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MINERAL DEPOSITS OF THE DHAHAR-AL HAJRAH REGION, SOUTHWESTERN SAUDI ARABIA, with A NOTE ON THE ANCIENT MINE AT SHASRAH

by

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SOUTHWESTERN SAUDI ARABIA,

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ABSTRACT

Two mineral zones at Dhahar, East Dhahar and West Dhahar, are within a series of tightly folded volcaniclastic rocks. East Dhahar is a series of lensoidal gossans in highly sheared quartz-crystal tuffs in contact with quartz-crystal pyroclastic breccia on the east and with basaltic flows on the west. The deposit is 400 m long and as wide as 25 m at the surface. The diamond drill hole sited at East Dhahar intersected 45 cm of massive sulfide bearing 23.68 percent zinc and 1.45 percent copper at approximately 70 m vertical depth. Layers of banded and disseminated sphalerite intersected on the hanging-wall side of the massive sulfide had a combined width of 3.40 m and averaged 4.17 percent zinc and 0.49 percent copper.

The East Dhahar deposit is believed to be of the volcanogenic type and, with the exception of the absence of pyritized jasper at the surface, all of the criteria of a volcanogenic model are met.

West Dhahar is separated from East Dhahar by approximately 500 m and is made up of a zone of abundantly disseminated pyrite approximately 900 m long and as wide as 200 m, within quartz-crystal tuffs. A geochemical survey carried out by rock-chip sampling delineated an anomalous zone high in copper and zinc values that closely coincides with the pyritized tuffs. The diamond drill hole drilled through the zone yielded low values of zinc. Very fine sphalerite as isolated crystals or as replacements of pyrite occurs throughout much of the pyritized zone. Chalcopyrite is much scarcer and erratically dispersed.

The relationship of this zone of disseminated sulfide to East Dhahar is not clear, but it possibly represents a metallized halo surrounding massive sulfide deposits.

The Al Hajrah district is 6 km southwest of Dhahar and is distinguished by widely and erratically distributed secondary copper within tightly folded and pyritized volcaniclastic rocks that have been intruded by quartz porphyry dikes. There appears to be a direct spatial relationship between the higher grade zones of copper and quartz porphyry dikes. The dikes are widespread in the area and are hydrothermally altered to quartz, quartz-sericite, and kaolinite.

Copper is found both within the dikes and in contact zones in pyroclastic rocks. Zones of pyroclastic rocks bearing copper are ordinarily altered to dark green chlorite.

The drill hole sited at Al Hajrah intersected erratically distributed chalcopyrite from the bottom of the oxidized zone to the bottom of the hole. The chalcopyrite is intimately associated with pyrite in disseminated and stockwork form, but the grade of copper found in the drill hole is too low to be economic.

INTRODUCTION

Ancient mine workings at Dhahar and Al Hajrah were found by W. R. Greenwood of the U.S. Geological Survey (USGS) during his mapping of the Wadi Malahah quadrangle (Greenwood, in press). Greenwood sampled deposits at Dhahar and sketch-mapped and sampled one of the ancient workings in the Al Hajrah area. The Dhahar workings are near long 18°13'25" N., lat 43°44'30" E., about 200 airline kilometers east-southeast of Khamis Mushayt (fig. 1), and the Al Hajrah workings are 6 km southwest of Dhahar. At both mining sites are ruins of ancient villages and scattered slag piles near ancient excavations, which, in most places, are now nearly filled with mining debris.

Field work, consisting of mapping and sampling at several scales, was conducted from September 1976 to October 1977. The immediate Dhahar area was mapped by use of low-level aerial photography at a scale of approximately 1:6,000, and zones of ancient workings at East and West Dhahar were mapped by compass and tape survey at a scale of 1:500. Concurrent with mapping, rock samples for trace-metal analyses were collected at 10-m intervals along three east-west lines 250 m apart. At Al-Hajrah, also concurrent with mapping, samples were collected at approximately 25-m intervals along east-west lines 250 m apart. Uncontrolled aerial photographs of approximately 1:10,000 scale were used as a base. In addition, photographs from the same aerial survey were used as a base in mapping a larger area that includes both Dhahar and Al Hajrah. Detailed mapping at a scale of 1:1,000 was also done at Al Hajrah where sulfide metallization, rock alteration, and numerous ancient workings are concentrated.

Low-level aerial photography of the region was flown by the USGS Mission before and during the time of field work. In May 1977, Mark Gettings, USGS geophysicist, spent 2 days in the region examining mineral zones and compiled a report, including maps (unpub. data) with suggestions on the types of geophysical surveys to be used. In October 1977, Maher Bazzari also of the USGS, assisted by the author, ran a Crone electromagnetic survey at Dhahar and Al Hajrah. In December 1977 and April-May 1978, the Arabian Geophysical and Survey Company (ARGAS) of Jiddah, was contracted by the USGS to run traverses across Al Hajrah mineral zones and measure induced potential, self-potential, and resistivity of the rocks (ARGAS, 1978). H. R. Blank, USGS geophysicist, was instrumental in setting up this program and field checking the results of the survey. The Arabian Drilling Company drilled two holes at Dhahar and one at Al Hajrah between October 1977 and February 1978.

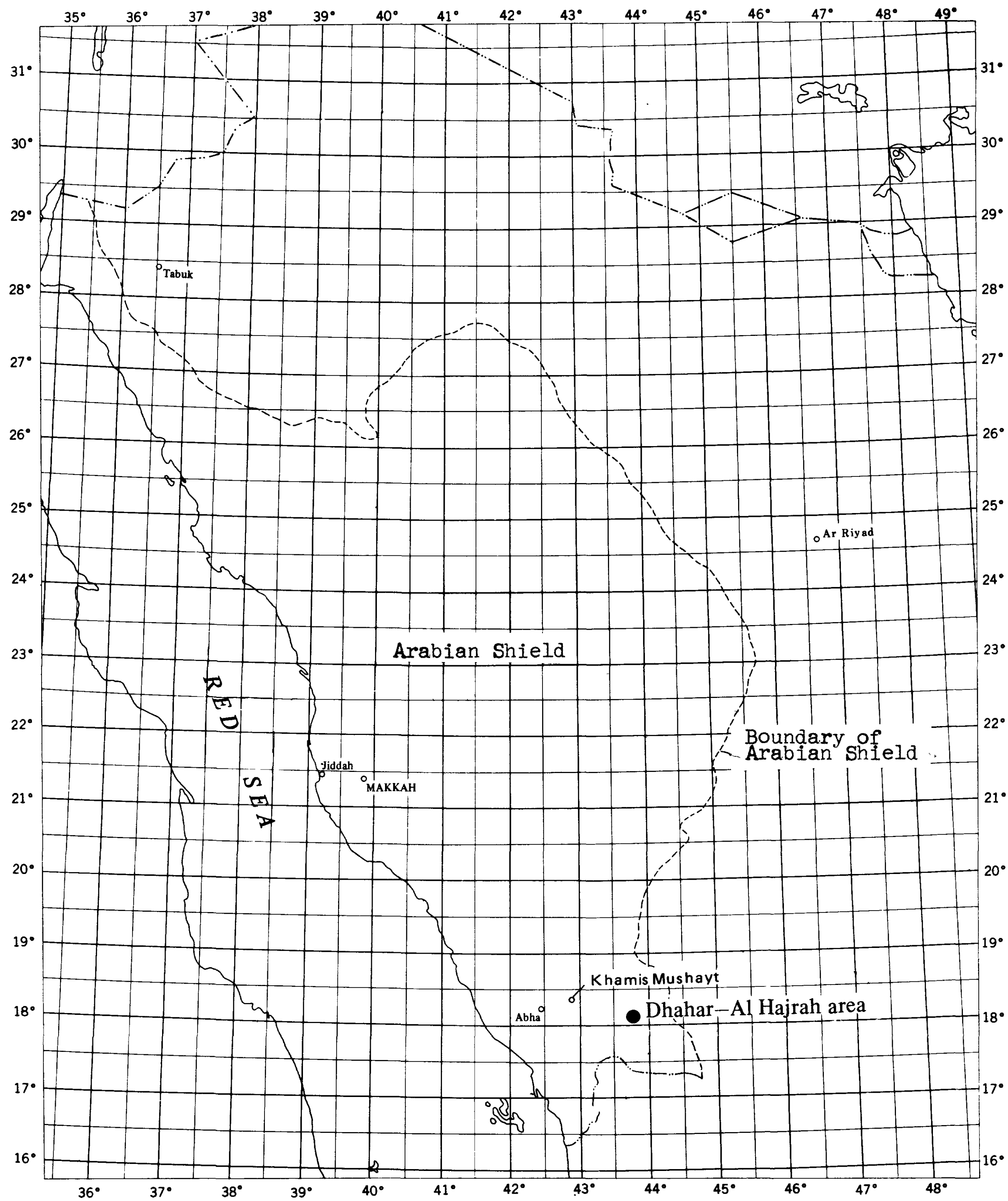


Figure 1.–Index map of western Saudi Arabia showing location of the Dhahar–Al Hajrah region.

The Dhahar-Al Hajrah region is approximately 1900 m in elevation, and relief consisting of rolling hills incised by a southeast-trending drainage system is gentle to moderate. Jabal Dhahar, a prominent north-trending mountain, is just east of the ancient workings at Dhahar and serves as a landmark in the region.

The climate is generally very dry and, because of the elevation, temperatures are moderate enough to permit field work the entire year. There are two rainy seasons, which ordinarily are in May and October.

Access to the Dhahar area by land vehicles is from the nearest large city, Khamis Mushayt. The route leaves the Khamis-Mushayt-Najran asphalt highway near the village of Haraja and follows an unimproved dirt road northeast through numerous villages along Wadi al Gasip. Approximately 40 km from the asphalt the road leaves the wadi and trends north-northeast for 30 km to the Dhahar region. Travel from the asphalt to Dhahar takes about 2 1/2 hours.

Work in the Dhahar-Al Hajrah region is part of a series of mineral investigations by the U.S. Geological Survey made in accordance to a work agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

GEOLOGY OF THE DHAHAR-AL HAJRAH REGION

Introduction

Precambrian rocks within the Dhahar-Al Hajrah region are mostly of volcanic origin, are coarsely to finely layered, and range in composition from basalt to dacitic tuffs (pl. 1). They are intensely folded and metamorphosed to greenschist and lower amphibolite facies. Compositional layering is generally parallel to foliation, and both layering and foliation strike north and dip steeply west. In the western part of the area, volcanic rocks have been syntectonically intruded by a hypabyssal quartz porphyry pluton and dikes that extend considerable distances from the main intrusive body. The quartz porphyry intrusives and volcanic rocks are cut by later quartz porphyry dikes in most of the mapped region. The dikes are generally sill-like, but in places cut across layering and schistosity. They are distinguished from other quartz-crystal rocks by the larger size and higher percentage of quartz crystals. Because of their complexity the dikes were not mapped separately.

W.R. Greenwood (1980) assigned the layered rocks in this region to the Jiddah group. This series of metasedimentary and metavolcanic rocks abuts against intrusives just north of Dhahar, and their extension north of these intrusives is in question. From Dhahar these layered rocks have been mapped south into Yemen. Greenwood (1980) assigned the mafic volcanic flows, cinder tuffs, and volcanic breccia to the Wassat formation of the Jiddah group, and his rock descriptions fit closely those for rocks of the Dhahar-Al Hajrah region.

The more acidic volcanic rocks are found higher in the stratigraphic section and are interpreted to overlie the more mafic volcanic rocks (pl. 1). Greenwood (1980), however, does not recognize acid quartz-crystal volcaniclastic rocks in the region; he considers all quartz-crystal units as sills, dikes, or plutons. There is general agreement between Greenwood and the author concerning intrusive quartz porphyry rocks in the western part of the mapped area, although Greenwood believes the area is underlain by adjoining quartz porphyry sills, whereas the author believes that the region was intruded by a large, hypabyssal, syntectonic pluton that sent out dikes a kilometer or more from the main intrusive.

No recognizable "key" layers were found in the mapped area to aid in stratigraphic correlation. Marbles would ordinarily serve as marker beds, but within the region they appear as lenses of short strike length, which are obviously boudins sheared into their present position, and thus serve no correlative purpose.

