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A GEOCHEMICAL EVALUATION OF THE ASH SHA'IB MINERAL PROSPECT

ASIR 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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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 mineralized zone at the remotely located Ash Sha'ib ancient mine contains only a small tonnage of moderately low grade sulfide-bearing rock. Based on present data the gross value of the deposit, with a value of $25.00 or more per ton, is $20,000,000.

A belt of metasedimentary rocks, intruded by gabbro to the south and granite to the north, was the host for fissure vein-replacement type mineralization. Most of the mineralization is in a siliceous dolomite transected by fissures. The main sulfide mineral is sphalerite, but minor amounts of chalcopyrite and argentiferous galena contribute to the value of the mineralized sections.

INTRODUCTION

Purpose and Scope

Geochemical studies of a number of ancient localities are being conducted by the U.S. Geological Survey program for the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia. The purpose of the studies is to indicate which localities are of potential economic interest and to provide geochemical, geophysical, and geological information that would be useful in evaluation of other sites. The base-metal deposit at the Ash Sha'ib ancient mine was selected for initial geochemical and geophysical studies. These data are essential for the location of subsequent diamond drill holes and for interpreting the geologic relationship between the surface and subsurface.

Previous investigations

The Ash Sha'ib ancient mine (fig.2) was located by Overstreet (1968/1969), who briefly described the gossan and host rocks. He (1969) recommended subsequent geophysical and geochemical studies for the mine area, which would determine sites for drilling. Geophysical investigations, including an EM dip angle survey, EM horizontal coil survey, natural potential survey, resistivity measurements and a magnetic study, were conducted by Davis and Kazzaz (1970). A helicopter airborne EM and magnetic survey was completed on the area by Sander Geophysics Limited in 1968. A Turam EM survey at the Ash Sha'ib site by Akrass and Kazzaz of the Ministry of Petroleum and Mineral Resources was completed in 1967, and during the same year a survey by Canadian Aero Mineral Survey Ltd. was made. Some of the results from these geophysical studies have been compiled on figure 3. The plane table survey of the mine area was by Kiilsgaard and Tompkins (1968), from which the geologic map (fig.2) was prepared.

Acknowledgements

Special acknowledgement is made to Ibne Mohammad Naqui for his assistance in the field and laboratory; to the staff of the U. S. Geological Survey laboratories in Jiddah, Saudi Arabia, under the direction of M.L. Gonshor, Chief Chemist, for analytical data; and

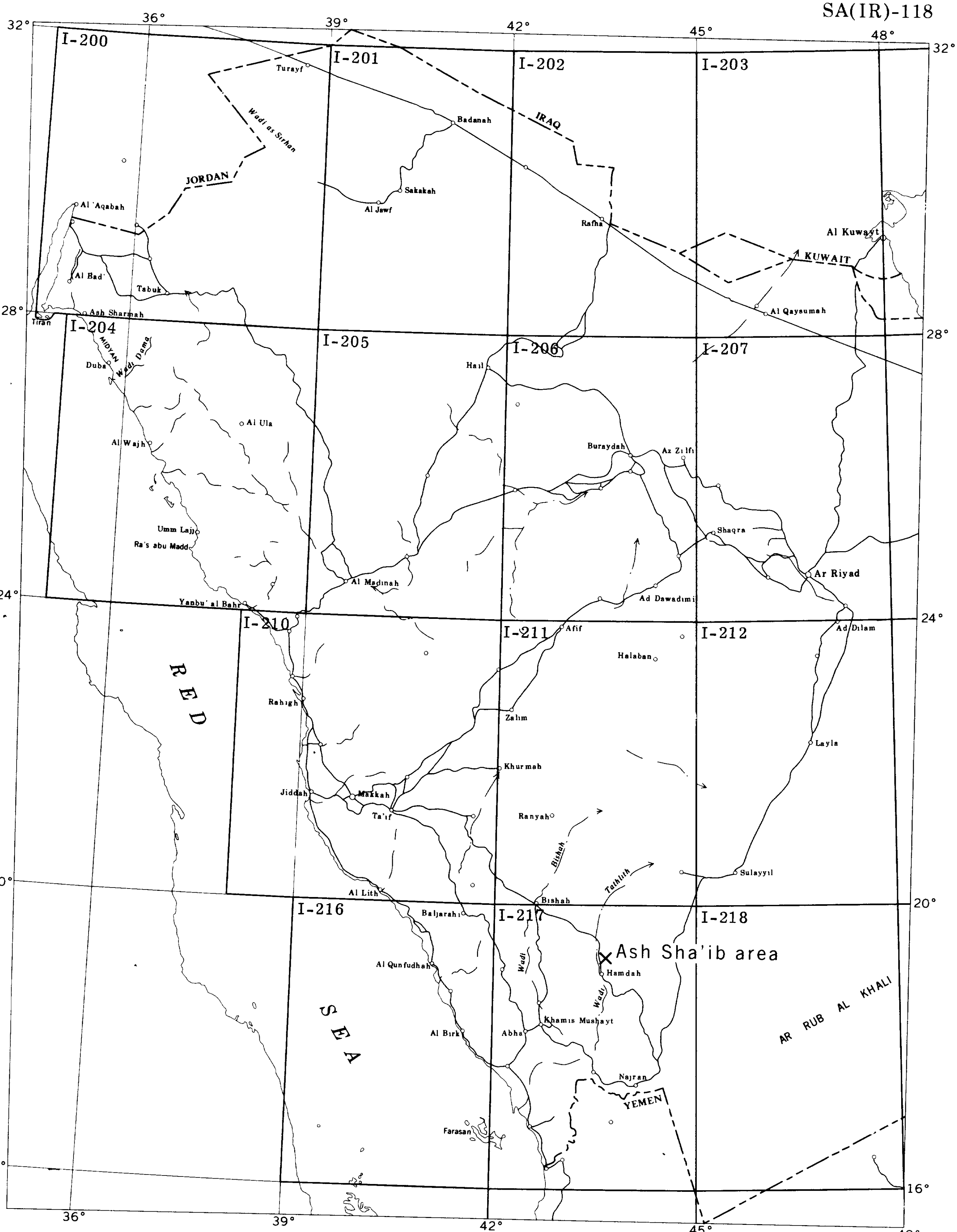

Figure 1.-Index map of the Arabian peninsula showing the location of the Ash Sha'ib area

