enter, but it appears from the character and small volume of the dump material that the workings are not of sufficient depth to penetrate unoxidized rock.

Geology

The rocks of the Gehab locality consist of amphibolite, chlorite schist, iron formation, metarhyolite and related quartz-sericite schist, and greenstone of the younger metavolcanic rock unit. The metamorphic rocks are intruded by a light gray medium-grained felsic dike which forms a diagonal pattern across the central part of the area. The dike is locally fine grained, rhyolitic and highly kaolinized.

The rocks are folded into a tight anticline with an average plunge of 15 degrees south. In the northern part of the area the anticline is overturned to the west. It is transected and displaced by all of the faults that are younger than regional metamorphism.

At least four fault systems are in the Gehab locality. The oldest faults are strike shears related to the major fold structure and to regional metamorphism. The next oldest is a low angle fault which is in the southern part of the area. The fault plane is locally characterized by soft sericite schist with highly convoluted, fairly flat foliation. The hanging wall of the fault is displaced to the east. The fault plane is tilted and displaced by faults related to the northeasterly striking transverse faults that represent the youngest faults in the area. Small displacements of the transverse faults on steep slopes are caused by slump.

The oldest rock is medium- to coarse-grained dark green-gray amphibolite, and it is exposed in the core of the anticline in the central and northern parts of the area. The ampiibole mineral is chloritized hornblende that in places is converted to chlorite. The rock contains well developed pillow structures and chilled and weakly vesicular flow tops. Columnar jointing extends from 10 to 20 centimeters below the flow tops, and volcanic detritus lies on top of each flow. Amphibolite is overlain by siliceous-hematitic iron formation or by metarhyolite in the northern part of plate 3, and is overlain by highly chloritized meta-andesite greenstone in the southern part.

The iron formation, from 0 to 15 meters thick, is mostly in the northern part of the area. It is partly cherty quartz and jasparoidal, and has irregular bands of specularite and maghematite(?) that are 2 millimeters to 1 centimeter wide. The formation is overlain by metarhyolite and locally by massive sulfides.

The metarhyolite overlies greenstone in the southern part of the area, and it overlies iron formation or amphibolite in the central and northern parts. Typically, the rhyolite is light gray, weathers tan, and weakly foliated with some flow banding. It consists mostly of fine-grained to glassy quartz with some feldspar that is partly to completely sericitized. Mafic minerals commonly comprise less than 5 percent of the rock and are generally chloritized. Blue-gray quartz phenocrysts, 1 to 3 millimeters across, are round to elongate. Commonly, the rhyolite is highly sheared and completely altered to porphyritic quartz-sericite schist. Narrow bands of chlorite schist are locally intercalated in the rhyolite.

Gossan in the metarhyolite consists of maroon, brown, tan, and yellow iron hydroxides and iron sulfates(?). Some manganese oxide is in the southern part of the area. The gossan commonly contains interbands of sheared rhyolite with disseminated limonite.

The rhyolite contains pyrite in amounts ranging from less than 1 percent to high concentrations so that positive identification of the rock type is uncertain. When rhyolite consists of approximately 35 or more percent pyrite it commonly contains significant amounts of associated chalcopyrite and sometimes sphalerite. Massive sulfide bodies in the rhyolite always contain highly significant copper values and near the tops of the bodies they contain significant amounts of zinc. Sulfide mineralization associated with rhyolite has been previously discussed in detail.

The rhyolite is of varied thickness due to folding and depositional differences. In the southern part of the area, thick sections of rhyolite result from repetition due to faulting, but the true thickness is about 110 meters. The minimum true thickness is 4 meters in the northern part of the area. The sulfide bodies are mostly in the thicker parts of the rhyolite.

In the vicinity of the southernmost mine working, the rocks near a geologic contact between weakly mineralized rhyolite and massive sulfides are coarsely brecciated by a fault related to the northwesterly striking fault system. The angular breccia fragments, as much as 20 centimeters across, consist of rhyolite which has the same intensity of mineralization as rhyolite west of the fault. The matrix consists of limonite derived from massive sulfide and from nearby unbrecciated massive limonite.

Metarhyolite, and in some cases massive sulfide, is overlain by greenstone that represent the youngest metamorphic rock. The composition of these rocks ranges from basic andesite to dacite. The more basic parts locally contain poorly developed pillow structures. An interbanded chlorite schist is in the greenstone locally. Pyroclastic rocks of equivalent composition to the flow rocks may also be included.

Sulfide mineralization and drill hole results

Sulfide mineralization was discussed in context with metarhyolite in the preceding paragraphs because of the close relationship of the sulfide deposits with metarhyolite. A previous section of the report presented detailed descriptions of the sulfide deposits.

Five drill holes tested for sulfide minerals in the Gehab ancient mine locality. Three of these holes were designed to undercut ancient mine workings in massive limonite in the central and northern parts of the area. The holes were located on the basis of high gold values obtained from samples of the old workings (table 1). None of these three holes penetrated massive sulfides or significant amounts of base or precious metals (table 2).

Two holes were drilled in the southern part of the area (pl. 3 and fig. 3). One hole was drilled on the east limb and one on the west limb of the anticline. Richly disseminated to massive cupriferous sulfide minerals are in both holes; one with significant values of zinc and precious metals. Diamond drill hole G-3, (pl.3 and fig.3) on the east limb, contain a 12.2 meter intersection of massive and richly disseminated sulfides representing a true width of 11.4 meters and averaging 1.54 percent copper, 1.18 percent zinc and approximately $2.00 per ton in gold and silver. By excluding the upper two meters of zinc rich material, the mineralized zone averages 1.71 percent copper, 0.85 percent zinc and approximately $2.00 per ton gold and silver over a true width of 9.6 meters.

Diamond drill hole G-4 (pl.3 and fig. 3) was drilled on the west limb of the anticline and encountered a wide zone of moderately to richly disseminated sulfides with narrow zones of massive sulfides. A 42.5 meter intersection with a true width of 32.5 meters has 0.45

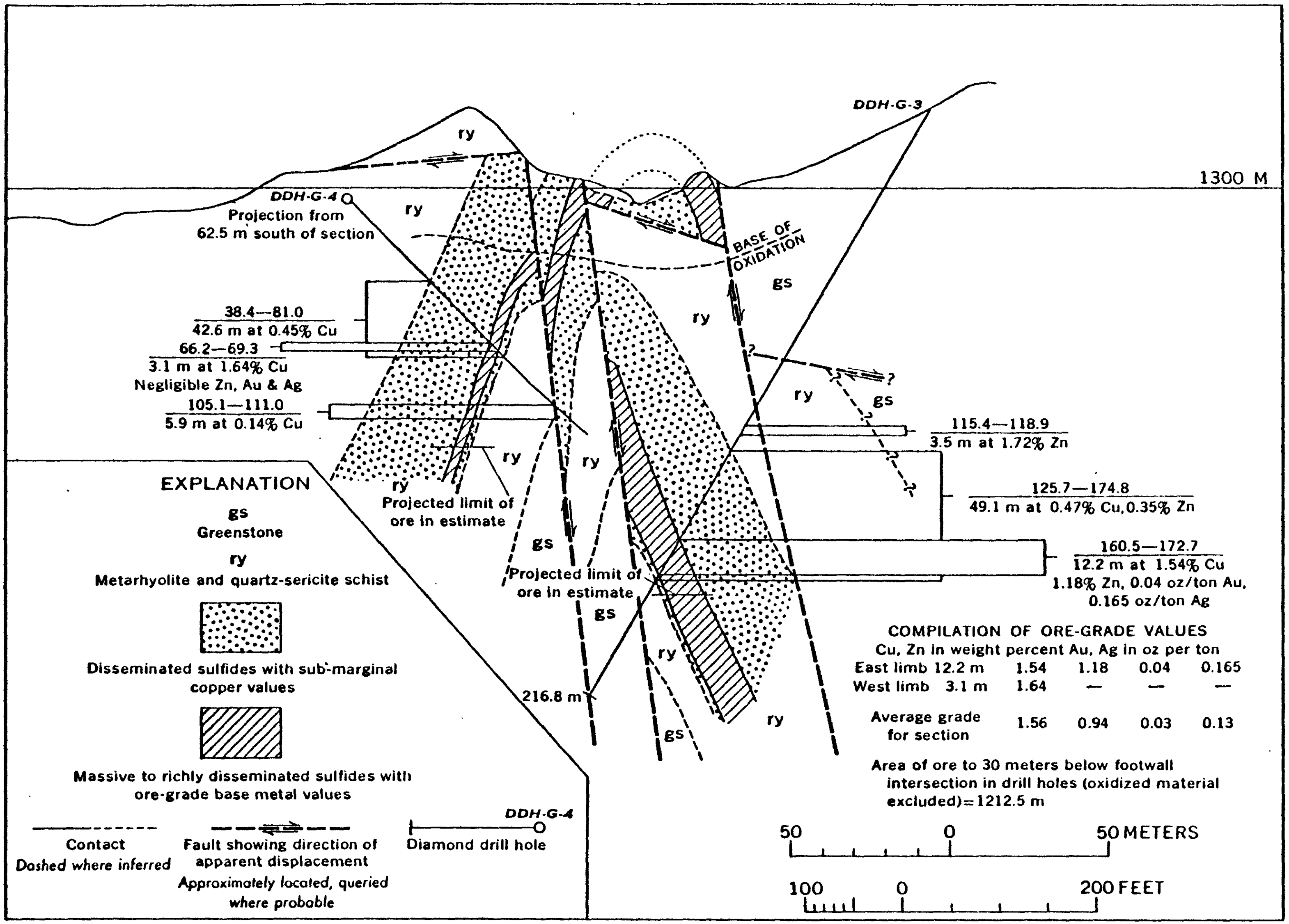


Figure 3.—Cross section of Gehab 3 drill hole showing strike projection of the upper part of drill hole 4, looking north.

percent copper with negligible amounts of other valuable metals. Included in this zone, a 3.1 meter intersection representing a true width of 2.7 meters averaged 1.64 percent copper with negligible amounts of other valuable metals. Perhaps the most significant aspect of this hole is that it demonstrates the possibility of an extensive mineralized body down dip beneath the rocks exposed on the west limb of the anticline in the southern part of the area. One hole is hardly sufficient for estimating the size and grade of this mineralized zone, and future investigators may consider testing the down dip and strike projections of the zone for higher concentrations of economic sulfide minerals. For reasons explained in the introduction of this report, only one hole was drilled in each of the east and west limb sulfide bodies.

Ore estimates based on diamond drilling and surface geology are discussed with indicated ore estimates of other localities in a subsequent section of this report.