Layers of quartz-crystal pyroclastic breccia were mapped at the East Dhahar workings, in a region about 2 km west of Dhahar, and at Al Hajrah. Although the breccias are similar in many respects, they are discontinuous, adjoin different rock types, and differ somewhat in texture and composition from one area to another and, consequently, are noncorrelative. One zone of pyroclastic rocks of intermediate composition just west of the mapped area displays a gradation from east to west of nonlayered pyroclastic breccias to crudely layered breccias and tuffs and then to finely laminated water-laid tuffs. These changes in layering and grain size are the best evidence that progressively younger rocks occur to the west. Conway (written commun.), in his mapping of the Mesane region 12 km southeast, came to the same conclusion.

In Precambrian times, the region was the scene of extensive volcanic activity. Pillow basalts suggest that some was submarine. Vast amounts of quartz-crystal pyroclastic breccias suggest that centers of volcanism were within or close to the mapped region. According to Greenwood and others (1976), the Jiddah group rocks were deposited during the Aqiq orogeny, the first episode in the Hijaz tectonic cycle, approximately 960 m.y. ago.

Stratigraphy

Volcanic rocks are crudely layered in most of the mapped area, and the stratigraphic sequence from bottom to top is: basaltic and andesitic flows (baf) underlying and interbedded with quartz-crystal tuff (qct). This sequence is probably not much more than 100 m thick. Massive quartz-crystal tuffs (qct) overlie basalts and are probably at least 1000 m thick, but direct measurements are impossible to make because of tight isoclinal folding, faulting, and lack of marker horizons. Lenses of dolomitic marbles as thick as 25 m are interbedded with quartz-crystal tuffs. The quartz-crystal tuffs are overlain by quartz-crystal pyroclastic breccia (qcb), which is the top of the volcanic pile for the felsic volcanic series. They are approximately 200 m thick. In the southern part of the mapped area (pl. 1), felsic volcanic rocks are overlain by pyroclastic rocks of intermediate composition. These intermediate rocks extend a considerable distance outside the mapped area and are perhaps several thousand meters thick.

Rock descriptions

Basalt and andesitic flows (baf)

Basalt and andesitic flows crop out only in the Dhahar area and appear to be interlayered with, and probably underlie, much of the quartz-crystal tuff (qct) (pl. 1). The rocks of this unit weather dark green, locally show flow and pillow structure, and are vesicular. In places the vesicles are lined with yellow-green zeolites. These rocks are definitely of volcanic flow origin. However, in places similar rocks appear to be dikes or sills within quartz-crystal tuff. Small areas of outcrop south of Dhahar are either of flow breccia or of pyroclastic origin as evidenced by large basalt fragments within a basaltic matrix. In thin section the rocks display a fine, felty chlorite matrix containing scattered hornblende, augite, pyrite, and magnetite.

Quartz-crystal tuff (qct)

Quartz-crystal tuff is everywhere strongly schistose and weathers gray to green (pl. 1). Typically, the rock is composed of 3-4 percent blue-gray, subhedral quartz crystals 3-5 mm in diameter in a nearly homogeneous matrix of chlorite, sericite, and silica. The blue-gray crystals are the distinguishing characteristic of the rock. Layering is not obvious in most outcrops. However, certain subtle variations in texture were noted in the Dhahar area where more detailed mapping was done. These variations are: 1-2-m-wide zones of pyroclastic material where clasts as large as 10 cm are barely distinguishable; narrow chlorite bands with associated carbonaceous material; strongly calcareous layers a few meters wide; layers of pumiceous material a few centimeters wide; and bands of lapilli tuff. Size of quartz crystals also varies within the unit.

Immediately west of Dhahar, where interlayered basaltic rock is absent, the quartz-crystal tuffs are devoid of any obvious layering, but farther west and thus closer to the quartz-crystal pyroclastic breccia and quartz porphyry intrusive (pl. 1), layering is obvious and is due to the presence of 2-3-m-thick layers of pyroclastic breccia alternating with massive tuffs.

Dolomitic marbles (dm)

Several lenses of dolomitized marbles are scattered within the region (pl. 1). These rocks weather to medium brown and are brownish gray on fresh surfaces. They are interbedded with quartz-crystal tuffs (qct) and are found in places in contact with coarse pyroclastic breccias (qcb), or pyroclastic rocks of intermediate composition (pc). The marble lenses are mostly a few meters in strike length and are generally brecciated and cut by a network of white quartz veins and stringers. Boudinage structure in these marbles is the result of de-formation of thin lenticular limestone beds that were minor components in the premetamorphic stratigraphic sequence of volcanic and sedimentary rocks.

Quartz-crystal pyroclastic breccia (qcb)

Quartz-crystal pyroclastic breccias adjoin the East Dhahar ancient workings, are in contact with an intrusive quartz porphyry about 2 km west of Dhahar, and overlie quartz-crystal tuff (pl. 1). Although more siliceous, they are compositionally very similar to the quartz-crystal tuffs and contain blue-gray quartz crystals in both clasts and matrix. The size of clasts varies; in the Dhahar area individual clasts may exceed 30 cm length, whereas in the Al Hajrah area they average 15 cm or less. The average thickness of the unit is approximately 200 m.

In some localities, the textures of the rocks are very well preserved and the lighter colored clasts, ranging from a few millimeters to more than 30 cm in length, stand out in contrast to the darker, fine-grained matrix. All of the clasts are angular and rectangular, and have preferred orientation, giving the rock a layered appearance. These rocks were probably formed as the result of ash flows as described by Ross and Smith (1961). They probably represent the final phase of differentiation and crystallization within a volatile-rich magma and are situated at or near the top of the volcanic pile close to a volcanic vent.

Pyroclastic rocks of intermediate composition (pc)

Pyroclastic rocks of intermediate composition are exposed mainly in the Al Hajrah area and extend south and west of the mapped region (pl. 1). The rocks weather dark grayish green to olive green and include volcanic flows, coarse breccias, and finely laminated tuffs. Pyroclastic rocks predominate, and parts of this unit several hundred meters thick are composed entirely of bomb fragments, which evidently formed huge piles. Parts of this unit also are composed of fragments averaging 10 cm long with little or no intervening matrix, but volcanic flows have clasts in a fine-grained, amygdaloidal, or vesicular matrix. Rocks of the unit are varied and include banded tuffs, feldspar porphyries, thin layers containing pillow structure, thick layers containing pumice fragments ranging from lapilli to bomb size, local zones containing large euhedral pyroxene crystals within a fine-grained matrix, and cherty lenses a few meters thick, generally containing finely disseminated pyrite.

These volcanic rocks range in composition from dacite to basalt, but andesites are predominant. Where vesicular, the vesicles are lined with tremolite or light-green zeolites. Large areas of this unit show propylitic alteration.

Quartz porphyry intrusives (qp)

Quartz porphyry intrusive rocks underlie the western part of the Dhahar-Al Hajrah region and extend a considerable distance west of the mapped area (pl. 1). In many respects, they closely resemble quartz-crystal tuffs, but they are less schistose and weather to rounded forms. In outcrop, they are light brown to tan in contrast to the tuffs, which weather gray to greenish gray. Locally these rocks display intrusive rock textures, and bluish-quartz crystals are more abundant than in the volcanic rocks.

The pluton is hypabyssal and contains xenoliths of older rocks ranging from several centimeters to several kilometers in length. It is of syntectonic origin and in many places displays evidence of folding and shearing.

Dike swarms of quartz porphyry extend out from the main pluton and are especially numerous in the Al Hajrah area. Although finer grained, they resemble the parent pluton in most respects and have also been folded and sheared. They are commonly hydrothermally altered and are thought to be genetically related to the deposition of sulfide minerals at Al Hajrah.

Late-phase quartz porphyry dikes intrude the quartz porphyry pluton and were observed cutting the earlier quartz porphyry dikes. They extend into all of the mapped area but are more abundant in the Dhahar area. They are distinguished from other quartz-crystal-bearing rocks because their bluish-gray quartz crystals are larger, averaging nearly 1 cm in diameter, and the quartz crystals make up a larger percentage of the rock volume. This quartz porphyry unit occurs in intricate dike swarms, especially in the Dhahar region. Although extensive, they were not mapped separately because of their complexity.

Metadiabase sills (ms)

On the northeastern edge of the mapped area (pl. 1), metadiabase sills form a belt as wide as 7 km that extends southeast into the adjoining Mayza quadrangle (Greenwood, 1980). The rock forms long, rounded hills and Jabal Dhahar, just east of the ancient workings, is composed of metadiabase. A few narrow dikes of metadiabase crop out in the Dhahar area, but generally are not present in the remainder of the mapped area. Greenwood (1980)describes the metadiabase as sill-like, weakly schistose, and with diabasic texture of coarse-grained phenocrysts of mafic minerals and plagioclase.

Biotite-hornblende granodiorite (gqm)

A biotite-hornblende granodiorite pluton intrudes Jiddah group rocks in the extreme northwest corner of the mapped area (pl. 1). This rock is light gray and medium grained, and modal analysis by Greenwood (1980) indicates a granodiorite to quartz monzonite composition. Both Jiddah group rocks and the granodiorite are strongly pyritized near the contact of the pluton.

Aplite dikes or sills (ad)

Aplite dikes or sills are found mainly in the Al Hajrah region where they trend north, parallel to rock foliation (pl. 1). In outcrop, they are light tan and exhibit a typical fine-grained aplitic texture. They are generally pyritized and locally silicified. These rocks may be genetically related to biotite-hornblende plutons.

Basalt dikes (bad)

Basalt dikes crop out north and south of Dhahar (pl. 1) and may be correlative with the As Sarrat basalt field of Oligocene age. The rock is a dark-gray, unmetamorphosed, amygdaloidal basalt.

Structure

Rocks in most of the region have been tightly, isoclinally folded, and layering and foliation strike approximately north and dip steeply west. Southward from the Al Hajrah area strikes of the foliation and layering change to a northwest direction, parallel to major faults at the periphery of the Wadi Tarib batholith (pl. 1) (Greenwood, 1980). Tight folding is best observed in the Al Hajrah region where there are north-trending anticlinal ridges of intermediate pyroclastic rocks (pc), which overlie the quartz crystal tuff (qct). These rocks do not appear to be overturned. Several lineation measurements taken in the Al Hajrah district indicate that the folded rocks plunge south. Such structures would account for the lack of quartz-crystal tuffs south of the Al Hajrah area and indicate that the Al Hajrah area is part of a south-plunging anticlinorium (pl. 1).

Major, late, east-trending faults and joints cut all rocks and controlled the development of much of the drainage system for the region. These breaks may be traced for many kilometers but displacement along faults is only a few meters horizontally. In several places outside the mapped area the faults are marked by the occurrence of Tertiary basalt.

MINERAL EXPLORATION IN THE DHAHAR-AL HAJRAH REGION

Introduction

During the first phase of investigation only the rocks immediately surrounding the deposits at Dhahar and Al Hajrah were studied. Later, mapping was expanded to include all of the area between the two deposits in an attempt to understand better the genetic relationship of the deposits and to gain a more thorough knowledge of the general geology of the region.

At East Dhahar, West Dhahar, and Al Hajrah, results of geologic mapping, sampling of veins and gossans, and geochemical sampling were encouraging enough to recommend a small diamond drilling program. Consequently, one hole was drilled at each deposit.

All samples were assayed in the DGMR* laboratories in Jiddah under the direction of Joe Curry of the U.S. Geological Survey. Each sample was assayed by atomic absorption method for gold, silver, copper,

*Saudi Arabia Directorate General of Mineral Resources lead, and zinc. In addition, each sample was assayed for these metals and 26 other elements using semi-quantitative spectrographic techniques.

Geochemistry - Dhahar

A preliminary survey of the Dhahar area (fig. 2) consisted of three lines oriented east-west and spaced about 250 m apart with sample intervals at roughly 10 m (figs. 3 and 4). Results from the preliminary survey indicated that much of the pyritized zone at West Dhahar is anomalous in copper and zinc values. A followup survey of fill-in sampling with spacing at roughly 25 m gave comparable results. It was not considered necessary that East Dhahar be sampled in much detail by this method because considerable sampling of veins and gossans had previously been done in this zone. The method of sampling was to gather rock chips around an area of approximately 1 m diameter.