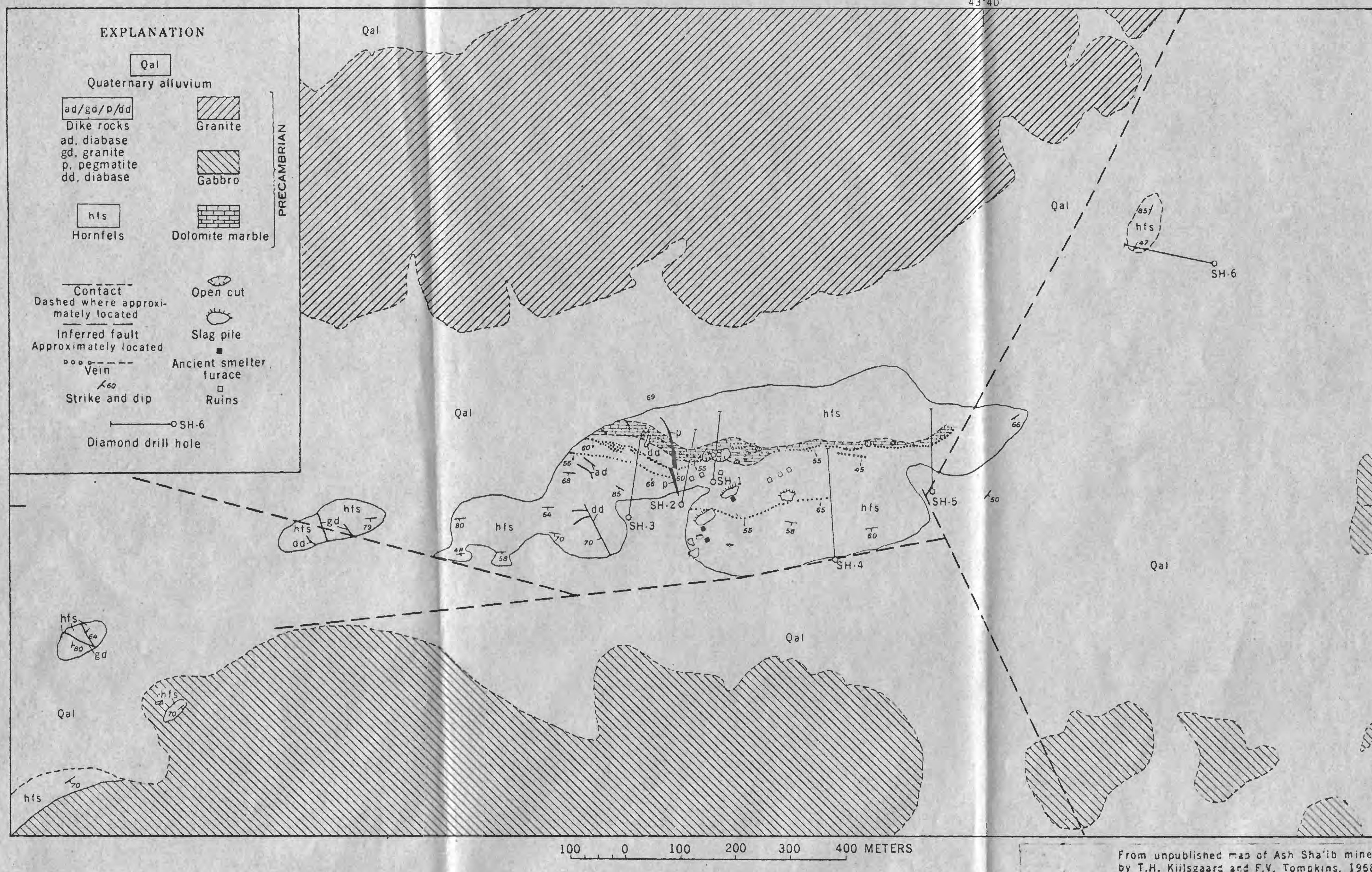

Figure 2.-Geologic map of the Ash Sha'ib area

to the staff of the chemical laboratory for the Ministry of Petroleum and Mineral Resources under the direction of Sayyid Matouq Bahijry, Director of the chemical laboratories, for fire assay data.

GEOGRAPHY

Location, accessibility, and culture

The Ash Sha'ib mine, located in the Asir at lat 19°15'N.; long 43°40'E., is 8 kilometers from the main road from Bishah to Najran. This road and the road from At Ta'if to Bishah, except for about 80 kilometers of macadam east of At Ta'if, range from sections of graded road to sections that are a series of tracks. Access to the mine from the main road is across a flat sandy plain. The village of Hamdah is 25 to 30 kilometers to the south on the Bishah-Najran road, whereas the village of Tathlith is about 45 kilometers north on that road. Normally it takes 3 days by vehicle to reach this remote area from Jiddah. During the rainy season long delays in travel result from flooded wadis, especially those between At Ta'if and Bishah and at Tathlith. A four-wheel drive vehicle is recommended to traverse the ungraded roads and trails.

Water is available from wells in either Hamdah or Tathlith, but the best water is at Tathlith.

Topography

The mine site is located along a tributary of Wadi Khatba, which is one of many intermittent streams draining a broad flat valley to the west. East of the mine the topography is rugged and in most places it is impassible to a vehicle.

Jebal Ash Sha'ib is the prominent landmark in the area. It is a steep-sided peak of dark gabbro surrounded on three sides by light-colored granitic rocks.

The area is characterized by an inselberg-type topography. Isolated exposures of granitic domes and pinnacles are in the flat plain west and south of the mine. In the vicinity of the mine site alluvium, scattered scree, or talus partly cover mafic and ultramafic rocks. The position of terraces with weathered iron-rich slope debris and former valley fill indicate rejuvination of an erosion cycle as a late event.

Climate, flora, and fauna

The abundance of flora and fauna in the area depends upon the amount of moisture received during the winter and to a lesser extent the summer monsoon periods of rainfall. Many wild flowers and grasses as much as 50 centimeters high thrive on the plains in years when there is abundant rainfall, such as during the period from February through May, 1968.

The temperature exceeds 40°C. during the summer, and it is as much as 35°C. during the winter. It is commonly about 30°C. during winter days but may be as low as 0°C. during winter nights. I recorded a low of 2.8°C. on November 22, 1966. The afternoon temperature on that date was 35°C.

Perennial vegetation, such as _Acacia tortilis_, _Acacia Ehrenbergiana_, and some unidentified shrubs other than acacia species, is restricted mostly to wadis. An important area of vegetation extends northerly from the east end of the mineralized outcrop. The vegetation here is noticeably more dense than elsewhere, indicating that its source of water may possibly be from a shear zone in rocks beneath the alluvium. This inference is supported by the fact that the trace of a vertical coil EM anomaly follows this zone of vegetation.

Domestic animals in the area are camel, goat, and sheep. Wild animals observed by me were rabbit, baboon, fox, wolf, and several species of birds. The local bedouin report that gazelle occasionally migrate into the area.

GEOLOGY

Regional setting

The Ash Sha'ib mine is an east-west trending portion of a septa of metasedimentary rocks between a granite pluton on the north and a gabbroic pluton on the south. The regional geology consists of a north-trending belt of gabbroic and ultrabasic rocks cut by a large north-trending granitic pluton (Brown and Jackson, 1959).

Intrusive igneous rocks

The intrusive rocks in the Ash Sha'ib mine area (fig.2) are gabbro and granite plutons, and pegmatite, granite, aplite, and diabase dikes. Granite is exposed along the north edge of the area, and gabbroic plutons are to the south and east of the area. Diabase dikes intrude the metasedimentary rocks. Pegmatite and aplite dikes cut granite, metasedimentary rocks, and gabbro. Granite dikes intrude the gabbro and metasedimentary rocks.