Conclusions

Small bodies of richly disseminated to massive pyrite with associated chalcopyrite, sphalerite, gold, and silver are in the southern part of the Gehab ancient mine locality. The sulfide deposits are in metarhyolite that is tightly folded into a south plunging anticline. The lack of massive sulfides in the drill holes in the central and northern parts of the locality, and their presence in the drill holes in the southern part, indicates that the massive sulfide bodies, like the anticline, plunge south. Only a small part of the mineralized zone or zones has been tested by drilling. The nose of the anticline as formed by metarhyolite should be drilled to test for a down plunge extension of the sulfide bodies. In addition, a large tonnage of disseminated cupriferous sulfides may be present on the flanks of the anticline in the southern part of the locality, but the grade may be too low to constitute ore.

Sha'ab Eltare ancient mine locality

Location and description

The Sha'ab Eltare ancient mine locality (pl.4) is in the central part of the district in the vicinity of 2,278,400 N. and 628,000 E. It is about 1 kilometer west of the airstrip and is accessible via a drill access road or by foot from the airstrip.

Sha'ab Eltare is in an area of low relief, and the west side of the Wadi Bidah valley rises sharply to the west of the locality. Ancient mining activity is indicated by two small slag piles in the central part of the locality, but mining excavations have been obscured by cave, talus, and wind blown sediment.

Geology

The rocks of the locality are metarhyolite to porphyritic quartz sericite schist and intercalated chlorite schist. They comprise the middle part of the younger metavolcanic rock unit. The foliation strikes northerly to northeasterly and dips steeply to the east, locally changing to vertical or steep westerly dips. The foliated rocks are transected by a light gray fine-grained felsic dike, and by white massive quartz veins.

The metarhyolite is weakly sheared in most places, but locally, near many of the gossans, it is highly sheared to a rhyolite-quartz-sericite schist with disseminated limonite along the foliation. The feldspar in the rhyolite is partially to completely altered to sericite. Rounded quartz phenocrysts are also present.

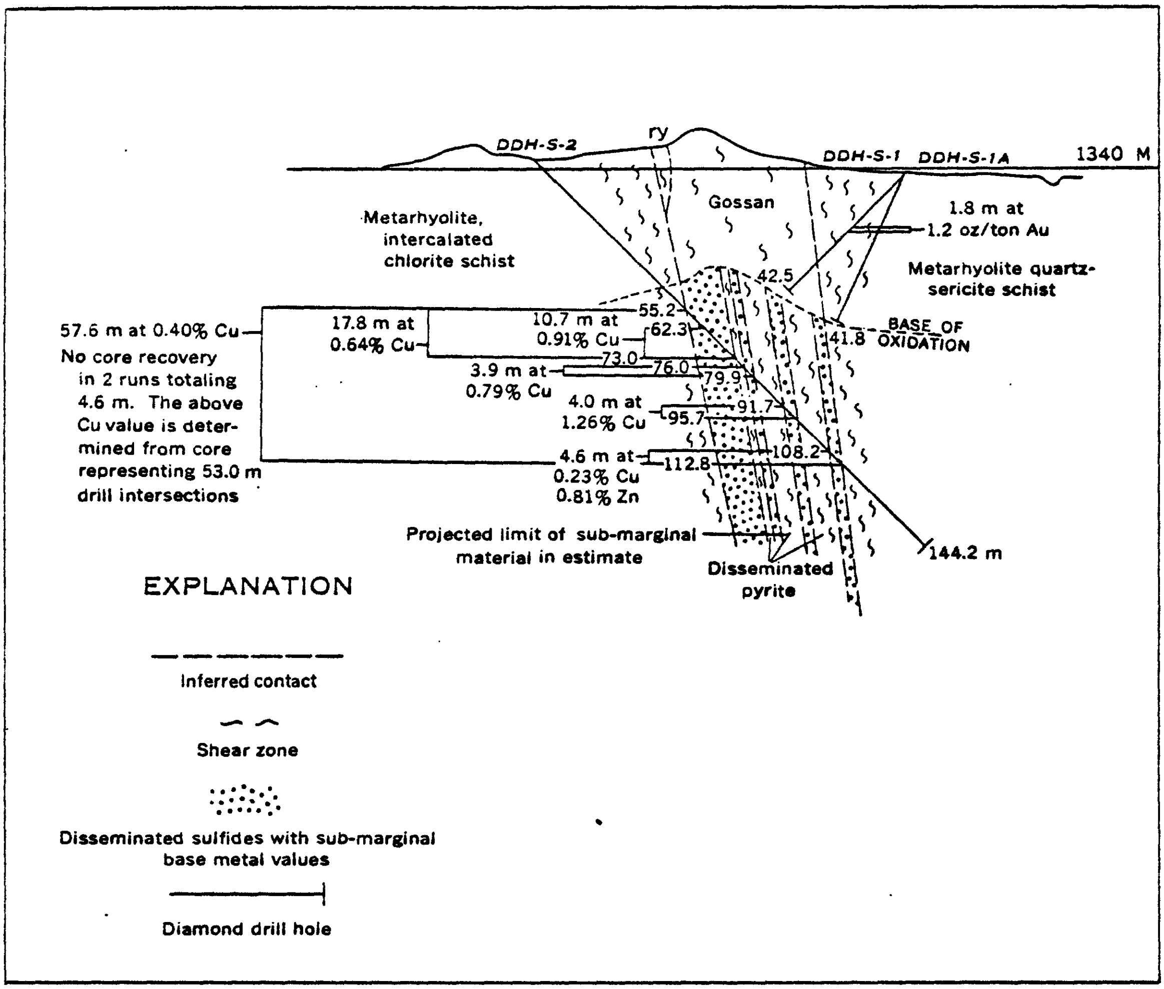
The gossan consists of varicolored iron hydroxides and sulfates(?) Some massive black hematite also is in the gossan in the southern part of the area. In places malachite is present.

The locality is near the confluence of two north to north-westerly striking faults that rransect highly sheared rocks, which are a result of strike faulting associated with regional metamorphism. As a consequence, the rocks of the area are convoluted and commonly brecciated or mylonitized.

Sulfide mineralization and drill hole results

Sulfide minerals are in massive to disseminated siliceous gossan material that is intermittently exposed over a strike length of 560 meters. The gossan strikes northerly, dips steeply east and tapers out on the ends. The width of the gossan varies from 0 to 34 meters, averaging 10 meters. The southern part of the gossan has been slightly displaced by transverse faults. A strike projection of the gossan between the central and northern parts is covered with overburden more than 180 meters thick. The results from a geochemical survey indicate that the mineralized zone may continue under at least part of the area concealed by overburden (G.H. Allcott, oral commun., 1969), and the results from a Turam (EM) survey indicate that the concealed rocks are the most highly anomalous part of a conductor which corresponds to the trend of the gossan (V.J. Flanigan, oral commun., 1969).

Disseminated to massive sulfides are in drill hole S-2 (fig.4) which undercut the gossan from the west (footwall) side after two unsuccessful attempts were made from the east (hanging wall) side. The latter two holes were abandoned before reaching the target zone because of extreme drilling difficulties due to brecciated, soft, gougy rock. The position, width, and attitude of the mineralized zone in drill hole S-2 corresponds well with the mineralized zone as indicated by surface measurements of the gossan; however, the drill hole results indicate that only a small part of the mineralized zone contains massive sulfides. The rest of the zone contains alternate layers of weakly to richly disseminated pyrite with minor associated economic sulfide minerals. Sulfide composition and texture are similar to that found at the other mineralized localities in the metarhyolite. Submarginal copper values were obtained from chalcopyrite-bearing massive and richly disseminated sulfides, and a



0 50 100 METERS

0 50 100 300 FEET

Figure 4.—Cross section of Sha'ab Eltare drill hole 2, looking north.

one-meter zone on the hanging wall has appreciable amounts of zinc in the form of marmatitic sphalerite. The mineralized intersection, from 55.2 to 112.8 meters, represents a true width of 32.0 meters. The intersection from 62.3 to 73.0 meters represents a true width of 6.8 meters with 0.91 percent copper, and is the highest grade found over a significant width. Gold and silver values are erratic in the mineralized zone. The highest value obtained was from a 1.5 meter intersection of massive sulfides beginning at 94.2 meters which contained $2.30 per ton in gold, $0.20 per ton silver, and 2.2 percent copper. The only other significant precious metal detected is from an inclined depth of 18.3 meters in the first hole. One meter of core representing a 1.8 meter intersection of gougy, fault zone material contain 1.2 ounces per ton gold. Trace to minor amounts of native copper, cuprite, and malachite are in the footwall rocks near the base of oxidation.

Core recovery in diamond drill hole S-2 (fig.4) averaged 58.4 percent, and over the critical zone from 34.1 to 95.7 meters it averaged only 29.9 percent including three drill runs from 1 to 2.5 meters from which core was not recovered. Consequently, the above analytical data may not be representative. Sludge samples were collected over part of the mineralized zone and a comparison of the sludge and core copper values with core recovery is presented in table 6. The equipment required to obtain accurate sludge samples was not available at the

TABLE 6. A COMPARISON OF SLUDGE SAMPLE COPPER VALUES WITH ANALYTICAL DATA FROM DRILL CORES AND CORE RECOVERY FROM DIAMOND DRILL HOLE 2, SHA'AB ELTARE.

Core sample No.	% Cu in Core	% Cu in sludge	% core recovery
46306	0.48	0.46	35
46307	0.27	0.60	53
46308	0.019	0.47	74
46309	0.046	0.46	10
46310	0.66	0.63	80
46311	0.017	0.74	48
46312	0.61	0.69	80
46313	2.20	0.75	100

time, so the data in table 6 is of dubious value. They are presented here to demonstrate that in some zones of very poor core recovery the copper values obtained from the analysis of drill core may not be representative of the interval drilled.

Conclusions

Sparse data indicates that the Sha'ab Eltare may not contain ore-grade material. The poor core recovery in diamond drill hole S-2 does not give a true representation of grade for that part of the sulfide body. Also the most highly conductive part of the EM anomaly, which is assumed to reflect the sulfide body, lies north of the drill hole. For these reasons, additional exploration in this locality may be warranted. The size and grade of mineralization based on existing data is included in the ore estimate section of this report and is presented as sub-marginal material.

Mulhal ancient mine locality

Location and description

The Mulhal ancient mine locality (pl.5) is located in the west-central part of the district in the vicinity of 2,272,700 N. and 627, 300 E. It lies near the top of a high hill west of the Wadi Bidah valley, and is the most inaccessible of the ancient mine localities in the district. The mine can be reached on foot by a vigorous climb from the valley floor or by helicopter.

Judging from the comparatively large amount of slag present, the Mulhal mine was one of the most active in the district. The workings consist of a pit about 18 meters across and 6 meters deep, a shallow excavation about 10 meters wide which follows a gossan zone for about 80 meters, and several small shafts and prospect pits. The ruins of ancient structures are in the locality.