A total of 370 points were sampled and values in copper and zinc were grouped statistically using the method of Lepeltier (1969) to determine anomalous values. It was found that four groupings for both lead and zinc would suffice in delineating anomalous zones. The zones of greatest interest were found to be the gossanized zone at East Dhahar and the pyritized area at West Dhahar where samples containing more than 150 ppm Cu and 480 ppm Zn form a north-trending area nearly coinciding with the pyritized rock (figs. 2, 3, and 4). Continuous sampling on three lines crossing the region between East and West Dhahar give only weak anomalies in copper and zinc, and, because geologic mapping revealed no indication of sulfide deposits, it was decided that the three lines would suffice in this area.

Sulfide deposits

East Dhahar

Geology and structure.--East Dhahar is a zone of intermittent, shallow workings about 400 m long, with irregular and narrow lenses of gossan (figs. 2 and 5). The mineralized zone, which was mapped and sampled on a scale of 1:500, contains a large, massive quartz vein as the prominent feature. Ancient miners worked secondary copper and zinc minerals along the selvages of the quartz vein and in country rock a short distance from the vein. Intense shearing and quartz-sericite-pyrite alteration roughly define the mineralized zone, which is about 25 m wide at its widest part. Pods of gray-brown, brecciated marble are dispersed along the zone, and locally gossans in contact with quartz-crystal tuffs have been worked. Ancient workings and sulfide metallization are found mostly within quartz-crystal tuffs and parallel to contacts between these rocks and basaltic flows to the west and quartz-crystal pyroclastic breccias to the east. A quartz porphyry dike intrudes both the quartz-crystal tuffs and pyroclastic breccia, and is also cut by quartz veins and sulfide mineralization.

The sulfide deposit lies on the east limb of what is thought to be a southerly-plunging antiform (fig. 2). Basaltic rocks in contact with the sulfide deposits have a well-developed fold axis a few meters

EXPLANATION

TERTIARY?

bad — MAFIC DIKES–Late, unmetamorphosed, fine-grained

PRECAMBRIAN

qcp — QUARTZ PORPHYRY DIKE–Blue quartz phenocrysts as much as 5 mm in diameter

qcb — QUARTZ–CRYSTAL PYROCLASTIC BRECCIA–Both fragments and matrix contain blue-gray quartz crystals. Weakly to moderately schistose. Weathers gray

qct/dm — QUARTZ–CRYSTAL TUFF–Not obviously layered. Displays marked schistose structure. Contains blue-gray quartz crystals as much as 5 mm in diameter. Weathers gray to light green. Contains narrow lenses of marble (dm), partly dolomitic; in places cut by veins of milky quartz; interlayered with quartz-crystal tuff; weathers brown to gray-brown

baf — METABASALT TO META-ANDESITE–Locally has pillow structures and is vesicular. Weathers to dark green

CONTACT

FAULT

GOSSAN

DISSEMINATED PYRITE

ANTICLINAL FOLD AXIS–Showing direction of plunge

80 STRIKE AND DIP OF LAYERING

85 STRIKE AND DIP OF FOLIATION

ANCIENT WORKINGS

ANCIENT SLAG PILE

DA–2 HORIZONTAL PROJECTION OF INCLINED DIAMOND DRILL HOLE

0 200 400 m

Figure 2.–Geologic map of the Dhahar area.

northwest of the northern extremity of the deposit. However, careful mapping indicated that the sulfides do not wrap around the fold nose at the surface. Quartz veining, lenticular gossans, and foliation parallel the fold limb, striking N.15° W. in contrast to the prevalent north-striking layering and foliation. All rocks, including those of the mineralized zone, dip steeply west.

Diamond drill hole DA-1, which penetrated the east limb of folded basalt, intersected a sharp, faulted contact between quartz-crystal tuffs and white, pure talc at approximately 60 m vertical depth (fig. 6). Mapping of the same contact at the surface disclosed metabasalt in sheared contact with tuffs, indicating that a drastic change in rocks occurs between the surface and 60 m depth. The talc may be the hydrothermally altered part of the basaltic fold limb or it may be hydrothermally altered dolomitic marble that has been sheared into its present position and thus lends no clue as to the relative movement of the rocks.

Previous work, including surface mapping and the drilling of one diamond drill hole, has provided no evidence concerning the relative position of the sulfide bodies in regard to the present erosional surface. Consequently, it is not known if that interval between the surface and the intersected sulfide zone at 70 m vertical depth is the top, bottom, or middle of the sulfide zone. Several more drill holes would be needed to establish the relative position, and also to learn more details concerning controlling structures associated with the sulfides.

Surface sampling results.--All exposed gossans, as well as part of the large quartz vein, were sampled. Sample locations are shown on figure 5 with values for gold, silver, copper, lead, and zinc.

According to sample results a rough zoning of copper and zinc minerals within the deposit is defined by higher zinc-copper ratios in the northern part of the zone. Neither gold, silver, or lead is present in anomalously large amounts.

High values of zinc were obtained in sheared and heavily gossanized marbles where the gossans are composed of medium- to dark-brown, earthy limonite, manganese oxide, and smithsonite ($ZnCo_3$). Apparently the marble acted as an efficient trap for zinc transported in the surface and near-surface environment.

Table 1 lists ranges of values and arithmetic means for gold, silver, copper, lead, and zinc for samples taken at East Dhahar.

Table 1.--*Summary of analytical results of 58 surface samples from East Dhahar*
[Average sample width 1.42 m]

	Gold 1/ (grams/ton)	Silver (grams/ton)	Copper (percent)	Lead (percent)	Zinc (percent)
Range	Nil-6.00	<0.05-11.5	0.01-4.23	0.001-0.48	0.02-58.50
Arithmetic mean	0.370	2.790	0.438	0.115	2.246

Because of leaching by surface water and enrichment of copper and zinc in carbonate-rich zones, surface sampling of gossans gives only a general indication of the amount of these elements present in the sulfide zone at depth. Nevertheless, the results of surface sampling at East Dhahar were favorable enough to recommend a drill hole that would intersect the sulfide zone.

Description of diamond drill hole DA-1.--Drill hole DA-1 was proposed in order to test a postulated sulfide zone below the area where gossans appear in greatest quantity. The hole, declined at a minus 45° angle in the direction N.75° E., was positioned to intersect the mineral zone at about 70 m vertical depth (figs. 2 and 6). A detailed log (pl. 2) is in the back pocket of this report.

Drilling began in andesite containing wisps of limonite after pyrite. This rock was penetrated to a down hole depth of 20.90 m, after which quartz-crystal tuff with alternating siliceous and sericitic bands was intersected. A few milky quartz stringers were cut within this zone. Disseminated sulfides, which are very sparse near the top of the hole, increase gradually with depth. They consist mainly of pyrite and very minor sphalerite and chalcopyrite replacing pyrite, but, on the whole, these minerals are not important economically in this section. At 99.60 m sphalerite and chalcopyrite appear as thin wisps and bands in minor amounts paralleling foliation. This type of mineralization continues to a depth of 111.00 m where a sharp faulted contact with white, talcose rock free of sulfides was penetrated. From 118.00 m quartz-crystal tuff continues to a depth of 122.10 m where a zone of nearly massive sulfides of 40 cm horizontal width composed of pyrite, light-brown sphalerite, and chalcopyrite was cut. The sulfide lens assayed 0.36 g/t Au, 20.6 g/t Ag, 1.45 percent Cu, 0.09 percent Pb, and 23.68 percent Zn. The weighted averages of the drill hole intersection from 119.00 m to 123.00 m, a horizontal width of 3.40 m, are 0.147 g/t Au, 4.84 g/t Ag, 0.487 percent Cu, 0.016 percent Pb, and 4.170 percent Zn.

1/ grams per metric ton, equal to parts per million, are used for analytical results in this report.

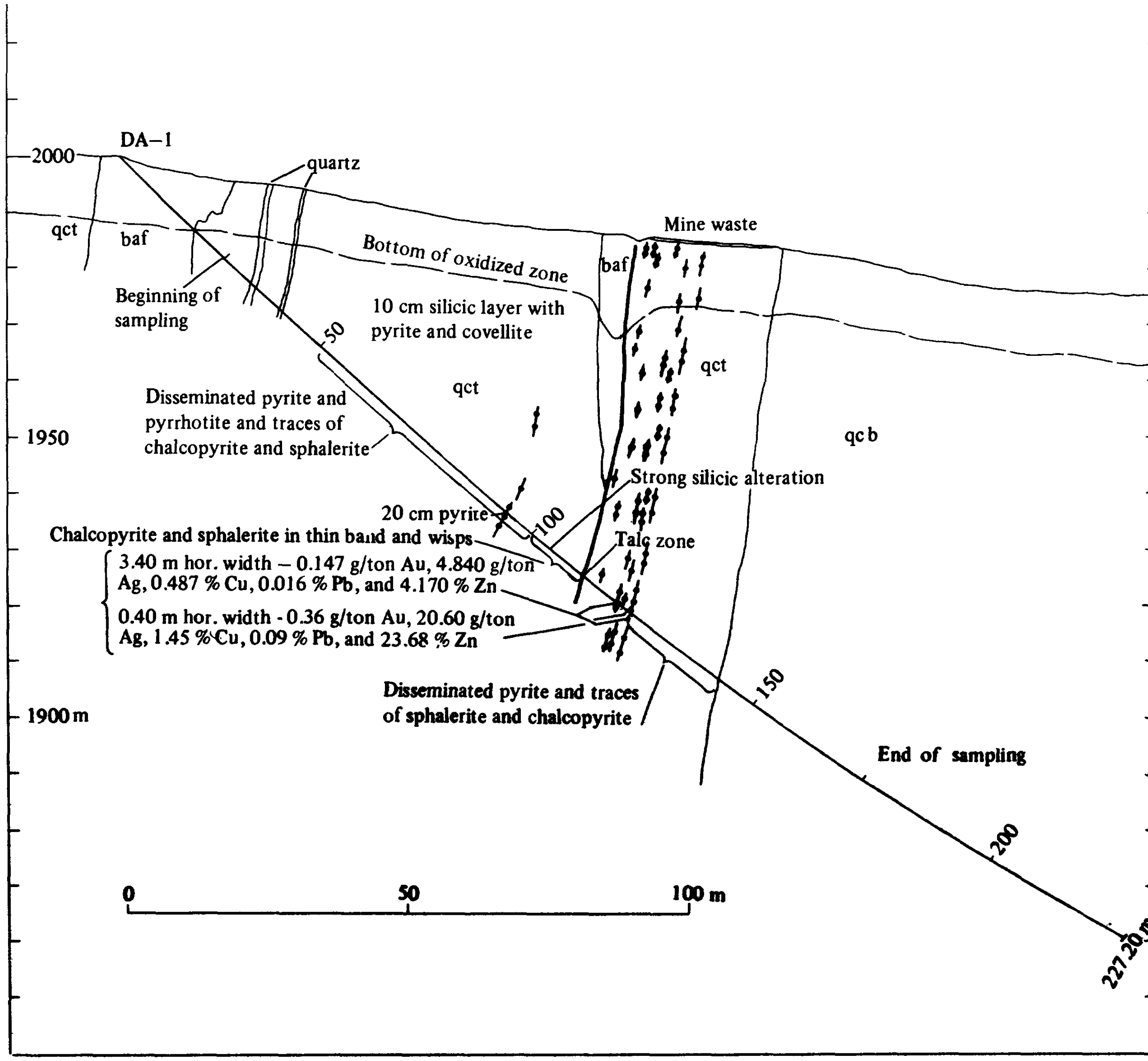


Figure 6.–Geologic section along drill hole DA–1.

One other intersection of moderate economic interest is the interval between 125.00 m and 128.00 m where a weighted average of 0.59 g/t Au and 5.4 g/t Ag and very low copper and zinc values were obtained. A one-meter interval within this zone assayed 0.96 g/t Au and 5.4 g/t Ag.

Below 128.00 m sulfides composed almost entirely of pyrite gradually diminish with depth and from 176.00 m to the bottom of the hole at 227.20 m the rock is almost entirely free of sulfides.

The hole bottomed in quartz-crystalline pyroclastic breccia.