Gabbro

Two varieties of gabbro are exposed in the Ash Sha'ib area. The gabbro pluton south of the mine is light greenish gray, medium to coarse grained and composed of 70 percent plagioclase (An 55), 20 percent clinopyroxene, 10 percent hypersthene, and minor amounts of oliviine and ore minerals. The gabbro (norite) exposure east of the mine area is hard, fine to medium grained, dark grayish green to black and is composed of olivine, hypersthene, urolite, biotite, calcic plagioclase (An 73), and minor ore minerals.

Chemical analyses of the two gabbros (table 1) and comparison (table 2) of abundances of selected elements to average ultramafic, mafic, and intermediate rocks (Parker, 1967) show their variations. The low nickel content is interesting when compared to the average values and to the content in the lateritic weathering product from Jebal Ash Sha'ib which has been enriched in nickel and chromium.

Granite

The granitic rock north of the Ash Sha'ib mine near the contact with the metasedimentary rocks is white to light gray, medium grained, and contains about 60 percent quartz, 20 percent orthoclase, 15 percent albite, 5 percent mafic minerals (mostly green hornblende), and minor accessory sphene. A chemical analysis of this rock (table 1) shows

Table 1. Analysis of some rocks and minerals from Ash Sha'ib (values in ppm). Semiquantitative spectrographic analysis by K. H. Shahwan and M. Jambi, Ministry of Petroleum and Mineral Resources Laboratory, Jiddah, Saudi Arabia.

Element	Sample*									
	1	2	3	4	5	6	7	8	9	10
Ag	-1	-1	-1	3	-1	-1	50	-1	-1	-1
B	15	-10	-10	50	-10	20	-10	15	15	15
Ba	30	-20	-20	/10000	700	3000	200	70	1000	70
Be	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Bi	-20	-20	-20	100	-20	-20	-20	-20	-20	-20
Cd	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50
Co	30	-5	30	15	5	-5	5	70	50	20
Cr	100	-5	5000	15	10	7	-5	300	300	300
Cu	30	-10	10	/10000	10	15	3000	-10	-10	15
Ga	150	-10	-10	10	15	50	-10	10	15	15
Ge	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
La	-50	-50	-50	-50	150	-50	-50	-50	-50	-50
Mn	1000	700	300	3000	200	200	500	700	700	5000
Mo	-2	-2	-2	7	-2	-2	-2	-2	-2	-2
Nb	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50
Ni	70	-5	1500	10	-5	-5	-5	50	30	10
Pb	-10	-10	-10	200	-10	20	3000	-10	-10	-10
Sb	-100	-100	-100	500	-100	-100	700	-100	-100	-100
Sc	70	10	-5	7	30	-5	-5	20	30	20
Sn	-10	15	-10	-10	-10	-10	-10	-10	-10	-10
Sr	100	700	50	300	200	200	100	300	200	300
Ti	5000	-20	30	500	2000	1000	50	500	3000	1000
V	100	-20	-20	50	20	-20	-20	50	150	100
W	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50
Y	50	30	-10	15	100	20	-10	-10	20	-10
Zn	150	-100	-100	/10000	-100	500	10000	-100	-100	-100
Zr	30	-20	-20	30	30	50	-20	30	100	30

* 1, biotite from a pegmatite at the foot of the north slope of Jebal Ash Sha'ib; 3, weathering product from Jebal Ash Sha'ib; 4, slag; 5, granite north of Ash Sha'ib mine; 6, pegmatite 80 meters west of open pit; 7, siliceous marble float, tan color, no obvious mineralization; 8, norite east of Ash Sha'ib mine site; 9, diabase dike 300 meters southwest Ash Sha'ib mine workings; 10, gabbro south of Ash Sha'ib mine site.

- = less than; / = more than.

Table 2. A comparison of concentrations (ppm) of selected elements in mafic rocks from Ash Sha'ib with average values for intermediate, mafic, and ultramafic rocks.

Element	Rock type					
	Ash Sha'ib*			Average rock**		
	norite	diabase	gabbro	ultramafic	mafic	intermediate
Ti	500	3000	1000	300	9000	8000
Ba	70	1000	70	1	300	650
Zr	30	100	30	30	100	260
Mn	700	700	5000	1500	2000	1200
Co	70	50	20	200	45	10
Cr	300	300	300	2000	200	25
Ni	50	30	10	2000	160	55
Sc	20	30	20	5	24	2.5
Sr	300	200	300	10	440	800
V	50	150	100	40	200	100

* Semiquantitative spectrographic analysis by K. H. Shahwan and M. Jambi, Ministry of Petroleum and Mineral Resources, Jiddah, Saudi Arabia.

** Parker, 1967.

it to contain a relatively high amount of lanthanium and yttrium. Away from the contact the granite is buff colored and less resistant to erosion than the border facies.

Dike rocks

Narrow diabase dikes with various orientations have intruded the metasedimentary rocks. Their trace element content (table 1) is similar to that of the gabbroic rocks and they may be related to the gabbro. Some of these dikes have been metamorphosed to amphibolite. One of these dikes transected in drill hole SH-1 is composed of about 40 percent plagioclase, 60 percent green hornblende, epidote, and chlorite, and minor quartz and opaque minerals.

Pegmatite, granite, and aplite dikes intrude the metasedimentary rocks and the gabbro. A few narrow pegmatite dikes composed of quartz, potassium feldspar, muscovite, and red garnet cut the granite. A pegmatite dike cut by a mineralized fault near the mine contains anomalous amounts of zinc, barium and gallium (table 1). Zinc and barium are elements associated with the mineralization. The gallium may be associated with epidotization of the pegmatite or the sulfide mineralization since both epidote and the massive sulfides are high in gallium.

Metamorphic rocks

A narrow belt of metamorphic rocks lies between the granite on the north and the gabbro on the south, and is the host for the base-metal mineralization at Ash Sha'ib. Although the metamorphic rocks are dominantly hornfels there are some units of dolomite, schist, and skarn. At the mine they have an easterly strike and a steep-southerly dip. Farther west, the rocks have a northeasterly strike and a steep southeasterly dip. About 400 meters east of the mine the rocks have a northerly strike and dip mostly to the east.

Hornfels is the major rock type in the mine area and its mineralogical composition differs somewhat from one area to another which probably reflects the degree of contact metamorphism. An arenaceous, dark-green, fine-grained, and glassy hornfels is on the crest of the ridge along section of diamond drill hole SH-4. In thin section it consists of 50 percent quartz and plagioclase and 50 percent poikiloblastic diopside. Petrographic examination of samples of the drill core show that most of the metamorphic rock is cordierite hornfels. One sample from 15.3 meters in diamond drill hole SH-1 contains 70 percent quartz and plagioclase, 20 percent cordierite, 2 percent hypersthene, 2 to 3 percent biotite, 1 to 2 percent sericite, and 3 to 5 percent ore minerals. Thin sections of other zones have the same general mineralogy, but differ in the relative amounts of these minerals.