Geology

The rocks of the Mulhal ancient mine locality are greenstone, chlorite schist, metarhyolite and related quartz-sericite schist, and quartz-barite veins (pl.5). All rocks, except the veins, probably represent the middle and upper parts of the younger metavolcanic rock unit. The gossan on the metarhyolite is varicolored and contain iron hydroxides and sulfates(?). Locally it has minor amounts of malachite, barite, and a siliceous material. The rocks are folded into a shallow double plunging syncline that forms the predominant structure of the locality. The syncline axis strikes northeasterly, parallel to the foliation in the rocks. The rocks dip moderately to steeply east and west. The syncline is terminated to the north by a prominent northerly striking fault. The fault transects and apparently terminates a mineralized shear zone which strikes parallel to rock foliation on the east limb of the syncline. The shear zone is also transected by transverse faults. Numerous small drag folds were associated with the faulting.

Sulfide mineralization

Sulfide minerals are indicated by massive and richly disseminated limonite in metarhyolite near the axis of a syncline. Sulfide minerals and related gossan are also in parts of a prominent shear zone on the east limb of the syncline. Although the gossan is poorly exposed, it can be traced intermittently for about 200 meters on the west limb of the syncline and for a short distance on the east limb in the northern part of the locality. The average width of the gossan is about 8 meters. It is brightly multi-colored and locally contains malachite. Barite is locally associated with gossan near the lower contact with quartz-sericite schist and it is also in the sulfide-bearing quartz-barite veins in the east limb shear zone.

Sulfide mineralization in the Mulhal locality was not tested by drilling: however, samples collected during the reconnaissance and mapping program are highly anomalous in amounts of gold and copper (table 1). The highest consistent gold values are from barite rich veins with disseminated, light colored pyrite or arsenopyrite in the round open pit excavation. The samples listed in table 1 are all select samples. Gold values range from .3 to 1.24 ounces per ton, and all samples contain highly anomalous amounts of silver, copper, and zinc.

Conclusions

The mineralized zone indicated by massive gossan at the Mulhal ancient mine locality was not tested by drilling, but surface observations and analytical data indicate that the gossan is from cupriferous and auriferous massive sulfides. The sulfide deposit is of very limited lateral extent however, and, if the structural interpretation is correct, it does not have a depth potential. Mineralization associated with the shear zone on the east limb of the syncline is erratic over a maximum strike length of 300 meters and it seems improbable that it has an appreciable amount of ore-grade material. The inaccessibility of the locality further detracts from its economic potential.

Rabathan ancient mine locality

Location and description

The Rabathan ancient mine locality (pl.6) is in the southern part of the Wadi Bidah district in the vicinity of 2,257,800 N. and 630.200 E. It lies in the eastern margin of the Wadi Bidah valley below the fault escarpment that forms the east side of the valley. The locality is about 3 kilometers long and 0.5 kilometers wide; it is accessible via a drill-access road which connects with the At Ta'if-Bishah road near the southern district boundary. The topographic relief is moderate, but the east side of the valley rises sharply to the east.

Ancient mining activity is indicated by a few small trenches and pits widely distributed from the north to the south ends of the locality. Small accumulations of slag are in the vicinity of the workings. The largest pile, about 100 cubic meters of slag, lies in the northern part of the locality and thus far removed from the mine workings. Ruins of ancient dwellings and fortresses appear to be of a later occupancy of the area, and therefore they are unrelated to the mining activity.

None of the ancient mining excavations are located in gossan, even though gossan zones are widely distributed throughout the locality. Instead, mining activity was restricted to narrow intensively sheared zones in tuffaceous rocks. The largest excavation is a trench 50 meters long and 3 meters wide, and it is shown at the north end of figure 6. The trench is now mostly filled with windblown sediment.

The rocks observed in the Rabàthan locality (fig. 5) extend north along strike to the central part of the district and a small unnamed ancient mine was located in similar rocks 13 kilometers to the north. Indications of sulfide minerals were noted in the rocks of the intervening area, but detailed investigations, including diamond drilling, failed to prove significant amounts of sulfide minerals (figs. 7 and 8). The area including the Rabathan ancient mine locality and the belt of rocks extending north to the unnamed ancient mine is referred to as the Rabathan area in the following discussion.