Ore genesis.--Core drilling at East Dhahar intersected a zone of obviously layered sulfides (fig. 6), mostly as thin wisps and bands paralleling layered rocks. Because of the lack of cross-cutting features, it is believed that the sulfides were originally deposited in this form.

This geologic environment, in which silicic, sulfide-bearing pyroclastic rocks are in contact with mafic volcanic rocks, seems to fit the model of a sulfide body generated by volcanic activity (Routhier and Delfour, 1974; Anderson, 1969; Kinkel, 1966). A jasper-pyrite lens, which ordinarily is found capping the sulfides, was not recognized at Dhahar, either on the surface or in the drill core. Otherwise, most of the criteria for a volcanogenic model are met.

West Dhahar

Geology and structure.--West Dhahar, which is separated from East Dhahar by approximately 500 m, is on a sharp, narrow, north-trending ridge about 500 m long. Centered on the ridge is a zone of disseminated pyrite at least 900 m long and as wide as 200 m (fig. 2). Quartz-crystal tuffs (qct), which display no layering, are the principal rock types within this zone, but they are locally interlayered with basaltic flows (baf), and are cut by late mafic dikes (bad). Narrow zones of weak to moderate silicification trend along the crest of the ridge. The tuffaceous rocks of the Dhahar area strike north and dip steeply west. The pyritized zone, also, is on a north trend and, according to drill hole information, dips steeply west.

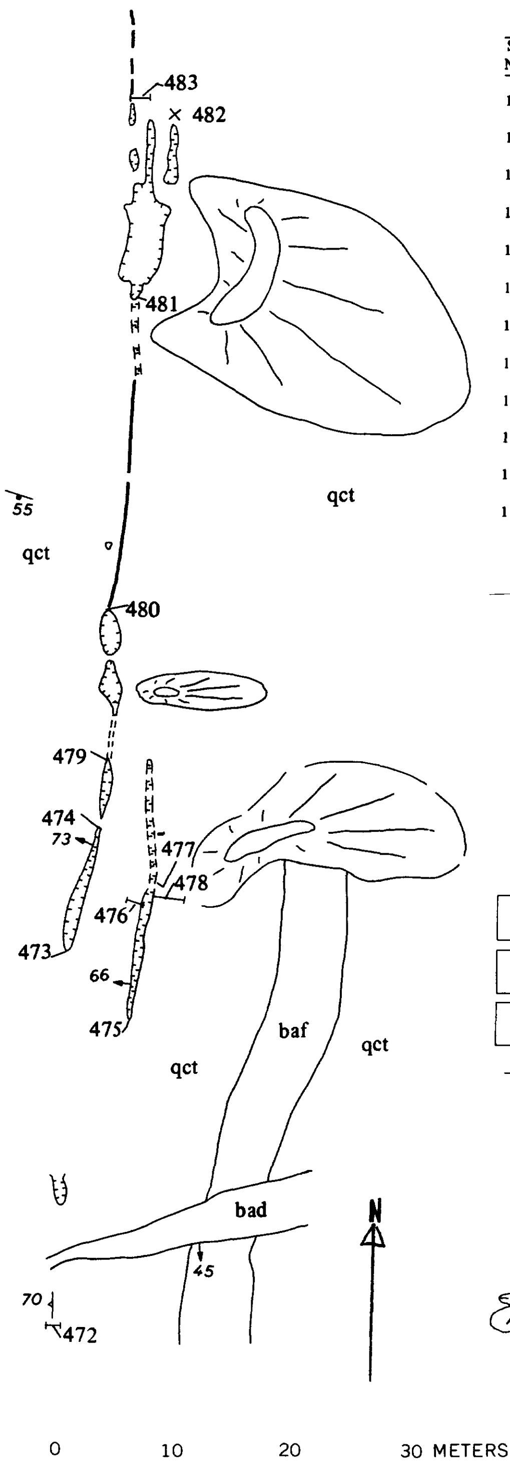
Detailed mapping and sampling.--Narrow ancient workings, which trend parallel to the crest of the ridge, were mapped and sampled at a scale of 1:500 (fig. 7). Evidently, the ancient miners were following secondary copper, zinc, and perhaps silver minerals, but only minor copper staining and no zinc or silver minerals were seen along the walls of the workings. Twelve continuous chip samples were taken across ends of workings, or where wall rock contained secondary copper minerals. Sample location and descriptions are shown on fig. 7. Samples 114475, 114479, and 114481 contained 12.6, 66.5, and 10.5 grams of silver per ton, respectively; otherwise metal content of the samples was low. A 50-cm-wide gossan north of West Dhahar ridge, but still within the pyritized zone, assayed 0.94 g/t Au, 16.00 g/t Ag, 0.30 percent Cu, 0.08 percent Pb, and 0.37 percent Zn. No other evidence of sulfide metallization was seen at West Dhahar other than the presence of hematitic limonite after disseminated pyrite.

Description of diamond drill hole DA-2.--The primary target of this drill hole was to intersect the pyritized copper and zinc anomalous zone at a depth of about 80 m below the surface (fig. 8). The hole was collared in the direction S.86°E. at an angle of minus 45°.

Rock descriptions.--The drill hole (pl. 2) began in quartz-crystal tuff having fine banding of lighter and darker laminations that are not readily apparent at the surface. With the exception of a narrow, late mafic dike exhibiting hematitic limonite on both contacts at 33.20 m and several milky white quartz stringers at various intervals, the hole continued through quartz-crystal tuff to 103.70 m where dark-green andesitic rock containing porphyroblastic amphibole needles was intercepted throughout approximately 1 m. The hole continued in banded metatuff to a depth of 152.00 m where a metadiabase dike less than 1 m wide was intercepted. At 162.00 m the hole passed through a 20-cm layer of pumice fragments and again re-entered banded metatuff to a depth of 169.00 m where alternating bands of pumice fragments and metatuff with mottled texture continued to 176.00 m. The remainder of the drill hole intersected banded tuff to the bottom of the hole at 216.30 m.

Sulfide metallization.--Drill hole DA-2 intercepted disseminated sulfide minerals in varying amounts from 68.50 m to 180.00 m. The horizontal width of the sulfide zone is 90 m and, projected from the surface the western border, is nearly vertical or dips steeply (fig. 8). The eastern border seems to be nearly vertical or dips steeply east. In any case, the disseminated sulfide body is nearly vertical, is defined by sharp contacts, and appears to parallel lithologic layering in the area. Sphalerite and chalcopyrite are associated with pyrite in minor amounts throughout the pyritized zone, sphalerite in greater quantity than chalcopyrite but because of its fineness more difficult to identify. Detection of sphalerite was by microscope only where particles smaller than approximately 0.5 mm may be seen replacing and rimming pyrite or as isolated crystals (fig. 9). Chalcopyrite on the other hand, is easily identifiable, even in minor amounts. It replaces pyrite and is found in thin wisps and bands, but chalcopyrite distribution is definitely not homogeneous and is found in greater concentrations within chloritized zones, or in areas of strong quartz-sericite alteration. The chloritized zone intersected from approximately 95.00 to 100.0 m contains the highest concentrations of chalcopyrite. Both sphalerite and chalcopyrite concentrated in bands 5 to 10 cm thick were intercepted at 135.40 m, 139.70 m, and 145.50 m. Sphalerite within these narrow zones is medium brown and may represent a different generation from the finely scattered material found throughout the sulfide zone.

Discussion of zinc plot along diamond drill hole DA-2.--A plot of zinc values in percent was made for the sampled part of drill hole DA-2 (fig. 8). Values for copper were not plotted because copper content of drill core is lower and erratic.



ANALYTICAL DATA

SAMPLE NUMBER	DESCRIPTION	WIDTH (meters)	GOLD (grams per ton)	SILVER	COPPER (percent)	LEAD	ZINC
114472	Siliceous pyritized tuff	1.10	<0.005	1.30	0.05	Tr	0.04
114473	Quartz stringers in tuff	0.32	<0.005	2.00	0.08	Tr	0.07
114474	Silicified tuff with pyrite	0.40	<0.005	2.30	0.17	Tr	0.06
114475	Mafic dike with copper stain	0.45	<0.005	12.60	1.22	Tr	0.13
114476	Siliceous chloritic tuff	1.30	<0.005	3.50	0.11	Tr	0.06
114477	Mafic dike with limonite	0.30	<0.005	6.20	0.38	Tr	0.06
114478	Siliceous chloritic tuff	2.60	0.06	2.30	0.12	Tr	0.03
114479	Gossan with copper stain	0.40	0.46	66.50	1.09	0.01	0.19
114480	Gossan	0.15	0.13	2.70	0.82	Tr	0.15
114481	Mafic dike with limonite	0.64	0.10	10.50	0.35	Tr	0.11
114482	Limonite, scattered	0.65	0.06	2.30	0.84	Tr	0.08
114483	Siliceous tuff	1.63	0.08	1.60	0.10	Tr	0.05

EXPLANATION

bad	BASALT DIKES–Unmetamorphosed
qct	QUARTZ CRYSTAL TUFFS
baf	METABASALT TO META-ANDESITE
	CONTACT
	FAULT
55	JOINT–Showing dip
70	FOLIATION–Showing dip
75	ANCIENT MINE WORKINGS AND DUMP–Showing dip of workings
472	SAMPLE LOCATION–Numbers are last three digits of 114000 series

Figure 7.–Geologic map of the West Dhahar ancient mine workings showing locations and analyses of samples.

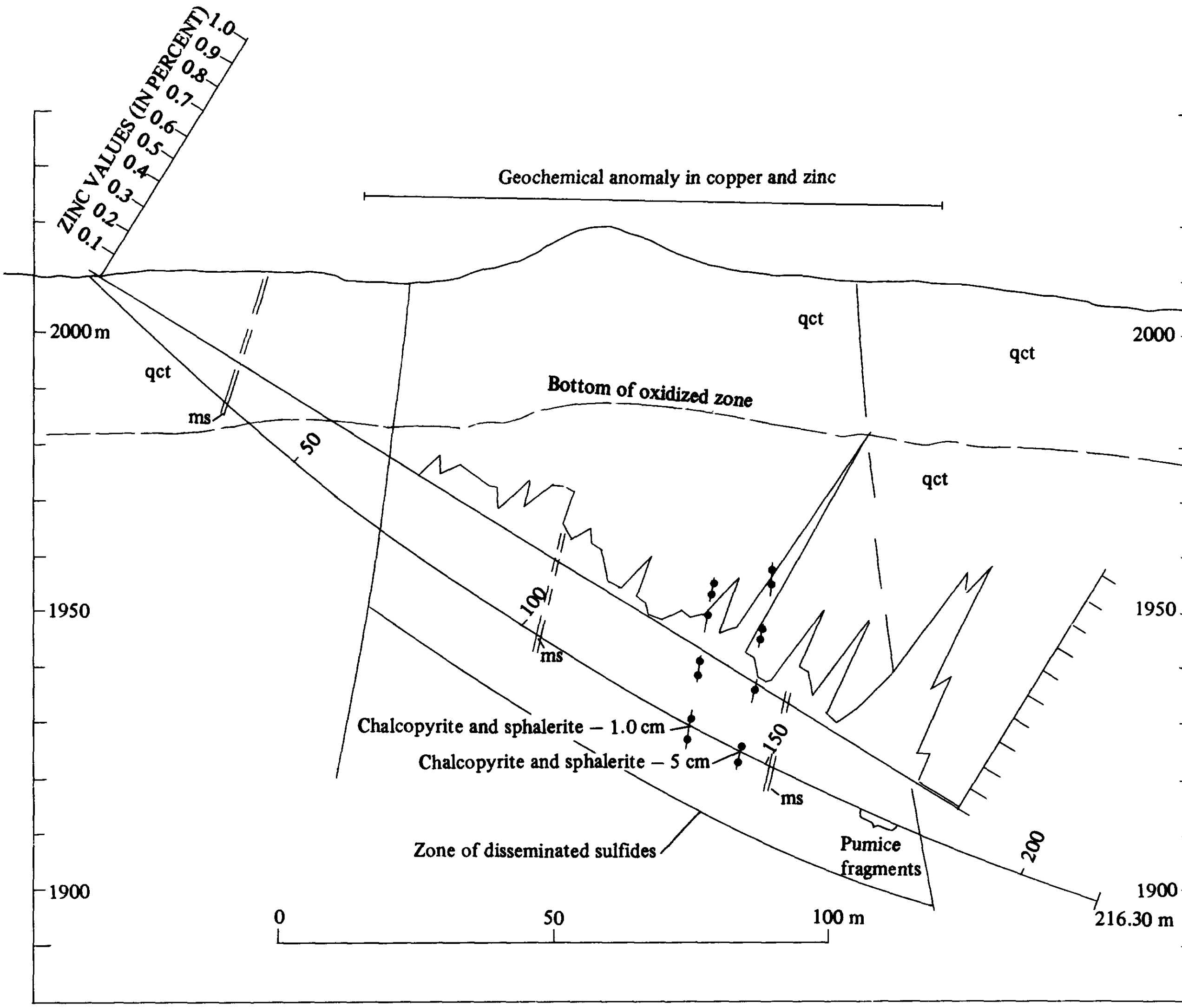


Figure 8.—Geologic section along drill hole DA–2 showing geology and plot of zinc values of sampled drill core. Each zinc value plotted is the average of two contiguous samples.