Some zones of tremolite schist, most less than a few meters thick, crop out in the mine area. In the zone of oxidation the schist contains secondary minerals of iron, copper, zinc, and silver.

A unit of dolomitic marble at the Ash Sha'ib mine (fig.2) is dense and light gray to white where unmineralized but vari-colored where oxidized. A sample of this unit from 75.0 meters below the surface in diamond drill hole SH-1, was identified by Robert Coleman (written commun., 1968) as ophicalcite, a "classic example" of a contact metamorphosed dolomite. It is composed of recrystallized carbonate, serpentine, garnet, olivine and, sulfide minerals.

Some skarn is in the area in addition to the hornfels, tremolite schist, and marble. Much of the exposed dolomite has been converted to calc-silicate assemblages in the subsurface. One exposure of skarn contains euhedral garnets as much as 10 centimeters across. The index of refraction of the garnet is 1.80; the specific gravity is 4.00.

Folding and faulting

A number of faults and folds are present in the mine area. All faults on figure 2, except the one along the mineralized zone, are inferred from magnetic maps (Sanders, written commun., 1968). They are only approximately located and most of them appear to terminate against or parallel the contact between the granite and the metasedimentary rocks.

Folding in the metamorphic rocks is probably related to the intrusion of the granite, as the strike of the rocks is parallel to the granite contact. In most places they dip away from the contact. The fold on the east end of the mineralized zone may reflect a change in the strike of the granite contact. It may also be a drag fold that formed during faulting.

Two parallel faults mostly south of the mine area strike about N30°W for several kilometers. One is shown near diamond drill hole SH-5 on figure 2. The other fault lies about 1.5 kilometers southeast of diamond drill hole SH-5 through a brecciated gabbro and a topographic low area.

An easterly-striking, right-lateral fault offsets the pegmatite dike located about 80 meters west of the large open pit. This fault has rotated the block between the offset ends of the dike. The fault may have served as a conduit for mineralizing solutions.

The two sets of faults discussed above may be due to compressional forces from a northwest direction. The attitudes of the fault planes are consistent with a stress model in which the granitic pluton was the source of the compressional force.

THE MINERAL DEPOSIT

History and production

Very little is known about the history of mining activity in this area. The only available evidence for the period of mining is the existence of a mosque in the ruins at the mine site, which indicates that at least some activity took place after the beginning of Islamic time.

Production of the mine can be crudely estimated on the basis of the ancient workings and the amount of slag. About 300 cubic meters of mineralized rock were removed from pits, trenches, shafts, and stopes, resulting in 100 cubic meters of slag. With a value of 4 tons per cubic meter for mineralized rock, about 1200 tons of ore and waste were removed. The slag, with a specific gravity of about 5, weighs about 500 tons. There is a waste-ore ratio of 1:1. The slag contains 2 percent copper, 3 percent zinc, 0.02 percent lead, less than 0.1 ounces per ton silver, and no gold (table 1). A very crude estimate of the smelter heads, made mainly from oxidized ore in the open pit and drill core, is 4 percent copper, 8 percent zinc, 0.2 percent lead, 2 ounces per ton of silver, and less than 0.02 ounces per ton of gold. The recovered metal is estimated to have about 10,000 kilograms of copper, 25,000 kilograms of zinc, and 30 kilograms of silver. The smelter product was probably a zinc-copper alloy with minor amounts of lead and silver. A brass alloy may have been obtained if some zinc was fumed off during smelting.

Character of the mineralization

Localization of the mineral deposit is the result of fissure vein filling and replacement. The several mineralized fissures, each a few meters from the next, all show evidence of wall-rock replacement. The main replacement is along fissures that intersect dolomitic rock, where the fissures split into many stringers resulting in wider replacement zones.

Mineralogy

The zone of oxidation extends 30 to 40 meters below the surface and contains secondary carbonate, oxide, silicate, and sulfate ore, and gangue minerals. The major base-metal minerals are malachite and smithsonite. Minor amounts of azurite, chrysocolla, hydrozincite, and hemimorphite(?) are also present. Minerals derived from gangue include limonite, manganese oxide, and barite.

In the hypogene zone, the ore minerals are sphalerite, chalcopyrite, and minor amounts of galena. The gangue minerals include pyrite, barite, quartz, and fluorite(?).

A sample of the mineralized zone taken from 150 meters in diamond drill hole SH-4 is a black massive sulfide. Here it consists of about 75 percent sphalerite, 5 percent pyrite and chalcopyrite, and 20 percent gangue minerals, mostly barite and quartz. The "exploded bomb" texture of some pyrite indicates that it has been replaced by chalcopyrite and sphalerite. The relationship of sphalerite and chalcopyrite in a vug shows euhedral chalcopyrite perched on sphalerite, but sphalerite also replacing the chalcopyrite. Adjacent to the massive sulfide is disseminated sulfides in which very fine grains of reddish-brown sphalerite appear to have formed along a replacement front.

Thermal history

A sequence of events can be interpreted from the present data at and in the vicinity of Ash Sha'ib. The first known thermal event was the intrusion of gabbro into metasedimentary rocks. Contact metamorphism formed the hornfels adjacent to the gabbro in the southwest corner of the area. Subsequently, granite was emplaced north of the mine area and the metasedimentary rocks may have again been altered. Pegmatite dikes were emplaced during the late stages of granitic intrusion, and subsequently some were displaced by recurrent faulting. The last stage of intrusion included hydrothermal solutions that moved up fault planes and sulfide minerals were deposited.

The mineral and trace element data are compatible with the thermal history of an ore deposit associated with a cooling granitic pluton. The presence of cordierite in the hornfels indicate a temperature of 400° to 600° during contact metamorphism. Cordierite was subsequently altered to sericite as a result of hydrothermal activity. The presence of moderately high concentrations of gallium and germanium in the sphalerite indicates intermediate to low temperatures during the sphalerite deposition. (Rankama and Sahama, 1950). Further evidence for a low temperature (Bateman, 1950) is the tentative identification of small amounts of purple fluorite in the ore zone in diamond drill hole SH-4. The fluorite must have been deposited at a low temperature as it loses its color above 175°C.

GEOCHEMISTRY

Surface sampling

Geochemical samples obtained on a 20 meter by 50 meter grid pattern over the mineralized outcrop were analyzed for heavy metal content in the field and in the U.S. Geological Survey laboratories in Jiddah, Saudi Arabia. These were either samples of rock in place or weathered material which had been transported only short distances, probably less than 100 meters. When both types of material were easily available at a sample site a sample of each was obtained. The sample was reduced to minus 80-mesh for semiquantitative colorimetric and spectrographic analyses.

Also, 160 samples of alluvium were obtained from drainages around the area of mineralization. Analyses in the field were carried out on a minus 80-mesh fraction, but samples analysed in the Jeddah laboratory were a minus 30-mesh fraction subsequently reduced to minus 80-mesh. The results of the analysis indicate that the alluvium does not contain the anomalous metals that are present in the Ash Sha'ib gossan (table 3). Even samples of samples taken from the drainages adjacent to mineralized material failed to show more than background values of base metals.