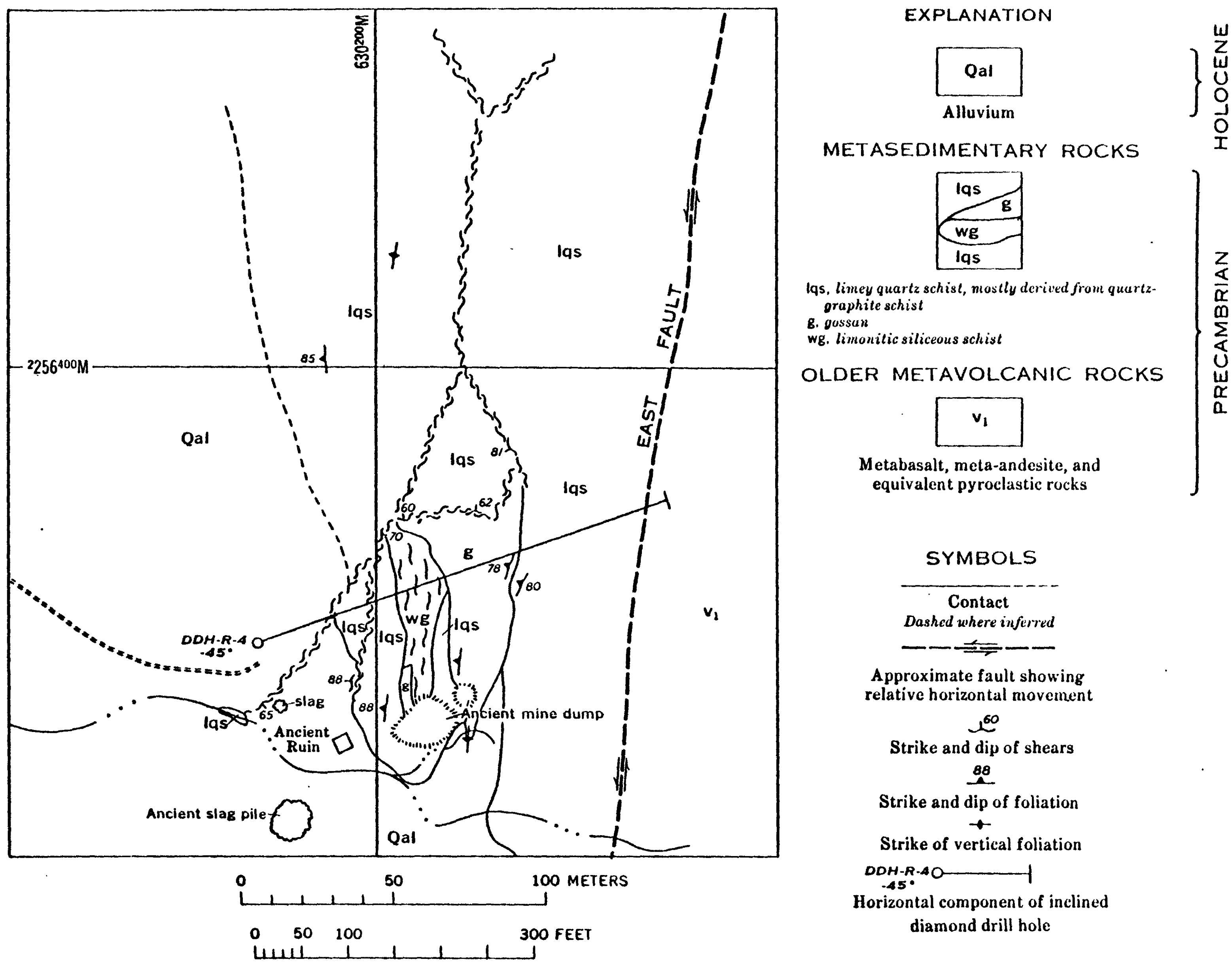


Figure 5.—Geologic map of the Rabathan drill hole 4 locality

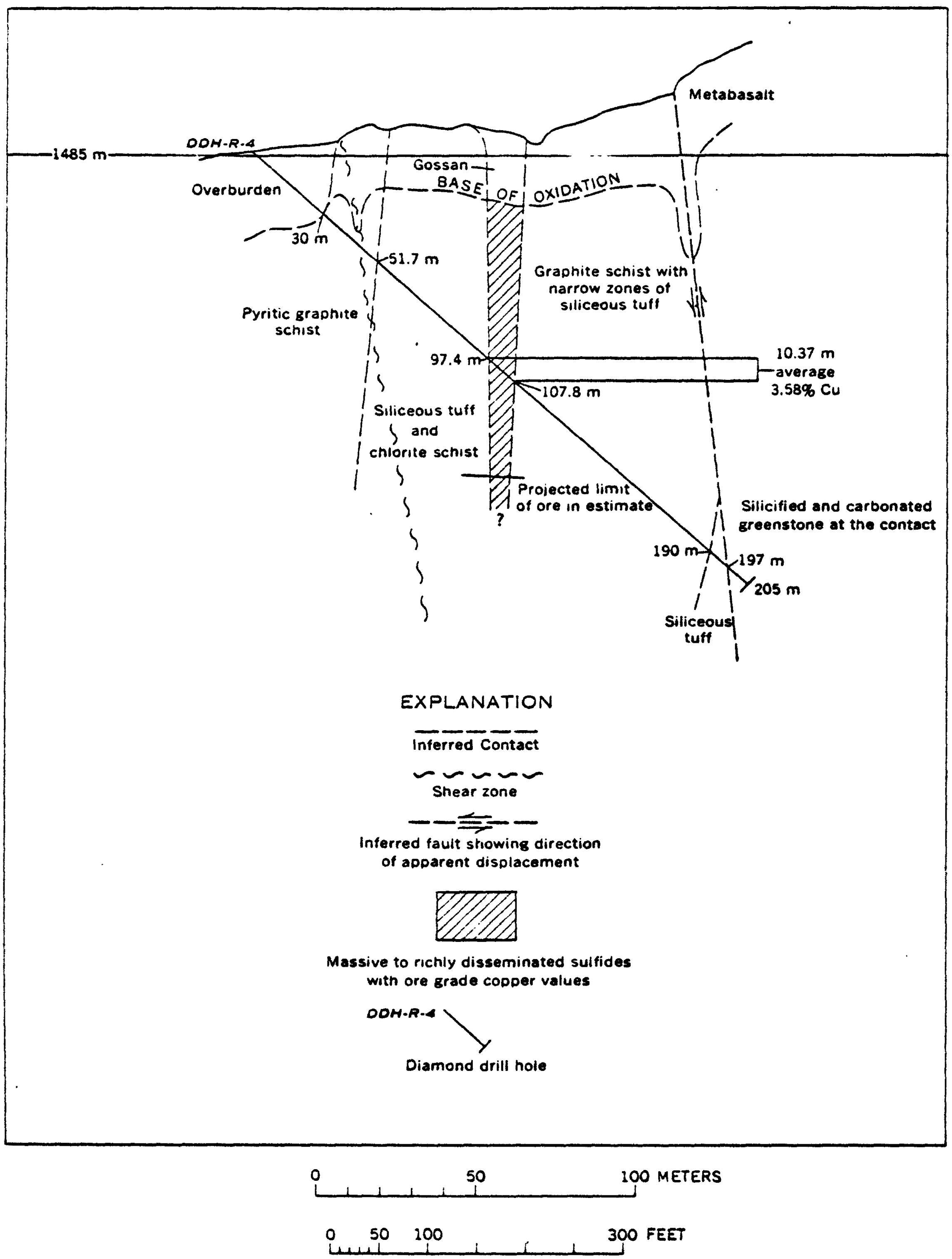
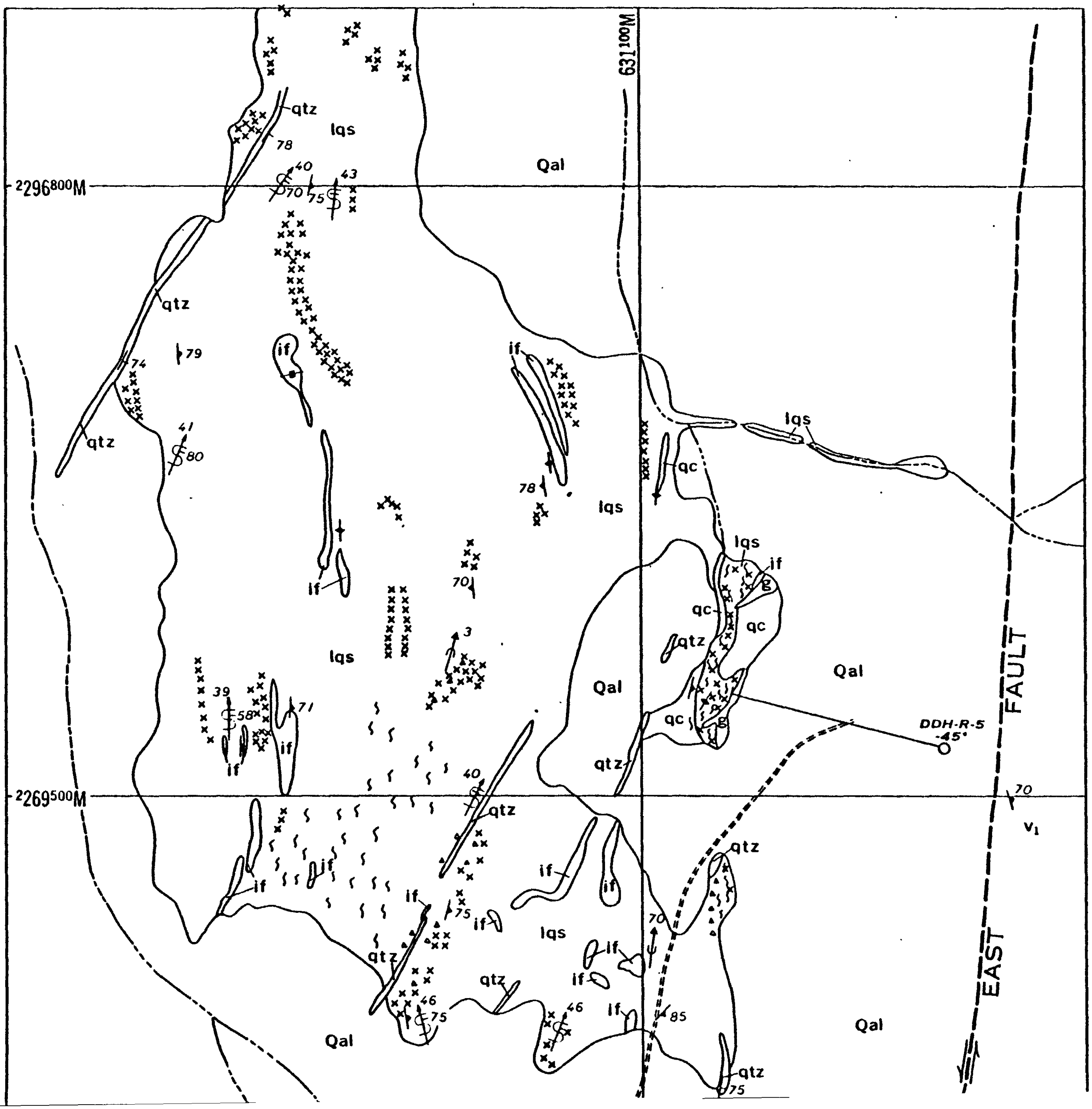


Figure 6.—Cross section of Rabathan drill hole 4, looking north.



EXPLANATION

Qal — Alluvium } HOLOCENE

qtz — Quartz vein } PRECAMBRIAN?

METASEDIMENTARY ROCKS

lqs, *limey quartz schist, partly from quartz-graphite schist*
if, *iron formation*
g, *gossan*
qc, *siliceous carbonate rock*

OLDER METAVOLCANIC ROCKS

v1 — Metabasalt, meta-andesite, and equivalent pyroclastic rocks

(Metasedimentary rocks and older metavolcanic rocks: PRECAMBRIAN)

SYMBOLS

Contact

Approximate fault showing relative horizontal movement

Limonite rich zone

Shear zone

Tectonic breccia

Minor anticline
Showing plunge and dip

Minor syncline

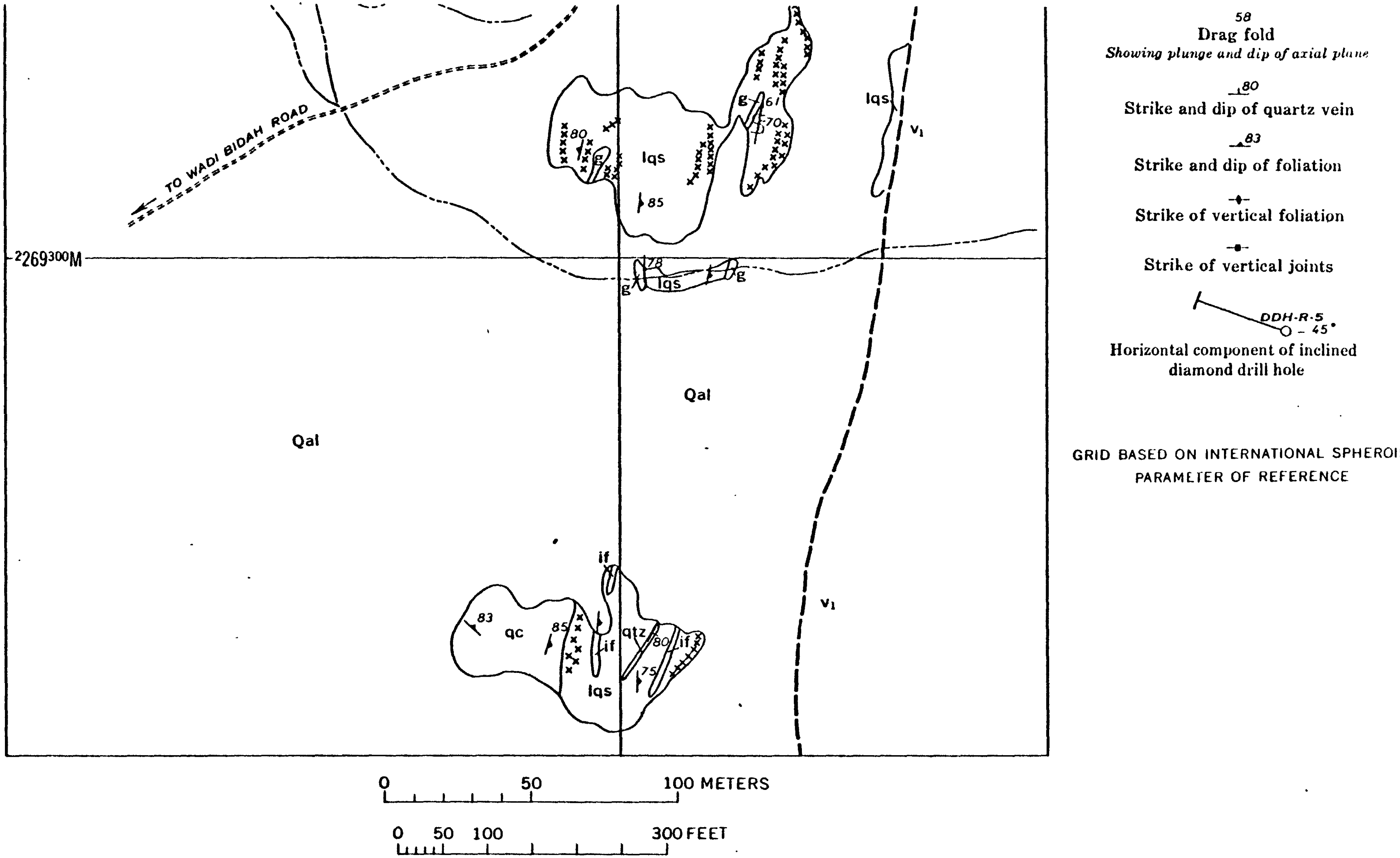
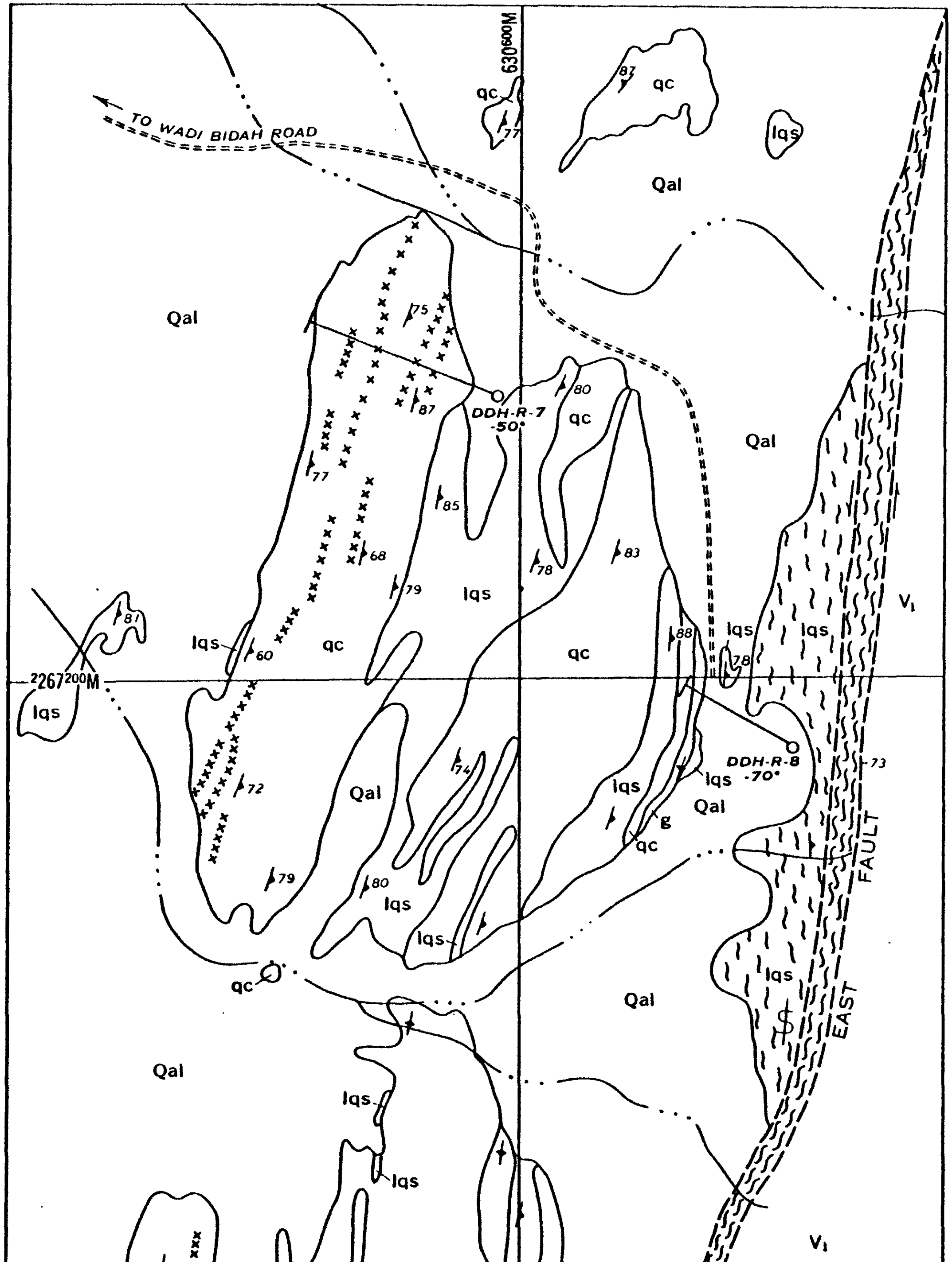