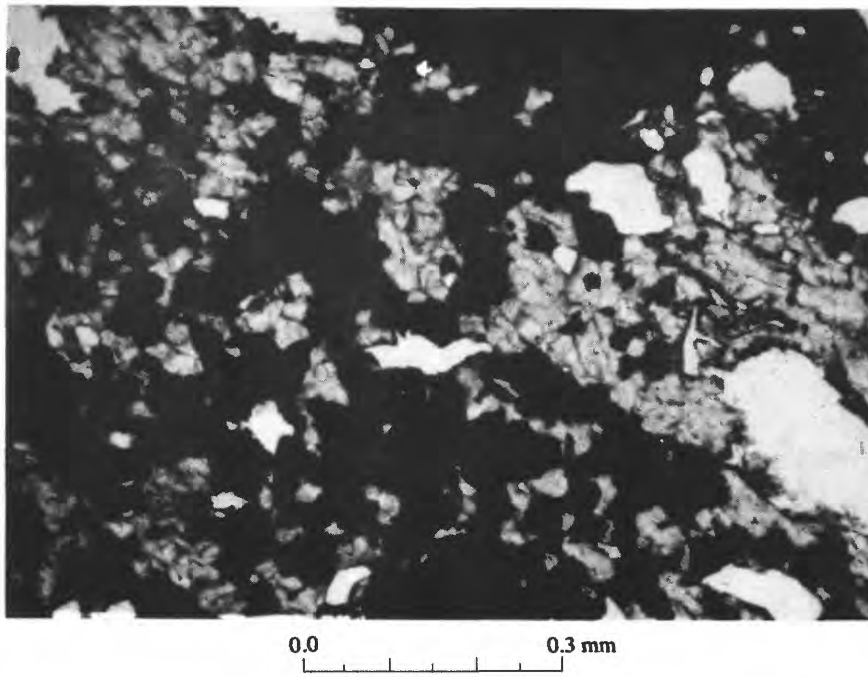


Figure 9A.–Photomicrograph of sphalerite (mottled gray) replacing pyrite (black). White areas are quartz. Plain light. From drill hole DA–2 at 128.75 m depth.

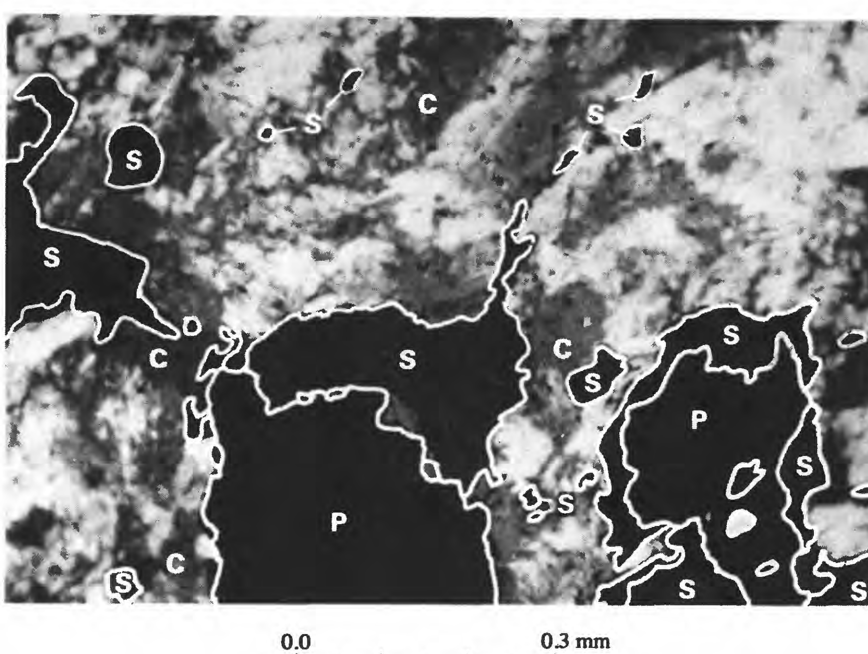


Figure 9B.–Photomicrograph of sphalerite (S) replacing and rimming pyrite (P) and disseminated within a chloritic groundmass (C). Partly crossed nic ols. From drill hole DA–2 at 128.75 m depth.

The entire sampled zone comprising 112 m along the drill hole averaged 0.18 percent or 1820 ppm Zn. The sampled width nearly coincides with the disseminated sulfide zone. For a rough comparison between results of rock sampling for geochemical analyses and sampling of the drill core, background values in zinc for geochemical sampling were found to range from 0 to 145 ppm. Thus, the average of 1820 ppm zinc within the sulfide zone would be approximately 13 times greater than background. This amount, of course, does not allow for oxidation, leaching, and transportation of zinc at the surface.

Zinc content along the sulfide zone is by no means homogeneous and most of the high values represent sample intervals containing sphalerite in bands 5 to 10 cm thick. A moderate high from 90.50 m to 96.50 averages 0.24 percent Zn. This interval coincides with a zone of strong chloritic alteration. Similarly, the interval from 125.50 m to 136.50 m averages 0.32 percent Zn, much of which is the result of 1 m of rock that assays 1.85 percent Zn. This zone is one of strong silicic and sericitic alteration. Near the end of the hole the interval from 158.50 m to 171.50 m averages 0.528 percent zinc. This zone contains layers of pumice fragments where sphalerite and chalcopyrite are found banded and disseminated at, or near, the contact with unmineralized tuffs.

Ore genesis.--Genesis of the sulfide metallization at West Dhahar is not known and most of the criteria for a volcanogenic model are not met. Only the proximity of this sulfide zone to that of East Dhahar suggests a possible genetic relationship. West Dhahar may represent an aureole of disseminated sulfides adjacent to a massive sulfide deposit. At the Mesane deposit 12 km southeast a strongly pyritized quartz-crystal tuff, similar in all respects to the tuffaceous rock at Dhahar, surrounds massive gossans. East Dhahar and West Dhahar may have been parts of the same sulfide-bearing rocks, but have since become separated because of folding and faulting.

Al Hajrah

Geology and sulfide deposits.--The Al Hajrah district measuring approximately 3.5 by 2.5 km is defined by a zone of pyritization, chloritization, and epidotization. The area, which lies between Wadi Harba on the north and Wadi Gharab on the south, is in contact with unaltered volcano-sedimentary rocks on the east and intrusive quartz porphyry on the west (pl. 1). Within this zone all of the quartz-crystal tuff (qct) and most of the quartz-crystal pyroclastic breccia (qcb) are strongly pyritized and typically weather to dark red. In addition the volcaniclastic rocks of intermediate composition (pc) have locally been subjected to chloritic and epidotic alteration, but these types of alteration are most subtle and not readily apparent. These alteration zones were not mapped separately because of the amount of effort and time needed to delineate them.

The tightly folded volcaniclastic rocks were intruded on the west by a large pluton of hypabyssal quartz porphyry, and dike swarms of the same rock type have invaded volcanic rocks a kilometer or more south and east of the main pluton. The center of copper metallization at Al Hajrah coincides with the area where dike swarms of quartz porphyry are most numerous (pl. 1). Part of this zone was mapped in detail (fig. 10) because ancient workings and scattered secondary copper minerals are more heavily concentrated here. Nevertheless, secondary copper minerals are found erratically scattered throughout all of the region defined above. Ordinarily copper oxides are within pyroclastic rocks of intermediate composition or within quartz porphyry dikes. The quartz-crystal tuffs are generally free of copper minerals. Scattered ancient workings and areas of secondary copper staining a considerable distance south and north of the dikes swarm area give evidence of the extensiveness of the scattered copper mineralization (pl. 1).

Most ancient workings are not large and judging from the size of waste dumps, are generally shallow, but there are literally hundreds of these small excavations, many only a few meters in length. Evidently any outcrop that displayed copper staining over a meter or two in diameter was worked. The number of house foundations left standing suggests that a large community perhaps related to the mining activity once existed on the banks of Wadi Mahanit. Small slag piles are adjacent to the Wadi, but most of the slag has been washed down stream by floods.

Geochemical survey of the Al Hajrah area.--The area chosen for geochemical evaluation at Al Hajrah coincides with a zone of pyritization, epidotization, and chloritization of volcaniclastic rocks. It measures approximately 3.5 by 2.5 km, and much of the zone has isolated outcrops of secondary copper minerals. Rock chip samples were gathered, where possible, at 20- to 25-m intervals along lines having trends of approximately N. 80° E., across the geologic structure of the region. Sample line intervals were ordinarily spaced at 250 m except where ease of access dictated their position (figs. 11 and 12).

A total of 901 rock chip samples were gathered and analyzed for gold, silver, copper, lead, and zinc content by the atomic absorption methods and for 26 additional elements by semi-quantitative spectrographic techniques. Analytical results for copper and zinc were then grouped statistically using the method of Lepeltier (1969) and plotted into four groupings ranging from background to highly anomalous values (figs. 11 and 12). Assay values for gold, silver, and lead were, without exception, very low and no further studies were made for these metals. Examination of semi-quantitative spectrographic analyses indicate no apparent anomalous trends for pathfinder elements such as arsenic, boron, molybdenum, or tellurium. As a result, semi-quantitative analyses for these samples are not presented in this report. However, this information is available in the Rock Analysis Storage System (RASS) maintained and operated by the U.S. Geological Survey in Jiddah.