Table 3. Statistics from surface sampling at Ash Sha'ib (in ppm) (Semiquantitative spectrographic analysis by K. H. Shahwan and M. Jambi, Ministry of Petroleum and Mineral Resources Laboratory, Jiddah, Saudi Arabia).

Element	Group I Gossan and wall rock			Group II Alluvium near gossan		
	Mean	Mode	Range	Mean	Mode	Range
Ag	7	<1	<1-500	<1	<1	<1-7
B	20	15	<10-100	15	10	<10-30
Ba	1500	500	<100->10000	300	200	<100-3000
Be	<2	<2	<2-2	<2	<2	<2
Bi	20	<20	<70-700	<20	<20	<20-20
Cd	<50	<50	<50-150	<50	<50	<50
Co	15	20	<5-50	10	10	<5-20
Cr	70	70	<10-200	150	150	30-700
Cu	700	100	<10->10000	30	<10	<10-700
Ga	10	10	<10-30	15	15	<10-30
Mn	2000	1500	300->10000	500	500	50-1000
Mo	2	<2	<2-70	<2	<2	<2-2
Ni	30	30	<5-100	30	30	15-70
Pb	200	10	<10-7000	10	<10	<10-500
Sb	100	<100	<100-1000	<100	<100	<100-150
Sc	15	10	<10-30	10	10	<10-30
Sn	<10	<10	<10-30	<10	<10	<10
Sr	200	200	<50-300	300	300	200-500
Ti	5000	2000	100-7000	3000	2000	500-10000
V	70	70	20-300	70	70	30-100
Y	15	15	<10-30	15	15	<10-20
Zn	2000	<100	<100->10000	100	<100	<100-3000
Zr	70	70	<10-200	100	70	20-300

Negative results also were obtained from pits that were dug in the alluvium for the purpose of determining a vertical change in metal values. A pit in the wadi north of the gossan, contained as much as 40 ppm copper to a depth of 90 centimeters. A pit in the wadi southwest of the gossan showed as much as 30 ppm of copper at a depth of 180 centimeters.

Some statistical data compiled from the chemistry of surface samples taken at Ash Sha'ib are listed in table 3. One group of samples (group I) is from gossan and associated rock, whereas the second group (group II) is from wadi alluvium surrounding the gossan area. The mean value of an element was calculated by assuming that indeterminate values of less than or greater than the element's detection range were, respectively, zero and the maximum value. For example, zinc reported as greater than 10,000 ppm was entered as 10,000 ppm in the calculation, while zinc reported at less than 100 ppm was assumed to be zero. Such calculation will give negative bias to the mean. In addition, since the values are from semiquantitative spectrographic techniques using six step standards all means have been rounded to correspond to these standards.

A comparison of the data for group I with that for group II (table 3) shows that silver, barium, copper, manganese, lead, and zinc have significantly higher means in group I. The means for bismuth, cadmium, molybdenum, and antimony are not definitive because they are near their detection limits, even though they are anomalous.

Chromium and strontium have higher means in group II than in group I. Chromium values are locally high in the alluvium because of the abundant gabbro outcrops in the area. Strontium is normally high in alluvium in an arid environment.

A few samples of trees and plants from the drainage indicate that molybdenum values in plant ash may be useful in geochemical exploration as an indicator element for base metal deposits, particularly copper. The molybdenum values from a grass, twigs of Acacia, and twigs from an unidentified shrub growing in different parts of the area, where sediments contain less than 2 ppm in molybdenum, ranged from 5 to 65 ppm. Background values for molybdenum in the ash of twigs of the two Acacia species present near Ash Sha'ib range from not detected to less than 2 ppm. Twig ash analysis is compared on table 3 with a wadi sediment sample from near the base of the shrub. The sediment sample was from a small playa rich in silt and clay which tend to absorb metal ions, thus possibly explaining the anomalous copper value shown in table 4. The plant ash sample indicated that copper, lead, and molybdenum might be useful in future exploration programs. Subsequent samples from this area, however, show that copper values are erratic, and lead values show little or no change.

Favorable sites for diamond drill locations as well as the main factors affecting the secondary dispersion can be determined from dispersion maps based on chemical analyses of surface samples. The secondary dispersion has been influenced mainly by oxidation of the

Table 4. A comparsion of analyses of ash from twigs and leaves of an Acacia tree with analyses of transported sediments near the base of the tree. (Semiquantitative spectrographic analysis by K. H. Shahwan and M. Jambi, Ministry of Petroleum and Mineral Resources Laboratory, Jiddah, Saudi Arabia).

Element	Spectrographic analysis in ppm	
	Wadi sediment	Plant ash
Ag	-1	-1
B	10	140
Ba	200	580
Be	-2	-2
Bi	-20	-20
Cd	-50	-50
Co	10	1
Cr	100	40
Cu	150	50
Ga	15	-10
La	-50	-50
Mn	1000	100
Mo	-2	15
Nb	-50	-50
Ni	30	-5
Pb	10	95
Sb	-100	-100
Sc	10	-10
Sn	-10	30
Sr	300	2000
Ti	3000	60
V	70	10
W	-50	-50
Zn	-200	-200
Ge	-20	-20
Y	15	-10
Zr	200	40
Fe	-	5800
Mg	-	8000
Ca	-	530000
Al	-	10000
Si	-	10000
Na	-	5100

- = less than

hypogene zone minerals, the chemical character of the rocks in the area, the chemical character of the individual elements, and the topography. Although absolute amounts of elements in the supergene zone differ from those of the hypogene zone the order of relative abundances in each zone are zinc, copper, lead, and silver. In the area west of diamond drill hole SH-1 dispersion of ore and gangue metals is greater than to the east because of steeper slopes and more widespread mineralization. Zinc and silver are more widely dispersed than lead and copper. Silver dispersion, however, has been restricted in the area north of the vein system, probably because of the dolomite unit along the north side of the main vein (fig. 2). There is a geochemical anomaly along the vein 200 meters east of the largest open pit that is much weaker than the anomaly along the west end of the vein as a result of a change of character of the vein caused by silicification.

A hypothesis of the history of the gossan

Silver-gold ratios, calculated from data from diamond drill hole SH-2, form the basis of a hypothesis of the history of the gossan at Ash Sha'ib. The ratios are divided into three groups, those with both gold and silver, those with gold and little silver, and those with silver and little gold.

The samples containing gold and silver are mainly from the hypogene zone; some are from a few meters below the surface of the ground. The silver-gold ratios have a mean value of 50 and a median of 60.

The group of ratios for those samples containing gold and little silver have a mean value of less than 13 and may be divided into two subgroups according to their occurrence. In the first subgroup the ratios are from samples of non-carbonate rocks in the oxidation zone. The second subgroup of ratios are from samples of a pyrite-quartz vein widely separated from the main zone of mineralization.