Figure 7.—Geologic map of the Rabathan drill hole 5 locality.

72a



EXPLANATION

Qal Alluvium } HOLOCENE

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if, lqs, g, qc

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OLDER METAVOLCANIC ROCKS

V1 Metabasalt, meta-andesite, and equivalent pyroclastic rocks

} PRECAMBRIAN

SYMBOLS

Contact
Dashed where inferred

73

Fault zone showing relative horizontal movement and dip of fault plane

Shears

Drag fold

× × × × ×
Limonite rich zone

79
Strike and dip of foliation

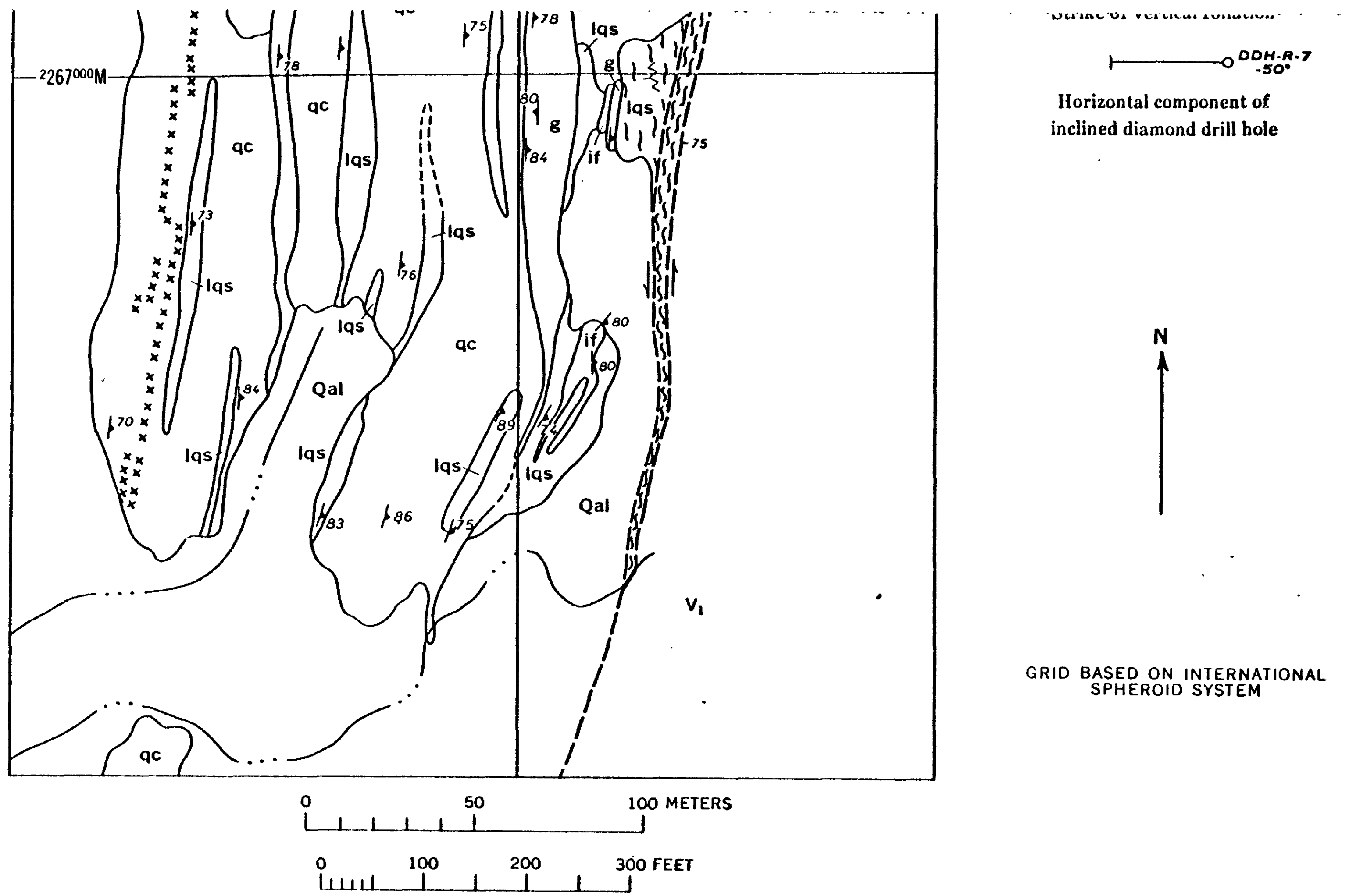

Figure 8.—Geologic map of Rabathan drill holes 7 and 8 locality.

Geology

The Rabathan area is underlain by intensely sheared and convoluted pyroclastic, fumarolic, and marine sedimentary rocks (pl.6). Some rock types in the area appear to be co-depositional and are interpreted to represent solfataric and explosive-type volcanic deposits in a marine sedimentary basin.

Except for local variations, the rocks strike northerly and dip vertical to steeply east and west. The rocks, in general, are overturned as indicated by the dominant easterly dips.

The main rock is graphite schist with highly variable amounts of granular, glassy quartz and euhedral pyrite. In places graphite is fairly pure over 1 to 3 meter wide intervals, except for minor amounts of pyrite. Quartz is commonly included however, and it is in segregated bands and lenses of highly variable width. Occasionally the quartz bands or lenses are several meters thick, but most are 2 to 5 millimeters in thickness. Pyrite makes up 5 to 10 percent and in places up to 25 percent of the rock. Minor amounts of calcite are locally in the quartz bands, and sometimes calcite is with quartz in stringers and veinlets. The schist has a high degree of intricate plastic deformation as a result of movement along the East fault. Outcrops of graphite schist are not easily recognized as they are highly weathered.

Chlorite schist with associated quartz, and in some cases associated graphite and calcite, is interbedded in the quartz-graphite schist and displays nearly the same degree of plastic deformation. Siliceous carbonate rock, iron formation, siliceous tuff, and massive sulfide bodies are the competent rocks that form structural lenses in the convoluted schistose rocks. The siliceous carbonate is medium-to coarse-grained, gray and weathers tan. It is locally limonitic. In places there are lenticular zones of gossan that consist of tan, maroon, and black goethite, hematite, and locally some pyrite boxwork. They are commonly banded and some bands have been convoluted by folding and faulting. In places the gossan is brecciated with a massive quartz matrix. Where tested the drill hole data indicate that the gossan was derived from cupriferous disseminated to massive sulfides. Siliceous tuff crops out in the western part of the area. It is fine-to medium-grained and green-gray to gray. The tuff is commonly schistose and includes lenses of siliceous limestone or limey tuff. Narrow gossan zones are along fractures. The unit is in gradational contact with a limey quartz schist. In the southwestern part of the area shear zones in the tuff locally contains quartz-sericite schist.

The schistose rocks are separated from older metavolcanic rocks to the east by the East fault and to the west they are overlain by foliated siliceous tuff. A true thickness of these rocks cannot be obtained as they have been intensely deformed. However the schists form an outcrop belt which is 200 to 600 meters wide along the west side of the East fault. The schists contain lenses of disseminated to massive gossan material, of medium-to coarse-grained silica-carbonate, and rarely carbonated fine-grained chloritic rock. Drill hole data indicate that much of the limey quartz schist consists of pyritic quartz-graphite schist at depth.

Barren white quartz veins are locally in the area. In the northern part of the area (fig. 7) a parallel set of prominent quartz veins occupy northeasterly striking fractures. Elsewhere, quartz veins are mostly parallel or sub-parallel to rock foliation and reflect deformation in the enclosing rocks.

Sulfide mineralization and drill hole results

Sulfide bodies in the form of structural lenses show a close spatial relationship to the quartz-graphite schist. A description of the physical characteristics and mineralogy of the lenses has been previously discussed. The position of the lenses appear to be the result of vertical to steeply southeast dipping shears which have an average strike of N 42 E. The shears are related to lateral movement on the East fault.

Eight diamond drill holes were drilled in the Rabathan ancient mine locality (pl.6, fig.5) and three were tested for sulfide mineralization in the area that extends 10 to 11.5 kilometers north of the center of the Rabathan ancient mine locality (figs.7 and 8).