Contouring of anomalous analytical results for copper and zinc was achieved by assuming that values are continuous along strike between sample lines. This assumption is believed to be valid based on

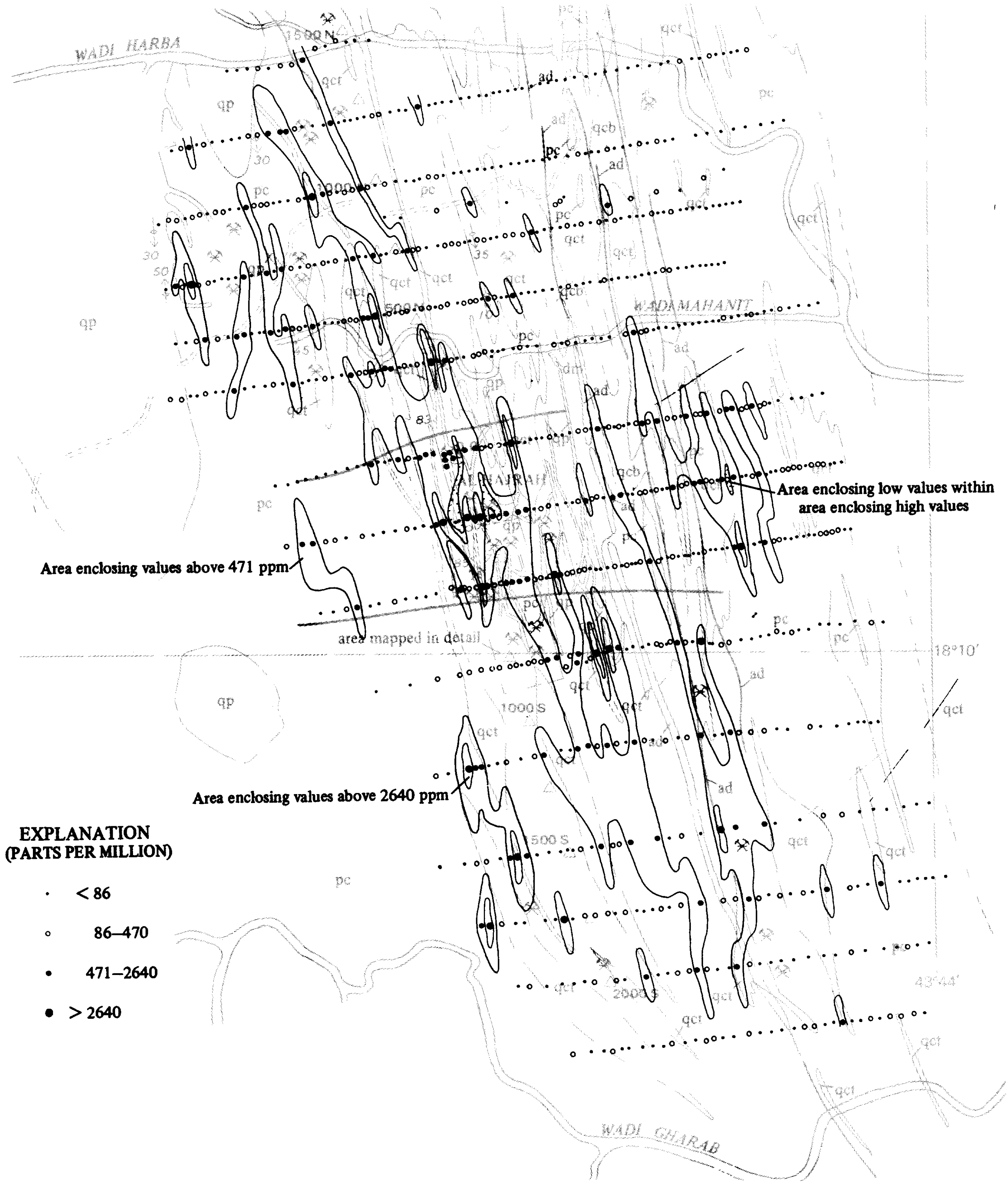


Figure 11.–Copper content of rock chip samples, Al Hajrah area.

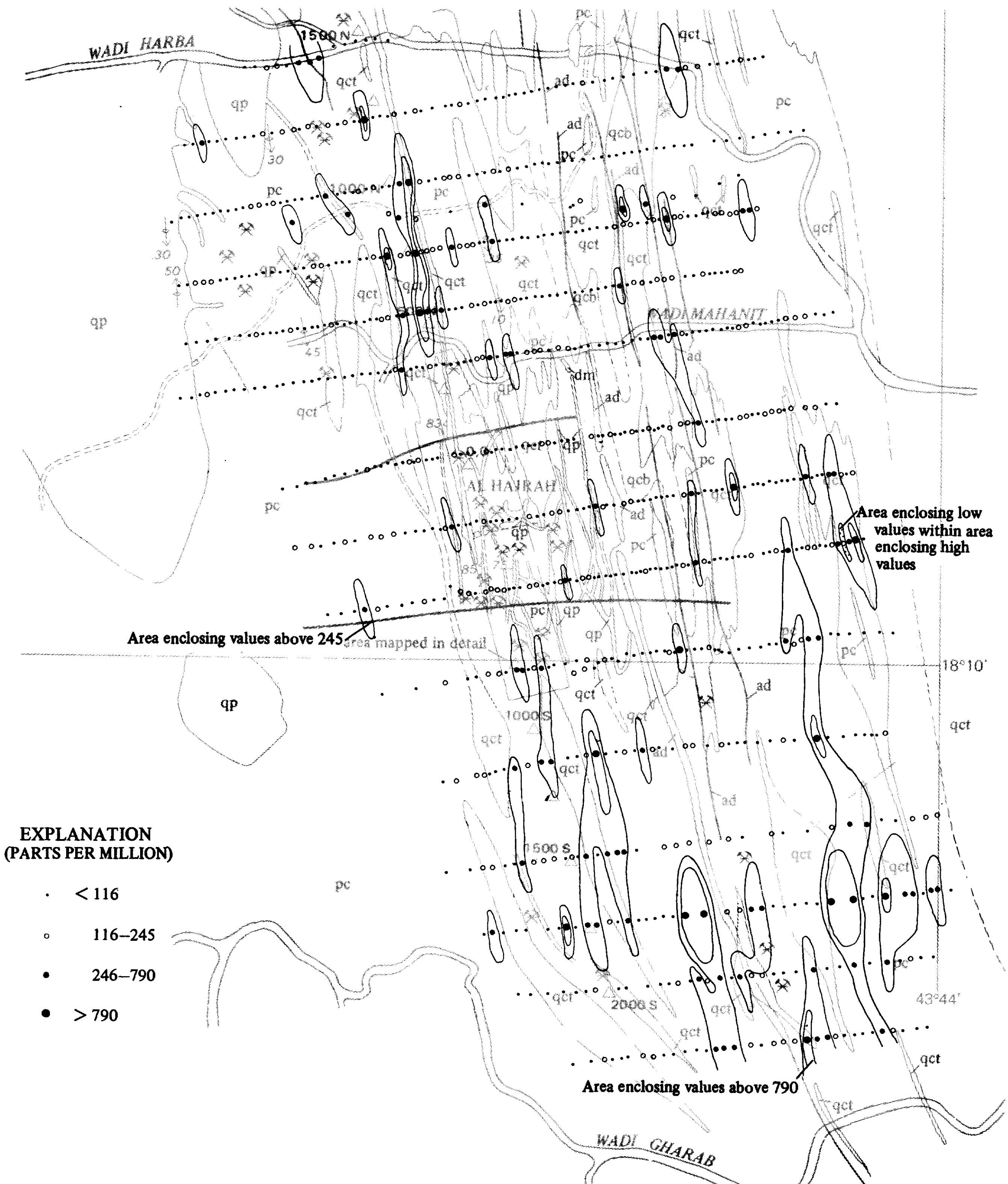


Figure 12.–Zinc content of rock chip samples, Al Hajrah area.

general geology, hydrothermal alteration, pyritization, and scattered secondary copper in outcrops and is valid especially where anomalous zones are two or more samples wide along sample lines. Only the two upper classes of copper and zinc were contoured.

The most prominent copper anomaly on figure 11 is a zone exceeding 470 ppm, which extends approximately 3.5 km in a north-northwesterly direction. Within this zone are limited areas containing greater than 2640 ppm Cu, many of which are single sample results. The large anomalous zone coincides with geologic features, mainly hydrothermal alteration and the presence of secondary copper, and indeed, in the area between 250 m north and 500 m south, where the zone approaches 400 m width, rock alteration, dispersion of secondary copper, and concentration of ancient workings are greater than in most of the remainder of the anomalous zone.

Other anomalous areas containing more than 471 ppm Cu are more confined, scattered, and in places based on the results of one sample. In the vicinity of station 1250 m south two copper-anomalous zones are shown lying east and west of the larger anomalous area. The western anomalous zone is three samples wide on two lines and delineates a sharp ridge containing a few ancient workings. The workings occur at, or near, contacts between intermediate pyroclastic rock (pc) and hydrothermally altered quartz porphyry dikes (qp) where secondary copper minerals are scattered in moderate amounts. The eastern copper-anomalous zone is underlain by pyroclastic rocks (pc) showing only minor, scattered secondary copper and a few, small, isolated, ancient workings. No quartz porphyry dikes were mapped here. Although this long, northerly-trending anomaly is only one sample wide along most of its length, it is believed to be valid because secondary copper can be found in many places within this narrow zone between sample lines. The same relationship is also true of other anomalous areas. The generalization may be made concerning the Al Hajrah area that anomalous copper zones are found only where visible secondary copper is present.

Much of the Al Hajrah area is underlain by pyritized quartz-crystal tuff (qct). Typically, the tuff contains disseminated hematite as pseudomorphs after pyrite; the occurrence of disseminated hematite pseudomorphs is similar to the situation at West Dhahar where zones anomalous in copper and zinc were found. In contrast to West Dhahar the rocks sampled at Al Hajrah show only a few copper anomalies, but the possibility of subsurface copper deposits must be considered because pH of solutions and thus leaching conditions during weathering may have been different in the two areas.

Zinc minerals were not recognized during the rock chip sample work at Al Hajrah. Sampling results indicate that zones anomalous in zinc are smaller, less continuous (fig. 12), and commonly peripheral to the copper anomalies. The higher zinc anomalies are found in the northern, southern, and eastern parts of the area. A narrow zone anomalous in zinc extends from line 500 m north to 100 m north along the base line, and is a few hundred meters east of a copper anomalous zone. Its position is controlled by a long, narrow, highly sheared and altered tongue of quartz crystal tuff (qct) that bears lensoidal gossans. It appears to represent the northern extremity of sheared, folded, and hydrothermally altered volcaniclastic rocks and coincides with the greatest concentration of ancient workings. A zinc anomaly three samples wide along Wadi Harba is open to the north, and this zone, along with a one-sample anomaly at 1250 m north, may be the northern extension of the major zinc anomaly that has been offset by faulting or en-echelon arrangement of zinc mineralization. This area is very complexly sheared, hydrothermally altered, and faulted.

Several isolated zinc anomalies trend semi-parallel to the contact between quartz crystal breccia (qcb) and pyroclastic rocks of intermediate composition (pc) and quartz crystal tuffs (qct) in the northeastern corner of the sampled area (fig. 12). Although these anomalies are apparently erratically distributed, their position adjacent to acidic volcanic breccia is of geological interest because this is a favorable environment for volcanogenic-type base metal ore bodies. A small prospect a few meters south of sample line 1250 m north, near Wadi Harba, reveals a strongly sheared zone containing brecciated pods of marble, quartz veins, and lensoidal gossans close to a body of quartz-crystal pyroclastic breccia. This association is similar to that of the sulfide deposits at East Dhahar and may be of special interest.

In the eastern and southern extremities of the district, several zones anomalous in zinc, in part only one sample wide, form a rough halo around some of the areas anomalous in copper and are open to the south on the southernmost sample line at 2000 m south. The stronger zinc anomalies appear to be nearly equally distributed between volcaniclastic rocks of intermediate composition (pc) and quartz-crystal tuff (qct), and without obvious geological control, such as gossans, hydrothermal alteration, structure, or observable zinc minerals.

In summary, the areas of anomalous zinc content at Al Hajrah generally coincide with geologic features such as gossans, favorable contacts, and hydrothermal alteration in shear zones. However, zinc anomalies in the southeastern and southern part of the sampled area are an exception because of the lack of such geological features.

Detailed mapping and sampling.--Prior to mapping and sampling at Al Hajrah, a base line 3.5 km long and running N.15° W., a direction parallel to much of the structure in the mineral zone, was laid out. Whitewashed markers, clearly visible on low-level photographs, were particularly useful in establishing position.

A zone extending approximately to stations 300 north and 750 south along the base line was selected for detailed mapping (pl. 1, fig. 10). Most of the map area is underlain by pyroclastic rocks of intermediate composition (pc) of which approximately 30 percent display irregular zones of sulfide leaching. These zones are defined by a fine cellular structure alined to foliation composed mainly of silica in which individual voids are lined with: dark-brown limonite; disseminated and finely reticulating hematite veinlets probably after pyrite; relatively large pockets of dark- to light-brown limonite in disseminated form; and massive hematite after pyrite. The leached cappings within pyroclastic rocks do not resemble those of porphyry copper deposits. There is virtually no zone of secondary copper enrichment at Al Hajrah, and also the ratio of pyrite to chalcopyrite is much greater than that found in most porphyry copper deposits (Schwartz, 1966).

Ordinarily, the leached zones are weakly to moderately stained by copper oxide minerals, mainly malachite and locally chrysocolla. Generally, rocks within the leached zones are altered and contain abundant dark-green, nearly black chlorite similar to rocks at Jerome, Arizona (Anderson, 1968) and Jabal Sayid, Saudi Arabia (Routhier and Delfour, 1974). All variations were found ranging from intensely altered rock with nearly pure chlorite to very weakly chloritized zones. Epidotic alteration is mostly associated with leached cappings and sulfide metallization in intermediate pyroclastic rocks. Epidotized rocks surround the leached and chloritized zones, but ordinarily do not contain sulfides.