The group of ratios obtained from samples with silver and little gold have a mean of 130, and may also be divided into two subgroups according to their occurrence. The first subgroup is in the hypogene zone where silver is more widespread than gold. Therefore, silver values are found on either side of, as well as with, a group of gold values. The second subgroup is in the oxidized zone, where gold values are widespread, but the silver values are associated only with carbonate veinlets.

The subgroup of low silver-gold ratios in the pyrite-quartz vein are not considered to be directly related to the main zone of mineralization. The other subgroup of low silver-gold ratios is probably due to the leaching and subsequent migration of silver in the zone of oxidation. It is apparent that the high silver-gold ratios in the zone of oxidation are associated with secondary carbonate veinlets. As mentioned before, the veinlets are also the host for secondary silver.

Based on the above data an idealized vertical section would have the upper part of the oxidized zone (upper few meters) with gold and silver, the lower part of the zone with gold in non-carbonate rocks and silver in carbonate veinlets, and the underlying primary zone with gold and silver.

In conclusion, evidence of leaching in the oxidation zone indicates that the gossan at Ash Sha'ib may have undergone oxidation under much wetter conditions than the present day. At that time the normal leaching and migration of the ore minerals was most extensive in zones of non-carbonate rock. Subsequent to oxidation, there was a period of exposure under arid conditions which resulted in the accumulation of insoluble carbonates of the base metals and silver near the surface. Such deposits have high-grade material at the surface or near the surface which diminishes downward within a few meters to a lower-grade leached zone. This distribution of ore may explain why many of the old mines in the shield area were mined only to a depth of a few meters.

Future recommendations for a drilling program must be based on a careful evaluation of chemical analyses of surface samples in relationship to the geologic environment, especially for those deposits that may have developed under the above conditions. Two extreme cases can be considered for fossil gossans in areas with different rate of erosion. In areas of low rates of erosion enrichment is possible in the upper portion of the zone of oxidation while in areas with high erosion rates this enrichment may not take place or may be much less. Other types of situations can be considered which will have effected the amount of ore minerals present in surface samples of gossan material and thus the analysis of that material. Low or high metal contents of gossans should not be used alone to determine drill targets.

GEOPHYSICS

Some of the results of previous geophysical work have been compiled on figure 3. The EM data is included for the purpose of illustrating the relationship among the EM techniques, and the magnetic data to lend support to interpretation of some of the EM data.

I have interpreted the northern trace of a vertical coil EM anomaly as being related to a contact zone. A plane formed by projection of this trace down-dip corresponds roughly with a plane formed by projection up-dip of a change in sodium concentration found in drill core samples.

The middle trace of a vertical coil anomaly is interpreted as being due, at least on the eastern end near the two in-and-out-of-phase EM anomalies, as being response to a wet-shear zone. The presence of this shear zone is supported by the fact that the trace follows a dense accumulation of vegetation and by sheared rock with weak sulfide mineralization intersected in core hole 5H-6.

The largest Barringer "INPUT" system anomaly corresponds well with the series in-and-out-of-phase EM anomalies detected on the helicopter survey by Sander Geophysical Limited (1968). I believe that the Barringer anomaly is broader as a result of the greater flight height used in that survey. The lineation apparent in the four in-and-out-of-phase EM anomalies and the 6-channel "INPUT" system responses

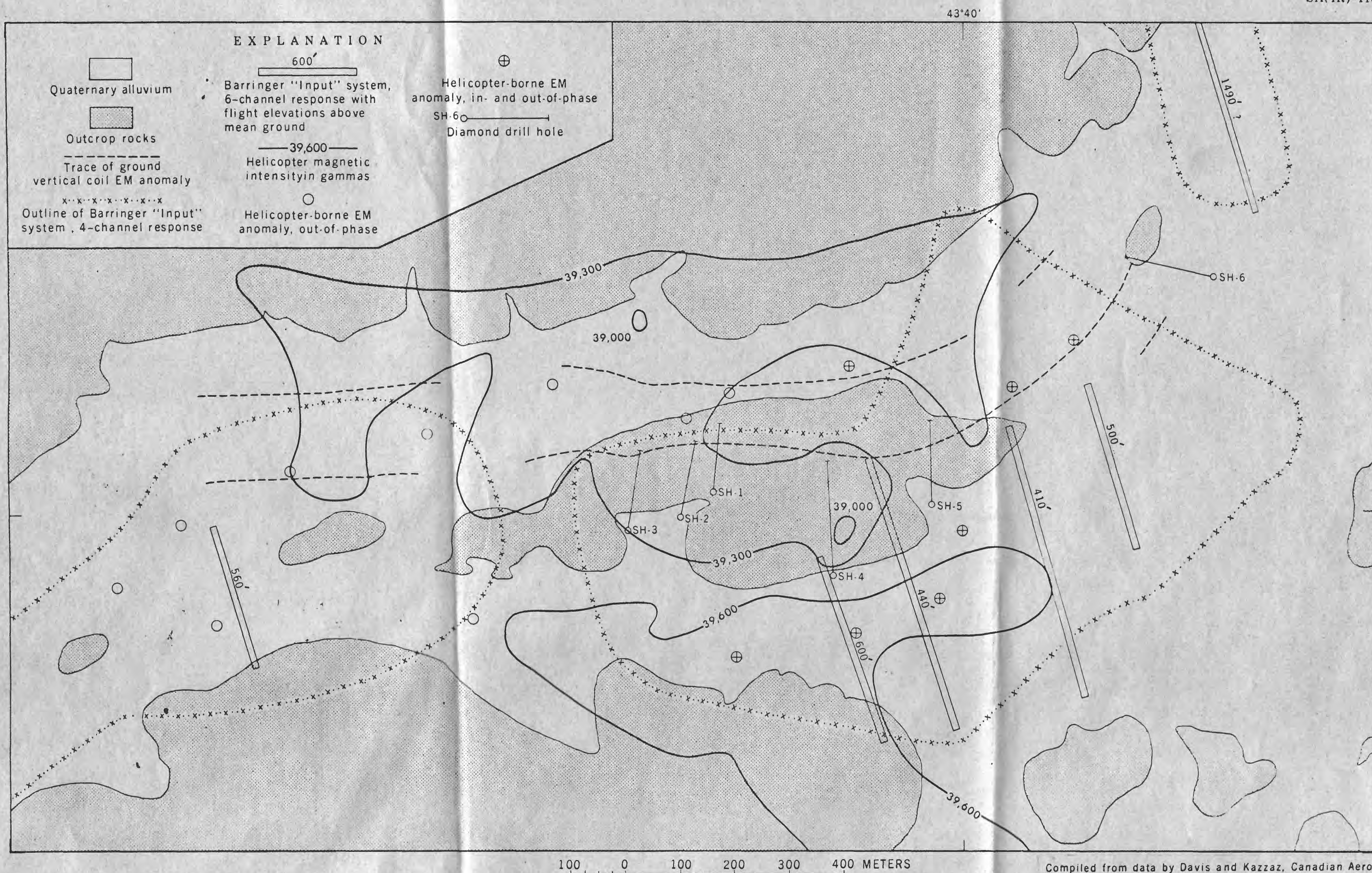

Figure 3.-Geophysical map of the Ash Sha'ib area

can be interpreted to be due to a sulfide conductor, a shear zone, or a contact zone. Since an east-striking fault can be postulated on the basis of the gradational magnetic data and the anomalies follow a topographic low area, support is given to an interpretation in which the anomalies reflect structure; drilling would be necessary to determine if there was a mineralized zone.