Drilling in the northern part of the area was based on the presence of limonitic zones which appear similar to gossan in the locality shown in plate 6. The holes were also designed to test sparsely limonitic zones in siliceous schist and siliceous carbonate rock. Minor to moderate amounts of pyrite are present, but without appreciable amounts of economic sulfides or precious metals.

The five holes drilled in the mine locality were designed to test the intensely sheared zones with malachite and/or limonite at the surface, and the massive sulfide zones suggested by the lenticular-shaped gossans. Drill hole R-1 (pl.6) in the shear zone, beneath the largest mine working in the locality, did not show economic sulfide minerals. Drill hole R-2 (fig.9) is about 1.9 kilometers north of drill hole R-1 and it intersected material beneath a small lenticular-shaped gossan which is 32 meters long and 9.5 meters at the point of maximum width. Schistose rocks near the gossan contact contain transported malachite. A 5.3 meter intersection in the hole contained appreciable amounts of pyrite, limonite, chalcopyrite, malachite and chalcocite in partially oxidized and fractured siliceous rocks beginning at inclined depth of 12.8 meters. Copper averaged 3.1 percent over this interval. The mineralized zone intersected in the drill hole does not correlate with surface indications of sulfide mineralization. The hole was designed to transect the sulfide lens

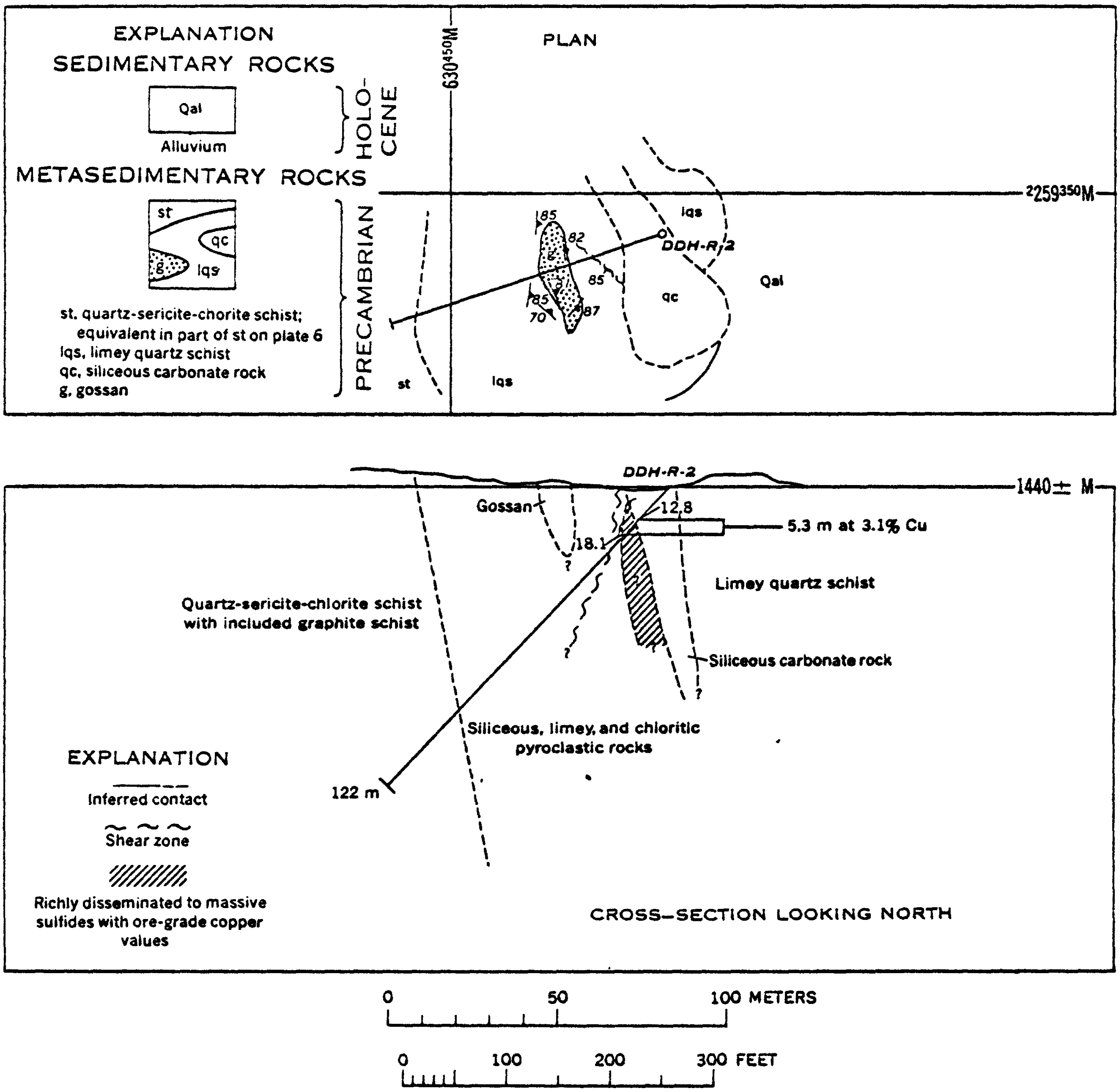

Figure 9.—Plan and cross section of the Rabathan drill hole 2.

at an inclined depth of about 40 meters, but did not find significant amounts of sulfide minerals below 15.2 meters. These data suggest that the lens indicated by gossan terminates at a vertical depth of less than 35 meters, and that the mineralized zone intersected at an inclined depth of 12.8 meters is from the border zone of buried sulfide body (probably another lens). It is equally possible that the mineralized zone in the drill hole is a faulted part of that represented by gossan at the surface. Data are insufficient to construct the configuration of the buried sulfide body.

Drill hole R-3 (fig.10) tested the southern part of a sulfide lens in the southern part of the locality shown on plate 6, about 0.7 kilometer south of drill hole R-1. It intersected a zone more than 4.3 meters thick of economic grade beginning at an inclined depth of 79.9 meters. The average grade over this distance was 2.20 percent copper, 1.51 percent zinc, 0.13 ounces of gold per ton and 0.17 ounces of silver per ton. The sulfide minerals consist of richly disseminated to massive pyrite with associated chalcopyrite and sphalerite. The sphalerite is mostly concentrated on the west side, or top, of the sulfide body. A configuration of the sulfide body represented by the mineralized zone can be estimated reasonably well by outcrop and drill hole data.

Drill hole R-4 (figs.5 and 6) was drilled in the southern part of the Rabathan ancient mine locality near the south district boundary

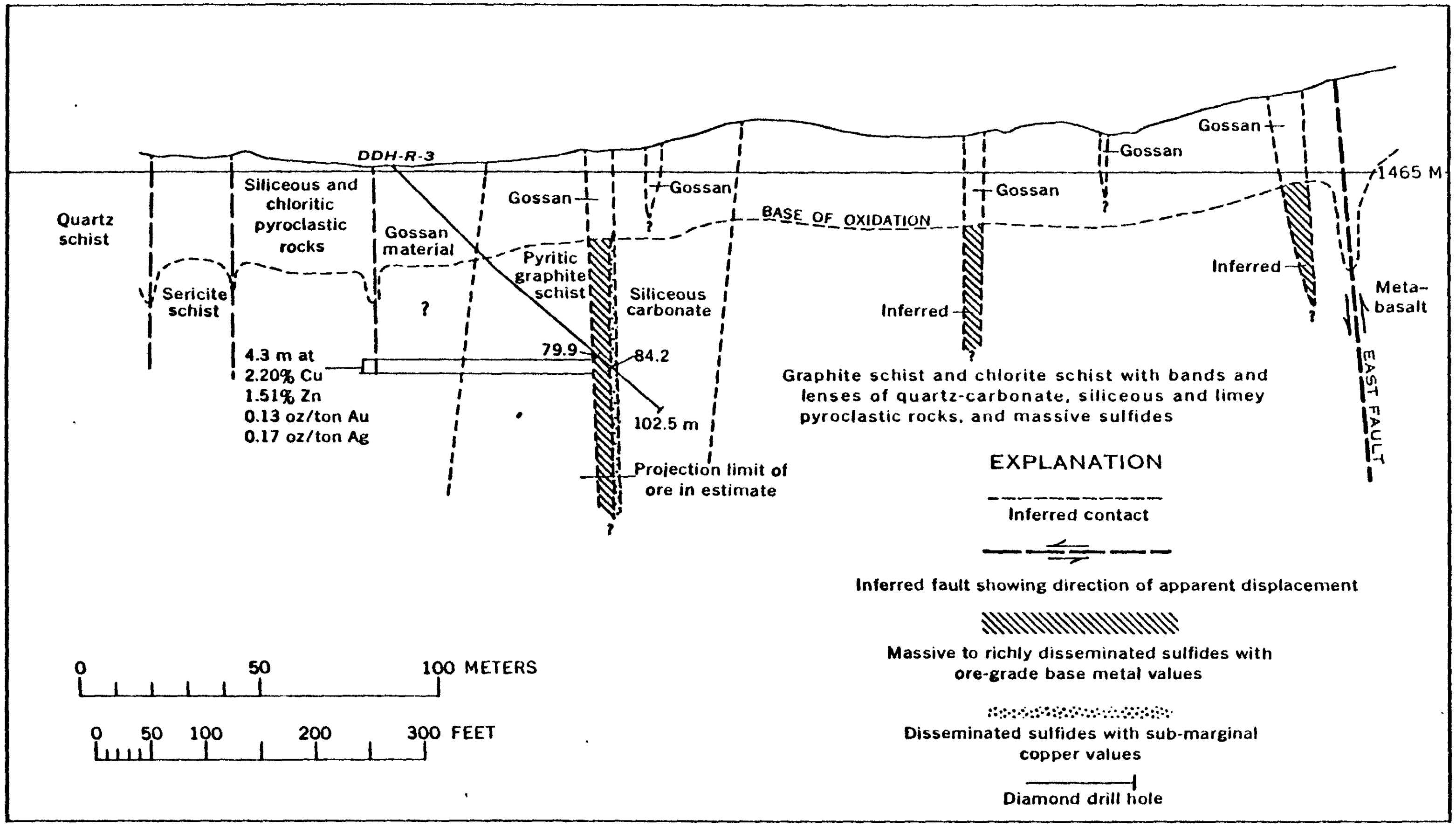

Figure 10.—Cross section of the Rabathan drill hole 3, looking north.

about 1.8 kilometers south of drill hole R-1. The hole was designed to determine the material beneath a gossan zone adjacent to a small ancient mine. Highly cupriferous massive sulfides in the footwall rock contain low but perhaps recoverable amounts of copper over a 2.9 meter interval below the massive sulfides. The massive sulfide zone averages 4.90 percent copper over an inclined width of 7.5 meters and 3.58 percent copper over 10.4 meters, which includes the disseminated sulfides. The analytical data indicate that copper is the only recoverable metal in the ore. Chalcopyrite is the main copper mineral, and an indigo-colored copper sulfide mineral which resembles covelite may compose less than one percent of the massive sulfides. The sulfide body correlates with mineralization at the surface, and a configuration of the ore body can be approximated on the basis of mapping and drill hole data. The grade and size of the ore body to a reasonable depth is included in the discussion on the ore estimates.