Secondary zinc minerals were not encountered during mapping, and results of surface, drill core, and geochemical sampling indicate that zinc is not anomalously abundant within the immediate area.

Numerous quartz porphyry dikes were mapped in detail, but these rocks extend throughout a much larger area in the Al Hajrah district (pl. 1, fig. 10). They are definitely of intrusive origin, and in many places cut across layering and foliation, follow shears at oblique angles to layering and foliation, and terminate against east-west vertical joint planes. They have been intricately folded, metamorphosed, and hydrothermally altered. In large areas, the quartz porphyry is affected by kaolinization, probably resulting from the breakdown of disseminated pyrite, which is widespread. In lesser areas, the porphyry is altered to quartz, sericite, and silica. Locally these alteration zones display copper staining accompanied by finely reticulating and finely disseminated brown limonite, probably after chalcopyrite.

Most of the ancient workings are on, or near, the contact of quartz porphyry dikes with pyroclastic rocks of intermediate composition. Although figure 10 shows numerous workings with no indication of quartz porphyry nearby, there is quartz porphyry rock, usually containing secondary copper on the waste dumps. Because much of the contact zone is covered by talus, alluvium, and mine waste, mapping of bedrock in these areas is impossible.

Pyroclastic rocks of intermediate composition range from coarse breccias to finely laminated material in the area (fig. 10), but graded bedding was not seen. In the western part of the mapped area a narrow zone of laminated rocks indicates very intensive and intricate folding on a small scale, and the same is true on a large scale as indicated by aerial photographs. Layering and foliation strike nearly north and dip steeply west.

Continuous chip sampling of outcrops bearing secondary copper minerals was done along lines approximately perpendicular to the strike in order to evaluate the copper content of the rocks through the stratigraphic section.

An attempt was made to sample as much of the rock section as possible in the area just north and east of station 750 south on the base line. Because of the lack of continuous rock exposure it was necessary to run three separate but closely spaced sample lines to test the surface copper content of some 70 m of rock section in this zone. Weighted averages of the sample width and copper content indicate that this part of the rock section contains approximately 0.36 percent Cu at the surface. Numerous other outcrops bearing copper oxides were sampled to the north over much shorter distances, and sample results for copper were mostly in the same general range (fig. 10). Much of the area of figure 10 is covered by alluvium; otherwise, more continuous and representative samples could have been taken.

Description of diamond drill hole DA-3.--Drill hole DA-3 (pl. 2) was inclined at an angle of minus 45° in the direction N. 82° E. (figs. 10 and 13). The location of this drill hole was based on geochemical and geophysical data. An extensive zone along line 250 south contains anomalous values in copper in geochemical rock chip samples (fig. 10), and continuous chip samples taken nearby ran 0.27 percent Cu for 17.00 m and 0.36 percent Cu for 8.00 m. An induced potential survey along line 250 south indicates a strong anomaly centered at 150 m east (ARGAS, 1978).

The hole was spudded in pyroclastic breccia of intermediate composition. About 20 percent of the core consists of cavities formed by leaching of sulfides. The cavities are lined with brown-black-maroon limonite, and much of the rock is stained by secondary copper minerals, mainly malachite with lesser chrysocolla. This rock continues to 18.00 m where 1 m of massive hematitic gossan was encountered. The gossan is probably an oxidation product after pyrite and is followed by 30 cm of fault gouge. Other hematitic gossans were intersected as follows: 10 cm at 20.50 m; 5 cm at 21.80 m; and 20 cm at 22.30 m. The hole continued through pyroclastic rock composed mainly of pumice fragments and containing secondary copper. At 29.00 m a quartz porphyry dike was intersected. The contact area closely coincides with the bottom of the oxidized zone. The dike rock is strongly altered to quartz and sericite. Sulfides, mainly pyrite with lesser chalcopyrite, are found disseminated and as stockworks throughout. The sulfides are not homogeneously distributed, and some zones in the porphyry are relatively barren. Pyroclastic breccias were again encountered at 75.70 m. These rocks are moderately to strongly epidotized and consist largely of pumice fragments. At 108.00 m the hole intercepted a quartz porphyry dike similar in lithology to the quartz porphyry intersected between 29.00 m and 75.70 m, except that the lower porphyry contains greenish-black chlorite association with zones of higher sulfide concentrations. The hole continued in quartz porphyry to 175.60 m except for a narrow interval of volcanic breccia encountered at 143.00 m. At 175.60 m the hole again entered volcanic rock ranging from banded tuff to coarse breccia, and, with the exception of two narrow zones of quartz porphyry at 220.00 and 229.55 m,

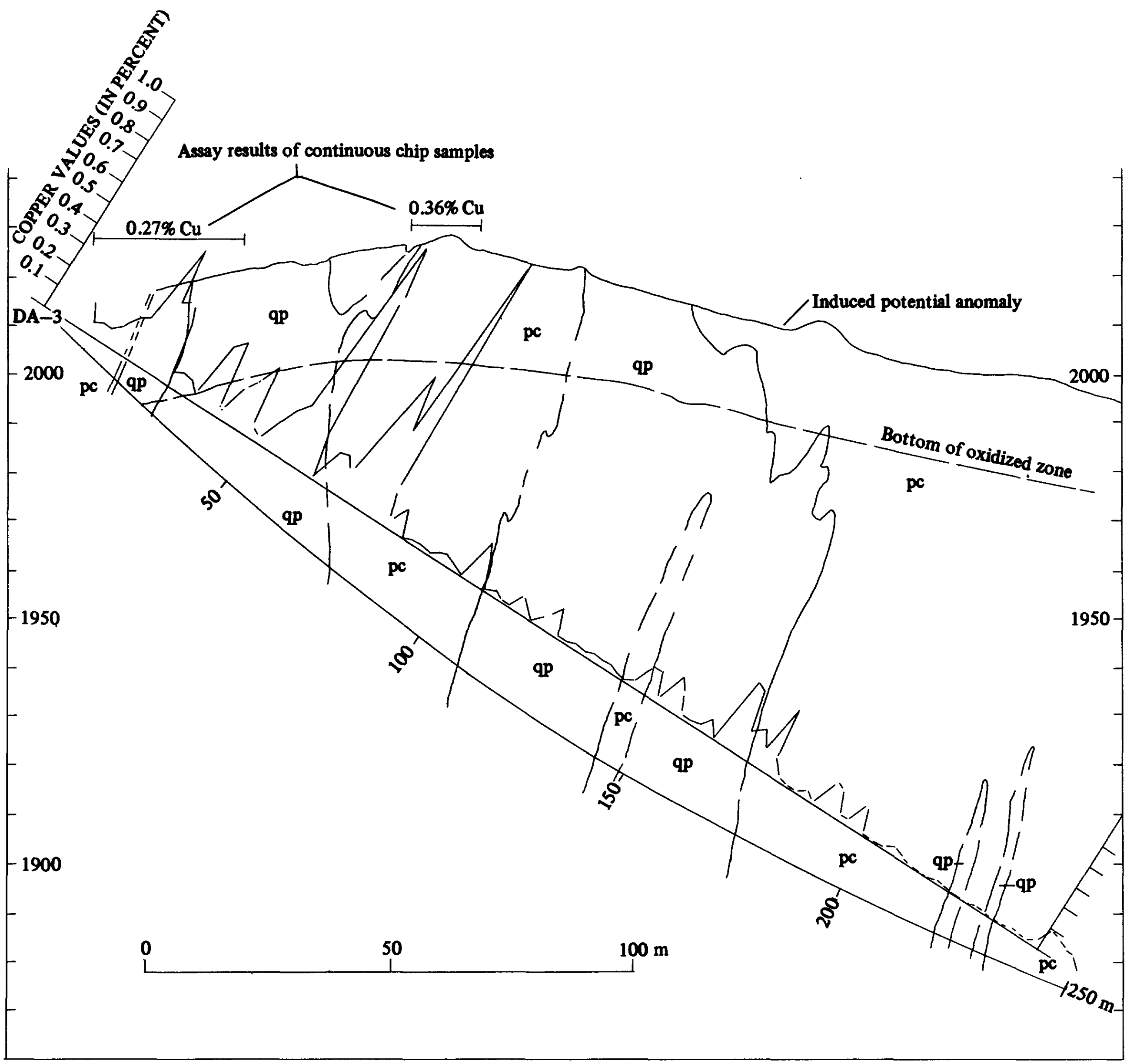


Figure 13.–Geologic section along drill hole DA–3 showing geology and plot of copper values of sampled drill core. Each copper value plotted is the average of two contiguous samples.

continued in this rock to the end of the hole at 250.00 m. Toward the end of the hole the core displays faint banding but otherwise appears textureless.

Discussion of copper plot along diamond drill hole DA-3.--Figure 13 shows the plot of copper in percent along drill hole DA-3. Continuous one-meter samples of drill core were assayed from 3.00 m to 250.00 m, the end of the hole. Zinc values for all of the samples were very low and were not plotted.

From 13.00 m to 26.00 m the drill core averaged 0.28 percent Cu and had a one-sample high of 0.75 percent Cu. This interval is in the oxidized zone and all of the copper content is in secondary copper. From 34.00 to 45.00 m the drill core averaged 0.247 percent Cu and had a one-sample high of 0.42 percent Cu. This interval is partially oxidized but secondary copper is not important. Most of the copper values come from chalcopyrite as intergrowths with pyrite, as thin wisps and bands along foliation, locally as finely reticulating stockworks, and in disseminated form. From 51.00 m to 79.00 m the drill core averaged 0.414 percent Cu, and the highest assay was 1.75 percent Cu within a one-meter interval at 76.00 m. Metallization from 51.00 m to 79.00 m consists mainly of chalcopyrite in a stockwork system within quartz porphyry, which has undergone strong quartz-sericite alteration. The last 2.2 m of the sampled zone consists of concentrated chalcopyrite in pyroclastic rocks at the contact with quartz porphyry. The one-meter samples assaying 1.75 percent Cu was obtained here.

Generally, the copper content of the pyroclastic rocks is relatively low, and, aside from two scattered one-meter intervals assaying 0.21 percent Cu and 0.13 percent Cu, only a three-meter interval from 100.00 m to 103.00 m near the contact with quartz porphyry assayed 0.20 percent Cu.

Chalcopyrite is less abundant in the quartz porphyry intercepted in the drill hole from 148.20 m to 175.60 m, although total sulfides consisting mainly of pyrite are equal to, or greater than, those in the quartz porphyry uphole. The induced potential anomaly found 150 m east of the base line likely measured the near-surface concentration of sulfides from this zone. From 163.00 m to 174.00 m the drill core averaged 0.185 percent Cu. This zone is composed of quartz porphyry locally altered to dark-green chlorite that bears chalcopyrite in bands, stringers, and disseminated form. In pyroclastic rocks the copper content again drops off markedly, but near the bottom of the hole at 240.00 m chalcopyrite reappears as tiny wisps along foliation. This mineralized rock continues to the end of the hole at 250.00 m but the highest assays obtained in this zone were no more than 0.10 percent Cu.

Ore genesis.--Surface mapping and sampling and diamond drilling have confirmed a direct spatial relationship between quartz porphyry dikes and copper metallization. The higher grade copper zones are within porphyry dikes, or in pyroclastic rocks near contacts with dikes. Therefore, it is thought that the porphyry played an important role in the formation of sulfide-bearing zones. The dike rocks are everywhere hydrothermally altered to quartz-sericite, quartz, chlorite, and kaolinite.

This type of environment is not difficult to correlate with the apparently volcanogenic deposits at nearby Dhahar. Gilmour (1971) has drawn a hypothetical section showing how various types of massive sulfide deposits may be related, and he includes a type that is related to altered intrusive pipes. This setting is applicable to the dikes of Al Hajrah.

Some of the copper metallization was relatively late. Major east-striking faults of short displacement (pl. 1) locally bear disseminated chalcopyrite within strongly silicified zones. In places aplite dikes trend along the faults and appear similar in every respect to the north-striking aplite dikes and sills in the area. Both systems of dikes are locally silicified, but only the east-striking dikes contain chalcopyrite.