ANALYSIS OF SAMPLES FROM DIAMOND DRILL HOLES

Core of the mineralized zone at Ash Sha'ib ancient mine were obtained from six diamond drill holes. Samples of core from drill hole each were analyzed by semiquantitative spectrographic techniques. Values of elements in the richest zones of mineralization were checked by atomic absorption methods. Discussion of the data is limited to those elements that have potential economic importance related elements in gangue, and a few trace elements.

Base metal and silver mineralization is presented graphically for each diamond drill hole section (pls. 1-6). Each section shows the interrelationship of the economically important metal concentrations, the lithology, and the core recovery. In addition, surface data are shown on plates 1-4. Even though the mineralization is complex, there is some evidence of zoning of metals on the cross sections.

Diamond drill hole SH-1

Diamond drill hole SH-1 (pl.1) was located about 50 meters south of the open pit. It was oriented N.05°E. and inclined 45° from the horizontal for the purpose of intersecting at depth the vein which was mined at the surface. The hole was collared on April 2, 1967, by a U.S. Geological Survey drilling crew and completed at 183.5 meters on May 9, 1967.

The zone of oxidation was deeper than predicted, particularly in the mineralized zone. As a result, core recovery was poor where the vein was transected. Only 30 percent of the core was recovered from the interval of 38.7 to 46.4 meters (pl.1). In addition, a sample of black and red sandy oxidized material was recovered from the interval of 33.6-38.7 meters by using an open end single tube core barrel without a bit or reaming shell and without water. It was packed in the core barrel by raising and lowering the rods until the end was thought to be blocked. The material represents the mineralized zone as indicated by the profiles of element concentration shown in plate 1. The sample provides some information on the missing interval even though it may not completely represent the interval

The zinc, copper, lead, and silver deposits are in the interval from about 14 meters to 93 meters in core hole SH-1 (pl.1). The enrichment of silver in carbonate veinlets of the oxidized zone is apparent in the interval from 25 to 28 meters and from 39 to 40 meters. In general, anomalous values of all four elements are together, but copper is absent in the interval from 63 to 68 meters and it is the only metal in the core from 118 to 122 meters.

Diamond drill hole SH-2

Diamond drill hole SH-2 (pl.2) was drilled west of hole SH-1, and it was oriented at N.10°E. at a 45°angle from the horizontal. The hole intersected the mineralized rock below the zone of oxidation. It was collared by Arabian Drilling Company on December 28, 1967, and completed to 208 meters on February 14, 1968. The amount of core recovery was increased over that from hole SH-1 by obtaining a larger diameter core and by the use of a wire-line technique.

Zinc and copper are more widespread than lead and silver in core hole SH-2 (pl.2). Anomalous silver values are with zinc and copper, and locally with lead. Silver may be in the form of argentiferous galena and an argentiferous copper mineral. Lead is the dominant metal in the interval from 83 to 84 meters and 107 to 107.5 meters. The lead intervals are on the footwall side of a zinc-copper vein.

Diamond drill hole SH-3

Diamond drill hole SH-3 (pl.3) was drilled to test the mineralized rock beneath a small open pit about 150 meters west of the main workings of the mine. The hole was oriented N.80°E. and drilled at an inclination of 45° from the horizontal. A sample from this area indicated (pl.3) high silver values (14 ounces per ton). The hole, collared on February 17, 1968, by Arabian Drilling Company was completed to 200 meters on March 19, 1968.

In hole SH-3 (pl.3), there are intervals where zinc, copper, or lead are found separately. Lead is along the hanging wall of the most intensive zinc-bearing rock. Two major intervals and several minor intervals of zinc and copper, but without lead and silver, are between 43 and 72 meters.

Diamond drill hole SH-4

Diamond drill hole SH-4 (pl.4) was drilled to test the surface geochemical anomaly located 200 meters of the main workings, the main vein at depth, and the smaller zones of mineralization south of the main vein. It was oriented at N.04°W, and the hole was inclined 44° from the horizontal. Arabian Drilling Company commenced drilling on March 21, 1968, and completed the hole on April 24, 1968, at a depth of 300 meters.

A weakly mineralized zone contains copper and zinc and little or no lead or silver in the interval between 67 and 104 meters in hole SH-4 (pl.4). Copper is the only important ore mineral in the interval 116 to 150 meters. The main zone of mineralization, from 156 to about 167 meters, contains copper, zinc, and silver. A weak copper, zinc, and lead zone is present between 200 and 203 meters. Lead mineralization is weak in this diamond drill hole compared to the three previously described holes.

Diamond drill hole SH-5

Diamond drill hole SH-5 (pl.5) was started by the Arabian Drilling Company on April 25, 1968, to test the eastern end of the exposed mineralization (pl.1). The hole was oriented N.02°W., and inclined 46° from the horizontal; it was completed to a depth of 206 meters on May 18, 1968.

The mineralization in the core is weaker than in the previous four holes (pl.5). Anomalous copper is more widespread than anomalous zinc. However, in the main zone of mineralization, the interval from 80 to 92 meters, zinc is more abundant than copper. A 1-meter interval from 73.5 to 74.5 meters contains pyrite, chalcopyrite, and sphalerite with chalcopyrite as the most important ore mineral. Only a trace of silver is in a vein in the core. A very weak and isolated occurrence of lead is in the interval from 66 to 70 meters. A small zone of anomalous zinc and lead, without copper or silver, is in the interval between 160 to 165 meters.

Diamond drill hole SH-6

Diamond drill hole SH-6 (pl.6) was drilled to test a possible northern extension of the main vein as indicated by geophysical and geological information. The hole extends N.78°W. and it is inclined at 45° from the horizontal. Drilling began on May 22, 1968, and was completed at 234 meters on June 7, 1968. Very little core was recovered in the mineralized part of the drill hole.

The weak mineralization encountered in the hole is not of economic interest (pl. 6). Of interest, however, is the presence of sphalerite and chalcopyrite.

Two zones of anomalous metal values were intersected in core hole Sh-6 (pl.6). The upper zone, from about 70 to 80 meters, is pyritiferrous hornfels which contain anomalous lead, but no zinc, copper, or silver. The lower zone, from 187 meters to 198 meters, has anomalous amounts of zinc, copper, and lead. The mineralized zone may be in sheared rock which would explain the low percentage of core recovery.