Drill holes R-5, 7, and 8 were drilled in the northern part of the Rabathan Area (figs.7 and 8), and did not find significant amounts of economic sulfide minerals.

Drill hole R-6 (pl.6) was designed to test the south part of a small sulfide lens near the intersection of a shear zone striking N 42 E and limonitic schistose rocks to the east and west of the lens. The hole is 0.75 kilometers south of drill hole R-1 and 200 meters east of drill hole R-3. Sulfide mineralization consist of pyrite that is mostly associated with graphite schist, without significant amounts of economic sulfide minerals. The sulfide lens as indicated by gossan outcrops is one of a cluster of sulfide lenses that are near the East fault in the central part of the Rabathan ancient mine locality. The results indicate that the drilled lens may terminate at a shallow depth, and that the shear zone and limonitic schistose rocks do not contain significant amounts of economic sulfide minerals. Another hypothesis is that the drill hole failed to intersect the lens because of faulting or other structural complications.

Conclusions and recommendations

The Rabathan may be the most important locality of the district in terms of economic potential. Small ore reserves are indicated in these parts of the locality drilled by holes 3 and 4, and the results from drill hole R-2 may indicate a sulfide body at shallow depth. The geologic map (pl.6) contain numerous sulfide lenses that have not been examined by drilling. The relatively high frequency of favorable drill hole results from sulfide lenses obtained during the investigations suggest the probability that some of the untested lenses may contain quantities of ore-grade material. Other buried sulfide bodies are very likely present at shallow depth.

The drill hole results indicate that the part of the Rabathan area north of drill hole R-2 does not contain economic mineralization. Therefore further exploration should be directed towards the location and development of sulfide bodies between drill holes R-2 and R-4.

Unfortunately, because of the preponderance of pyritic graphite schist in the locality, standard geophysical techniques would probably be ineffective in distinguishing buried sulfide masses. The best exploration approach may involve detailed diamond drilling of exposed lenses and comparing the resulting structural information with detailed vertical and horizontal topographic data. Such studies may indicate a spacial pattern which would be helpful in predicting the position and size of buried lenses. Future investigators should keep in mind that such patterns may be complicated or unpredictable because the sulfide bodies have very likely been subjected to three distinct periods of deformation associated with (1) compressive stresses related to regional metamorphism, (2) vertical movement on the East fault, and (3) horizontal movement on the East fault.

An alternate exploration approach is saturation-type diamond drilling on a grid net. The initial spacing of drill sections should be about 150 meters: a more closely spacial grid net may be desirable if the early results are favorable. The initial grid would require a minimum of 6000 meters of drilling to cover the favorable area.

If the high frequency of sulfide lenses indicated by gossan in the vicinity of drill holes R-3 and R-6 (pl.6) persist with depth, the over-all copper content of the lenses and the intervening material may be sufficient to permit mining by open pit methods. However, the analytical results from holes R-3 and R-6 indicate the uncertainty of a large tonnage of open pit ore.

Ore estimates

Introduction

Before ore* estimates for any given area can be discussed, it is necessary to determine the minimum tonnage and grade factors which will permit a profitable mining or milling enterprise. In making preliminary ore estimates, the economic geologist commonly relies upon mining precedent in the area, or in another area where conditions are similar, in order to approximately determine the minimum requirements by conducting extensive studies on development, mining, milling, transportation, and marketing costs. Such studies were not within the scope of the present investigations. Consequently, the term 'ore' cannot be used in the correct technical sense, and an assumed value for ore must be applied.

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* "In its technical sense an ore is a metalliferous mineral or an aggregate of metalliferous minerals, more or less mixed with gangue, and capable of being, from the standpoint of the miner, won at a profit; or from the standpoint of the metallurgist, treated at a profit." J. F. Kemp, Trans. Canadian Mining Institute, Vol. 12, p-367, 1909.

Deposits of possible ore-grade material in the Wadi Bidah district are small by world standards, and because of their configuration they are probably not amenable to low-cost, open pit mining. Disregarding problems related to mining and metallurgy, it is assumed that sulfide deposits in semi-remote areas which are exploitable by underground mining methods should contain a gross recoverable metal value of $15.00 (67.5 SR) a short ton or better in order to be extracted at a profit. This dollar value is highly arbitrary, and in fact varies greatly from place to place. The scale of mining, availability and cost of labor, and innumerable other factors determine the minimum dollar value which constitutes ore for any given area. Because of the location of the Wadi Bidah district, and because of the size and configuration of the ore bodies as determined by the present investigations, it seems reasonable to assume that rock with a gross recoverable metal value of less than $15.00 (67.5 SR.) per short ton, based on current metal prices,* cannot be profitably mined now nor can it be in the foreseeable future. The cut-off grades used in the ore estimates are based on this assumption.

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* Copper	2.00 SR.	($0.44)	per pound
Zinc	0.64 SR.	($0.14)	" "
Gold	157.50 SR.	($35.00)	per ounce
Silver	9.00 SR.	($2.00)	" "

Basis of estimates

Each of the sulfide bodies included in the ore estimate was explored by one drill hole, except for the Gehab ore body which was explored by two drill holes. The ore tenor encountered in a drill hole is assumed to be representative of the mineralized zone indicated by outcrops, except where surface geologic evidence indicates that such an assumption is unreasonable. In most cases, minimum planar limits of a mineralized zone can be established on the basis of geologic mapping.

In the Rabathan locality, the combination of the physical data from geologic mapping and diamond drilling permits the construction of simple geometric forms which are inferred to approximate the form of the ore bodies. Therefore, geometric formulas are used to determine volumes of ore in that locality. Because of the lenticular nature of the sulfide deposits in the Rabathan locality, application of this method results in a more conservative volume estimate than a method by which volume is determined by multiplying the area of ore on a section by the strike length of the mineralized zone as indicated by outcrops. The latter method is used in the volume estimate for ore at the Gehab locality since the sulfide deposit of that locality is a folded and faulted tabular body which cannot be easily adapted to a geometric formula. In this case it is assumed that the sectional area of ore on a cross-section of drill hole No.3 which contains a strike projection of the critical data from drill hole No.4, is representative of the mineralized zone over the strike length indicated by geologic mapping. The results from geologic mapping in the Gehab locality indicate that this assumption is reasonable.

For estimate purposes, the ore bodies are projected to a vertical depth of 30 meters below the footwall ore intersections in the drill except where geologic evidence indicates that this is unreasonable. The drill holes were designed to intersect mineralized zones at a much shallower depth than normal mining limits. As a result, the amount of ore included in the estimates is sharply limited, and it is probable that deeper drilling could add substantially to the ore reserve estimate.

The criterion used to determine ore estimates satisfies the minimum requirements for indicated ore* as agreed to by the U. S. Geological Survey and the U. S. Bureau of Mines in April 1943, thus the ore estimates are represented as indicated ore.

* "Indicated ore is ore for which tonnage and grade are computed partly from specific measurements, samples, or production data, and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely spaced or otherwise inappropriately spaced to outline the ore completely or to establish its grade throughout."

The analytical data used in grade calculations are included in table 4. All samples used in grade calculations were assayed by the U. S. Geological Survey laboratories in the United States and every tenth sample was analysed in triplicate for copper, lead, zinc, gold, and silver. All of the triplicated results checked within tolerable limits of accuracy. Therefore, the values from the U. S. Geological Survey laboratories are used in the determination of average grades.

The specific gravities used in the ore estimates are derived from the averaged results of tests on ten core samples of ore grade material taken from drill holes in the Gehab, Sha'ab Eltare, and Rabathan localities. Specific gravity (SG) was determined by the immersion method, and three tests were conducted on each sample. The SG values on six core samples of massive sulfides ranged from 4.25 to 5.10 and averaged 4.80. The SG values on four samples of disseminated sulfides ranged from 2.80 to 4.20 and averaged 3.60.

Notwithstanding the compactness of the ore, the averaged SG value for massive sulfides is somewhat high as compared to SG values of comparable ores in other parts of the world. In Canada, for example, the massive sulfide SG used in tonnage estimates ranges from 3.80 to 4.36 in the various localities where massive sulfides are mined, and values of 4.0 to 4.2 are most commonly applied*. These values are

* Data derived from Special Volume 9, Ore Reserve Estimation and Grade Control, Canadian Institute of Mining and Metallurgy, 1968.

used in measured ore estimates and are conservatively chosen so as to take into account unexpected gangue material in the ore. The estimates included in this report are indicated ore and possible dilution by unexpected gangue is not taken into consideration. The specific gravities used in the following ore estimates are determined proportionately from the amounts of disseminated and massive sulfides included in the ore zones as indicated by diamond drill hole data, and they are based on the averaged results from the ten core samples previously mentioned. It is recognized that the specific gravities are based on a small number of tests, and that the values are somewhat higher than those commonly applied in ore estimates of massive sulfide deposits.

Gehab ancient mine locality

Drill holes G-3 and G-4 (fig.3) in the Gehab locality intersected ore-grade material on the east and west limbs of a tightly folded and faulted anticline. The results from geologic mapping indicate that the ore zones may persist over a minimum strike length of 249 meters (pl.3). The ore zones are plotted on cross-section normal to strike (fig.3). Mineralized material above the base of oxidation is considered as oxidized waste. The sectional area of ore between the base of oxidation to 30 meters vertically below the footwall ore intersections in the drill holes is 1212.5 square meters. If this area is representative of the ore zone to a comparable depth over a 249 meter strike length, the volume of ore to a depth of 150 meters on the east limb of the anticline and 105 meters on the west limb of the anticline is: 1212.5 X 249 = 301,912.5 cubic meters. The ore zones consist of 65 and 35 percent massive and disseminated sulfides respectively. Therefore, the theoretical SG is 4.38. The indicated ore reserves are as follows: 301,912.5 X 4.38 = 1,322,377 metric tons or 1,457,656 short tons*. The average grade of the ore as indicated by the averaged analytical values of the drill cores is:

Copper - 1.56 percent

Zinc - 0.94 percent

Gold - 0.03 ounces per ton

Silver - 0.13 ounces per ton.

The recoverable metal value per ton of ore in the ground based on current metal prices is $17.78, and the gross value of indicated ore is $25,917,123.