These findings suggest that the early- and late-stage copper metallization was genetically related to magmatic activity, including the formation of a quartz porphyry dike swarm that underwent hydrothermal alteration; and the formation of aplite dikes, or sills, which were locally silicified and where, very locally, sulfides formed.

Gold deposits

As Salif Agarat

A few ancient workings on quartz veins in the southeast end of the Al Hajrah district (pl. 1) are thought to have been worked for gold because no base metals have been found in the area. All of the workings are small with minor waste dumps, and generally appear to be prospects. The dumps contain iron-stained milky quartz displaying minor cubic pyrite on fresh surfaces. No free gold was identified.

Dumps from four of the workings were sampled. Locations are shown on plate 1; the following is a brief description of each of the open stopes.

Workings No. 1 are along a quartz vein 50 m in length that strikes N. 40° W. The vein pinches and swells along the entire length but probably averages 2 m wide. The enclosing rock is unaltered pyroclastic breccia (pc). Small excavations on vein selvages are interspersed along the vein but the vein proper was not mined. A grab sample of rusty quartz taken from the largest workings assayed 3.90 g/ton Au, 0.30 g/ton Ag, and a trace of copper, lead, and zinc.

Workings No. 2, 3 m long and 2 m wide, was sunk on a milky quartz vein 2 m wide that crops out for a distance of 10 m along strike. The enclosing rock is pyroclastic breccia (pc).

A grab sample of milky, iron-stained quartz from the dump assayed 4.90 g/ton Au, 0.70 g/ton Ag, and a trace of copper, lead, and zinc.

Workings No. 3 is on a quartz vein 2 m wide, and the excavation is 15 m long and 3 m deep. The vein is traceable for only a few meters on either end of the open stope. Wall rock is composed of unaltered pyroclastic breccia.

A grab sample from the dump assayed 20.00 g/ton Au, 3.10 g/ton Ag, and a trace of copper, lead, and zinc.

Workings No. 4 is an open stope 5 m long on a vein of short strike length. A grab sample from the dump assayed 7.50 g/ton Au, 0.80 g/ton Ag, and a trace of copper, lead, and zinc.

Although appreciable gold was found in some of the samples, prospective tonnages are small. The lensoidal veins are all of short strike length, and the vein system generally appears to terminate at the southeast corner of the mapped area (pl. 1).

Shasrah ancient mine

The ancient workings at Shasrah are located at 18°13' 30" N., 43°52'00" E., or 14.5 km nearly due east of the deposits at Dhahar (fig. 1). The workings are on quartz veins that cut a fine-pebble conglomerate, mapped by Greenwood as part of the Qatan formation of the Jiddah group (Greenwood, *in press*).

The mapped and sampled area covers a zone of north-striking, east-dipping, lenticular, milky quartz veins and is approximately 130 m long (fig. 14). Most of the veins are in major faults, strike in a northerly direction, and dip 50°-60° east, but in places they follow cross faults trending easterly. The veins rarely exceed 50 cm in width and consist entirely of milky quartz and are generally iron stained. They display sparse pyrite on fresh surfaces.

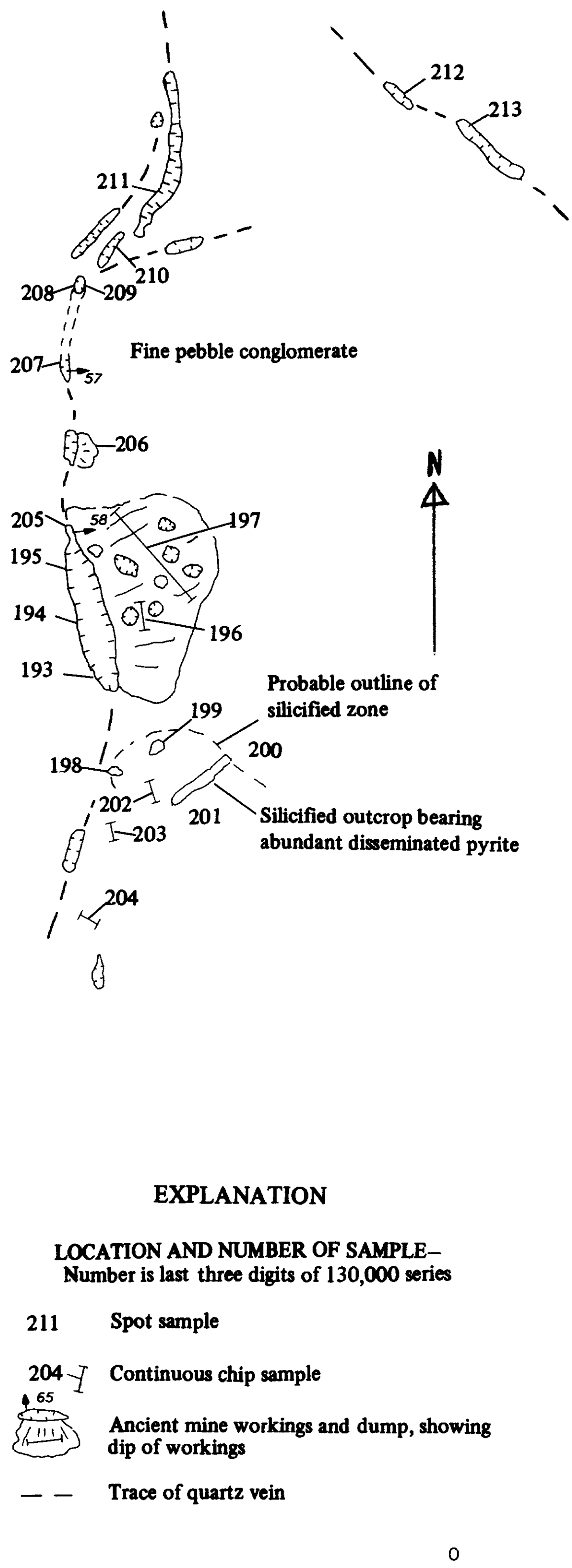
Wall rock alteration is not prevalent but immediately south of the largest workings (fig. 14) is a local zone of strongly silicified and pyritized conglomerate.

Results of sampling are generally disappointing, and only one sample from fines in a sorting pile ran as high as 17.00 grams of gold per ton. The remaining sample results are low in gold, and of those only two assayed more than one gram of gold per ton.

From these results it was interpreted that gold may be concentrated at random in pockets along the vein system and that this factor may preclude the possibility of finding large tonnages of ore-grade material here.

Apparently the dump of the largest workings was sampled or reworked after the initial mining operations because numerous depressions were noted on the dump surface (fig. 14).

Approximately 1 km south are a few other very small workings in the same type of quartz veins. Each of five samples from veins in these workings assayed less than 0.06 grams of gold per ton.



ANALYTICAL DATA

SAMPLE NUMBER	DESCRIPTION	GOLD (grams per ton)	SILVER (grams per ton)
130193	Grab sample–rusty quartz	0.08	0.30
130194	Grab sample–rusty quartz	0.06	0.30
130195	Grab sample–rusty quartz	0.06	0.20
130196	Grab sample–rusty quartz	0.06	0.30
130197	Grab sample–rusty quartz	0.12	0.20
130198	Chip sample, 1.20 m in strongly silicified and pyritized conglomerate	0.24	0.70
130199	Chip sample, 0.40 m in limonite zone	0.12	1.00
130200	Chip sample, 2.60 m in strongly silicified and pyritized conglomerate	0.06	0.60
130201	Chip sample, 5.00 m in rock as above	0.06	0.70
130202	Channel sample from sorting pile of fines	17.00	1.40
130203	Channel sample from sorting pile of fines–coarser material	0.66	1.00
130204	Channel sample from sorting pile of fines	0.58	0.90
130205	Chip sample, 1.3 m across stope pillar, quartz stringers in conglomerate	0.12	1.30
130206	Grab sample–rusty quartz	1.62	1.10
130207	Chip sample across face–white quartz, 25 cm wide	0.06	1.10
130208	Chip sample, 30 cm on white quartz	0.06	0.90
130209	Chip sample, 50 cm across quartz veinlets	2.50	1.80
130210	Chip sample, 50 cm across quartz veinlets	0.06	1.50
130211	Chip sample, 1.50 m across pyritized conglomerate	0.06	0.90
130212	Chip sample, 1.50 m across thin quartz veinlets	<(0.05)	1.20
130213	Chip sample, 0.50 m across	9.06	1.20

Figure 14.–Geologic map of the Shasrah ancient mine showing locations and analyses of samples.

CONCLUSIONS AND RECOMMENDATIONS

Sulfide deposits in the Dhahar-Al Hajrah region are found within a series of volcaniclastic rocks and may be of volcanogenic origin. The rocks and sulfide deposits have been tightly and intricately folded and faulted. East Dhahar is of moderate size at the surface, and, because only one drill hole penetrated the sulfide zone, more drilling is needed to delineate metallized rock at depth. At 70 m vertical depth the drill hole penetrated a massive sulfide lens of 40 cm horizontal width assaying 23.68 percent Zn and 1.45 percent Cu. In addition bands, stringers, and disseminations of sphalerite and chalcopyrite were intersected on the hanging-wall side of the massive sulfide. This entire zone of 3.40 m horizontal width averaged 4.17 percent Zn and 0.49 percent Cu. These metal values and widths may be of economic interest provided enough tonnage could be proved and, aside from underground mining, drilling would be the only feasible method of determining this. Detailed, ground, electromagnetic surveys would undoubtedly be helpful in delineating drill targets.

West Dhahar is of scientific interest and perhaps of economic interest because it could possibly be the target for massive sulfide deposits. A few, very narrow zones of massive sphalerite and chalcopyrite were cut in the drill hole; in addition, a 50-cm-wide gossan, which is almost completely covered by wadi alluvium, was found on the north end of the pyritized zone. The gossan bears both copper and zinc. Such evidence indicates a possibility of finding larger sulfide lenses here, and detailed, deep-penetrating electromagnetic surveys are recommended for this zone. It is also recommended that additional rock chip sampling be done on the north end of the pyritized zone. If these programs are successful, detailed drilling should be recommended.

The Al Hajrah area is more difficult to evaluate because many of the copper values are erratically distributed, and also because pyrite is invariably associated with chalcopyrite in disseminated form and as stock works. Drill hole DA-3 found copper in varying amounts from the beginning of the hole to the end at 250 m, although not in commercial quantities. No massive sulfides were encountered in the hole, although 1 m of hematitic gossan, probably mostly after pyrite, was intersected near the surface.

Induced potential survey lines run across the Al Hajrah mineral zone were helpful in the selection of a drill target. Drill hole DA-3 was positioned to intersect an induced potential anomaly, but other information such as that from geochemical sampling and rock alteration studies aided in the selection of the drill site.

During the course of detailed mapping and sampling it was determined that higher-grade secondary copper is associated with strong chloritic alteration in pyroclastic rocks and strong quartz or quartz-sericite alteration in quartz porphyry dikes. Leached cappings are also asssociated with these zones. It was determined that the zones bearing higher copper content in pyroclastic rocks are on, or near, contacts to quartz prophyry dikes. Drilling, on the other hand, encountered higher copper values within quartz porphyry dikes near contacts with pyroclastic rocks. Consequently surface leaching and transport of copper is believed to have occurred at Al Hajrah.

Geophysical traverses on lines spaced at 250-m intervals have now been completed at Al Hajrah. The survey consisted of induced potential, resistivity, and self-potential methods, and survey results have delineated drilling targets. Each of the targets should be evaluated on the basis of rock alteration, leached-capping studies, and geochemical sampling results. Drill sites could then be selected upon the favorability of all of these factors.

Massive sulfides are present at Al Hajrah as evidenced by drill hole intersections of massive hematitic gossan and the presence of moderate amounts of the same type of material strewn about on mine dumps and waste-filled areas. In consideration of this it is believed that detailed electromagnetic surveys may be useful in defining massive sulfide bodies, especially in the area that was mapped in detail.

The small gold deposits at As Salif Agarat and Shasrah are of no further interest because of their very limited tonnage potential.

In summation, results of work at Dhahar and Al Hajrah deposits are encouraging enough to recommend further investigations in both areas.

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