Statistical analysis of data from drill hole SH-2

Nonparametric correlation techniques, using Kendall's correlation coefficient (Siegel, 1956), were applied to the data from hole SH-2 to illustrate possible correlation between pairs of elements in the deposit. The probability of no correlation (p) between the pairs of elements is shown in table 5. In table 5, those elements with probabilities of no correlation greater than 0.10 are shown as NC (that is, there is no correlation assumed), while those element pairs with probabilities of no correlation less than 0.10 are listed with their probability.

Table 5. Probability of no correlation between selected pairs of elements in diamond drill hole SH-2 from 76.80 to 83.90 meters.

Element Pairs	p
Cu-Zn	0.0046
Cu-Ag	0.03
Cu-Pb	NC
Zn-Pb	NC
Zn-Ag	NC
Ag-Pb	0.00006

In the narrow mineralized interval from 76.80 to 83.90 meters no correlation ($p = >0.10$) is indicated for three pairs of elements (table 5); a correlation between copper and silver ($p=0.03$), copper and zinc ($p=0.0046$), and between lead and silver ($p=0.00006$).

Some element pairs generally showing probabilities of no correlation of less than 0.00X (where X is an interger 1-9) and therefore may be related. They are silver and manganese, silver and gold, gold and barium, gold and manganese, barium and zinc, and barium and manganese. Other pairs with probabilities of no correlation between 0.01 and 0.05 are barium and gold, barium and silver, barium and copper, and zinc and manganese.

VALUES OF THE MINERALIZED ZONES

Mineralized intervals of economic importance in the diamond drill holes are listed in table 6. The starred intervals are those that are correlated from one hole to another. The values used in calculation of dollar worth are copper at $0.42 per pound, zinc and lead at $0.14 per pound, and silver at $2.45 per troy ounce.

The correlated intervals form an easterly striking, southerly dipping, roughly tabular body of mineralized rock with variable thickness, a strike length of about 650 meters, and a down-dip length of 170 meters, the latter based on the deepest intersection of the vein by drilling.

For the purpose of estimating the economic potential of the deposit, this tabular body is divided into five blocks by diamond drill hole sections. The blocks are included here only to illustrate the grade of the best material available in mineable widths based on present limited data, and do not constitute estimates of reserve. It is doubtful that any of the zones could be presently mined in view of the location and grade of the deposit and the available tonnage of the metalliferous rock.

Table 6. Major intervals of mineralized rock encountered by drilling at Ash Sha'ib. (Atomic absorption analyses by I. Baradja and L. Al Dugaither, Ministry of Petroleum and Mineral Resources).

DD#	Down hole Interval (meters)	Core analysis			$/ton value **			*** Total value
		Zn%	Cu%	Ag oz/ton	Zn	Cu	Ag	
SH-1	24.4-27.9	4.0	0.6	2.27	11.20	5.04	5.56	22.00
	*39.7-48.7	3.2	0.7	0.7	8.96	5.88	1.71	17.00
	68.9-69.3	5.0	0.15	0.7	14.00	1.26	1.71	17.00
	75.5-76.0	4.0	0.16	0.56	11.20	1.34	1.37	14.00
	77.3-79.3	3.2	0.25	0.7	8.96	2.10	1.71	13.00
SH-2	55.4-56.8	8.9	0.23	0.33	24.92	2.52	0.81	28.00
	*69.7-71.2	6.2	0.07	0.14	17.36	0.59	0.34	18.00
	*74.7-75.8	4.2	-	-	11.76	-	-	12.00
	112.7-113.4	2.0	-	0.10	5.60	-	-	6.00
SH-3	*99.1-103.6	4.5	0.32	0.47	12.60	2.69	1.15	16.00
SH-4	*156.7-161.7	11.1	0.25	0.78	31.08	2.10	1.91	35.00
SH-5	*86.9-88.6	1.0	-	-	2.80	-	-	3.00

* Correlated intervals along strike (from one hole to another)

** Zinc at 0.14/lb, copper at 0.42/lb, and silver at $2.45/troy ounce.

*** Rounded to nearest dollar.

The thickness and grade of block one was obtained by extending the data from the section of diamond drill hole SH-3 to the west. The thickness and grade of blocks two through five were obtained by averaging data from the diamond drill section at each end of the block.

Block one extends west from the section of diamond drill hole SH-3 for 100 meters and averages 4.5 meters in thickness. It has an average metal content of 5 percent zinc, 0.32 percent copper, and 0.47 ounces per ton of silver, for a current value of $18.00 per ton. This block contains 310,000 tons of mineralized rock. It has a value in place of $6,000,000.

Block two of mineralized rock averages 3.6 meters in thickness, and extends, 100 meters along strike and 170 meters down dip between the sections of diamond drill holes SH-2 and SH-3. This block contains 240,000 tons of protore. The value of the 5 percent zinc, 0.16 percent copper, and 0.27 ounces per ton of silver is $16.00 per ton. The value of the block, in place, is $4,000,000.

Block three is 50 meters long, 170 meters down dip, and 6.0 meters in thickness. It is between the sections of diamond drill holes SH-1 and SH-2 and contains 210,000 tons of protore. The block averages 5 percent zinc, 0.03 percent copper and 0.07 ounces per ton of silver for a value of $14.00 per ton. It has a value, in place, of $3,000,000.

Block four averages 7 percent zinc, 0.47 percent copper, and 0.74 ounces per ton of silver. It has a value of $25.00 per ton of mineralized rock. It lies between the sections of diamond drill holes SH-1 and SH-4 and contains 960,000 tons. The value of this block, in place is $20,000,000.

Block five is between the sections of diamond drill holes SH-4 and SH-5. It contains 450,000 tons of mineralized rock with a value of $18.00 per ton. The value of this block in place, is $8,000,000.

The gross value of the deposit depends upon where the ore-no-ore cutoff is established. The estimated value of the five blocks as calculated is about $40,000,000, but using a $25.00 per ton cutoff the gross value is about $20,000,000. Calculations based on narrower widths and higher grade material also indicate a gross value of about $20,000,000.

SUMMARY

The economic evaluation of the Ash Sha'ib mineral deposit indicates that development is not feasible under present conditions. With an estimated gross value of $20,000,000 for the rock in place using a $25.00 per ton cutoff, the prospect shows little promise as a producer under present conditions.

Evaluation of geochemical exploration techniques used in the study show that wadi sediment sampling could not have located the deposit. The restricted secondary disperses of the ore minerals plus the massive dilution by unmineralized sediments resulted in no more than background values in the sediments near the deposit.

Biogeochemical techniques indicated that molybdenum in plant ash might be useful as an indicator for detecting areas in which there is copper mineralization. Additional work will be needed to fully evaluate the potential of this technique.

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U.S.GEOLOGICAL SURVEY
SAUDI ARABIAN PROJECT

KINGDOM OF SAUDI ARABIA
MINISTRY OF PETROLEUM AND MINERAL RESOURCES

SA(IR)-118
PLATE 1

PLATE 1.- CROSS SECTION THROUGH DIAMOND DRILL HOLE SH-1, ASH SHA'IB PROSPECT

By Glenn H. Allcott