Rabathan ancient mine locality

Two ore bodies are indicated by geologic mapping and diamond drilling in the Rabathan locality. The northernmost ore body was drilled by drill hole R-3 (pl.2, fig.10). The ore body is lenticular-shaped and its configuration approximates that of an elongate hemi-ellipsoid, the volume of which can be determined by the formula:

* 1 metric ton = 1.1023 short tons

$V = 2/3\pi abc$, where a is one half the strike length of the ore body, b is one half the width, and c is the depth. The strike length of the ore body at the surface is more than 216 meters* and less than 263 meters (fig.4). A 230 meter strike length is used for estimate purposes. The maximum width of gossan outcrop is 18 meters, and the depth of the ore body to an imaginary point 30 meters below the foot-wall intersection of the mineralized zone in the drill hole is 93 meters. The depth of oxidation as indicated by drill hole data is 25 meters and oxidized material is treated as waste. By substituting values in the formula, the volume of indicated ore is:

$$V = 2/3\ (3.1416)(115)(9)(93-25)$$
$$= 147{,}404 \text{ cubic meters}$$

The sulfide body consists of 60 and 40 percent massive and disseminated sulfides respectively, so that the theoretical SG is 4.32. Therefore, the indicated ore reserves are: 147,404 X 4.32 = 636,785 metric tons or = 701,928 short tons.

The average grade of the ore as indicated by the ore intersection in drill hole R-3 is:

Copper - 2.20 percent

Zinc - 1.51 percent

Gold - 0.13 ounces per ton

Silver - 0.17 ounces per ton

* The main gossan outcrop is about 100 meters strike length. Smaller gossan outcrops extend to about 50 meters north and 110 meters south of the main gossan outcrop. The area between gossan outcrop is alluvium containing gossan float material.

The recoverable metal value per ton of ore in the ground is $28.59 and the gross value of indicated ore is $20,068,122.

The southernmost ore body in the Rabathan locality was explored by drill hole R-4 (figs.5 and 6). The exposed part of the ore body is assymetric and is not easily adapted to a geometric formula. The results from geologic mapping and diamond drilling indicate that the average true width of the south part of the ore body is 9.2 meters over a strike length of 74 meters. This part of the ore body is projected to 30 meters below the footwall ore intersection in the drill hole to a depth of 110 meters. The uppermost 22 meters of the mineralized zone is inferred from drill hole data to consist of oxidized waste. The volume of the south part of the ore body is:

$$V = (9.2)(74)(110-22)$$

$$= 59{,}910 \text{ cubic meters.}$$

The north extension of the ore body is not exposed, but its presence is strongly suggested by geologic evidence. This part of the ore body plunges N.62° beneath unmineralized schist and is bounded on the east and west sides by shear zones which dip toward each other at steep angles. The shear zones coalesce at a point 44 meters north from where the mineralized zone plunges under barren schist, and their juncture probably terminates the ore body. If the dips of the shear zones as measured at the surface persist with depth, they would bottom the ore at 79 meters. The shape of the north extension of the ore body may approximate that of a reclining pyramid whose volume can be determined by the formula $V = \frac{h\ AB}{3}$ where h represents the horizontal distance at the surface from the line of section common to the south part of the ore body and the north extension to the apex formed by the junction of the shear zones, and AB represents the area of the base of the pyramid which in this case is the sectional area of ore on a cross-section common to the south part of the ore body and the north extension. The gossan is 42 meters wide along this section line and if the mineralized zone bottoms at 79 meters the area of the base is, $AB = \frac{42 \times 79}{2} = 1659$ square meters. The volume as determined by the pyramid formula is:

$$V = \frac{(44)(1659)}{3}$$
$$= 24,332 \text{ cubic meters.}$$

The south part of the north extension will contain oxidized waste. The shape of the oxidized waste will approximate that of a right triangular prism whose volume can be determined by the formula: $V = \frac{abl}{2}$ where a represents the horizontal distance along the oxidized zone from the base of the prism to its north termination, b represents the vertical distance from the surface to the bottom of the oxidized zone at the base of the prism, and l represents the length of the prism base which in this case is the width of gossan outcrop on the line of section common to the south part of the ore body and the north extension. If the depth of oxidation is 22 meters, and the north extension of ore body plunges N. 62° the value for a as determined graphically is 12 meters. The volume of oxidized waste is then determined as follows:

$$V= \frac{(12)(22)(42)}{2}$$

$$= 5,544 \text{ cubic meters.}$$

Therefore, the volume of ore in the north extension is:

24,332 - 5,544 = 18,788 cubic meters, and the volume of ore in the ore body to the indicated depth is:

59,919 ≠ 18,788 - 78,698 cubic meters.

The ore zone intersected in drill hole R-4 consists of 72 and 28 percent massive and disseminated sulfides respectively. Therefore, the theoretical SG is 4.46, and the indicated ore reserves are:

78,696 X 4.46 = 350,993 metric tons

or = 386,900 short tons.

The analytical results of core samples from drill hole R-4 show that the average grade for copper is 3.58 percent and that it is the only recoverable metal present in the ore. If this grade is representative of the entire ore body the recoverable metal value per ton of ore in the ground based on current metal prices is $31.50 and the gross value of indicated ore is $12,187,350.

Sha'ab Eltare locality

The analytical results of drill core from the Sha'ab Eltare locality indicate sub-marginal grade copper mineralization. These results may be sufficiently encouraging to warrant additional studies by future investigators. For this reason, a tonnage and grade estimate of the sub-marginal material is included.

Drill hole S-2 intersected a mineralized zone from 62.3 to 73.0 meters which contained 0.91 percent copper (fig.4). This intersection represents a true width of 6.8 meters, and is the only intersection of significant width that contains copper values approaching ore grade.

The sulfide zone as indicated by massive gossan is locally offset by transverse faults but crops out for a total strike length of 570 meters except for a 180 meter interval between the center and north end which is covered by overburden. Geochemical and geophysical survey results suggest that the overburden area may be underlain by copper mineralization which is at least equivalent in width and grade to that intersected in the drill hole. The narrow width of gossan over an approximate strike distance of 70 meters at the extreme north end precludes the possibility of a minable width of sulfide mineralization, so this part of the mineralized zone is excluded from the estimate. The mineralized zone is projected 30 meters vertically below the footwall intersection in the drill hole to a depth of 105 meters. Due to extensive shearing, oxidation extends down to 35 meters, and the oxidized part of the mineralized zone is considered as waste. If the width of the mineralized zone encountered in the drill hole is representative of the strike length indicated by geologic geochemical, and geophysical evidence, the volume of submarginal material to a depth of 105 meters is:

$$V = (570-70)(6.8)(105-35)$$

$$= 238{,}000 \text{ cubic meters.}$$

If the SG for disseminated sulfides is applied, the tonnage represented is: 238,000 X 3.6 = 856,800 metric tons

or = 944,450 short tons.

The gross value per ton of rock in the ground based on current metal prices is $8.01, and this value is considered to be uneconomical in the Wadi Bidah district.

Conclusions

A summary of indicated ore estimates and sub-marginal material is given in table 7. The actual ore potential may be many times greater than what the reserves indicate. This is particularly true of the Gehab and Rabathan ancient mine localities where target areas outlined by geologic mapping have not been tested by drilling. In view of this, the indicated ore estimates probably represent minimum values. It seems probable that substantially larger reserves could be developed by diamond drilling designed to test (1) the ore zones included in this estimate at greater depth, (2) strike extensions of the ore zones included in this estimate, and (3) additional targets outlined by geological, geochemical, and geophysical studies that were not tested

TABLE 7. SUMMARY OF INDICATED ORE ESTIMATES

ORE-GRADE MATERIAL

Locality	Millions of short tons	Recoverable metals	Average Grades	*Gross value per ton	*Gross value
Gehab	1.46	Cu, Zn, Au, Ag	1.56% cu 0.94% Zn 0.03 oz/ton Au 0.13 oz/ton Ag	$17.78	$25,917,123
Rabathan (R-3)	0.70	Cu, Zn, Au, Ag	2.20% cu 1.51% Zn 0.13 oz/ton Au 0.17 oz/ton Ag	$28.59	$20,068,122
Rabathan (R-4)	0.39	Cu	3.58% cu	$31.50	$12,187,350
District Totals	2.55			$22.85	$58,172,595

SUB-MARGINAL MATERIAL

Sha'ab Eltare	0.95	None	0.91 % cu	$8.01	

* Values are for ore in the ground based on metal prices of February 1969.

by diamond drilling during the present investigations.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Sulfide deposits in the Wadi Bidah district are found in two stratigraphic positions: (1) In the lower part of the metasedimentary rock unit, and (2) In the middle part of the younger metavolcanic rock unit. The sulfide bodies are interpreted to be volcanic strata-bound type deposits which were emplaced at or about the same time as the host rocks. All deposits show evidence of sulfide remobilization and reconcentration into dilatant zones associated with faulting and folding. Ore-grade copper, zinc, gold and silver mineralization has been found at the Gehab and Rabathan ancient mine localities. The indicated ore reserve estimate to shallow depth is 2.55 million short tons with an average value of $22.85 per ton. Sub-marginal copper values are indicated by analytical results of core samples from the Sha'ab Eltare ancient mine locality.

The most direct approach to developing larger ore reserves in the district would involve diamond drilling of the down dip and strike extensions of the ore bodies described in this report. The analytical results from the drill hole in the Sha'ab Eltare locality may not be a good representation of the sulfide body in that locality because core recovery was very poor. The copper values from this drill core are sufficiently encouraging to warrant further drilling and evaluating by future investigators.

Other sulfide bodies are probably present in the Rabathan ancient mine locality. Many of the lenticular-shaped gossans have not been tested by drilling. The results from drill hole R-2 demonstrates the possibility of locating sulfide lenses buried at shallow depth. Additional holes in the drill hole R-2 sulfide lens could result in an increase of the ore reserves. Methods of possibly locating other buried sulfide lenses in this locality have been presented in this report.

Extensive limonitic zones in metarhyolite were noted in several areas in the western part of the district. The chances of finding ore-grade mineralization, especially in the thicker parts of the metarhyolite, should be explored. Isopach mapping of the metarhyolite may aid the exploration for base metals in this rock unit.

The rock types noted in the district probably extend far beyond the district boundaries. If the genetic considerations discussed in this report are correct, there should be a reasonably good chance of locating sulfide deposits in outlying districts where the geology is similar. The logical approach to exploring this possibility is a continuation of district and regional mapping. The target areas resulting from mapping should be chosen on the basis of the geologic settings of sulfide deposits in the Wadi Bidah district, and should be mapped and sampled in detail. The targets should be diamond drilled if the preliminary results from detailed studies on the surface indicat a possibility of ore deposits.

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