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GEOLOGIC RECONNAISSANCE OF THE AL QUNFIDHAH AREA TIHAMAT ASH SHAM 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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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

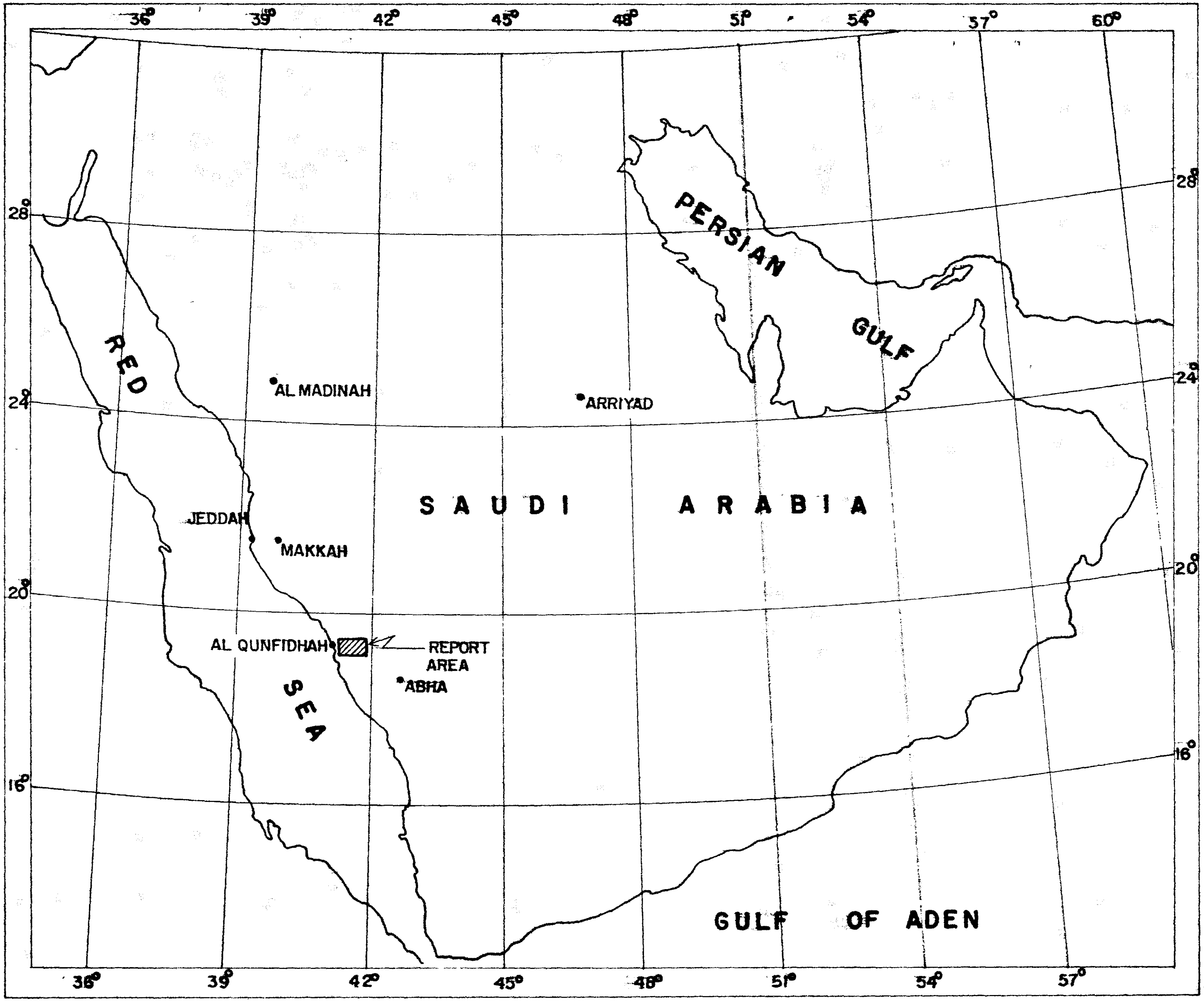
Preliminary mineral investigations in the Al Qunfidhah area, Tihamat Ash Sham quadrangle, indicate that four target zones merit detailed study. These are (1) the West Gossan, (2) the pyrocalstic pile 13 Kilometers of Suq Al Khamis, (3) the Wadi Sishah copper prospect, and (4) the Wadi Yiba copper prospect. Copper sulfides and carbonates appear to be the most abundant economic minerals present, although nickel, zinc, lead, molybdenum, gold, and silver may also occur in important amounts. In addition to locating specific target zones, the results delimit particular stratigraphic horizons which should be included in future regional mineral investigations.

The rocks of the area are comprised of a eugeosynclinal assemblage of Precambrian metavolcanics and metasediments which are intruded by granitic rocks of at least two ages. Rocks which predate the latest granite intrusive are regionally metamorphosed, folded, and faulted. In most cases, zones containing economic minerals occur at or near the top of a volcanic pile and in marine sedimentary rocks above the volcanic pile. The results from preliminary studies suggest a close genetic relationship between sulfide mineralization and volcanism.

INTRODUCTION

Location and general description

The area included in this report is east of Al Qunfidhah in the Tihamat Ash Sham quadrangle, Kingdom of Saudi Arabia (Brown and others, 1958). It is approximately defined by latitudes 19°00' and 19°15' N. and longitudes 41°10' and 41°50' E. (fig. 1). Al Qunfidhah, a port on the Red Sea, is the principal



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town in the region, and is about 55 kilometers west of the center of the area. The locality of study is part of an extensive region investigated in a helicopter mineral reconnaissance survey conducted from February to June 1967. The area is divided into two sectors for reporting purposes. The western sector is here referred to as the Suq Al Khamis area (fig. 4) and the eastern factor includes the Wadi Yiba copper prospect and surrounding area (fig. 5).

The purpose of the reconnaissance was to make an initial assessment of the mineral potential of the area by geological, geophysical, and geochemical means and, if possible, to delimit target zones which would merit detailed investigations. Emphasis was placed on the search for sulfide minerals and precious metals. Electromagnetic surveys were directed by W. E. Davis and geochemical studies by G. H. Allcott, who also participated with the author in geological reconnaissance.

Field operations were conducted from a camp and an airstrip near the village of Suq Al Khamis in the central part of the report area. Two G-2 Bell helicopters were utilized during most of the work, and the camp was serviced by Otter and Beaver aircraft from Jeddah.

The western part of the area is accessible via the unpaved coastal road from Jiddah to Al Qunfidhah. A tertiary road connects Al Qunfidhah with Suq Al Khamis, which is 40 kilometers east of the Red Sea coast. The eastern sector can be reached by an unpaved road which joins the Jeddah-Jizan coastal road 35 kilometers north of Al Qunfidhah at Al Mudhalif.

The area is sparsely populated by small permanent communities and nomads. Grazing of sheep and goats is the principal industry. Limited areas, mostly in the major wadis and on the mountain sides, support minor agriculture.

The topography ranges from flat to mountainous. The flat coastal plain extends east from the Red Sea coast for several kilometers; low but rugged hills dominate the landscape in the vicinity of Suq Al Khamis, and north-trending mountains which attain elevations exceeding 1,000 meters lie 12 kilometers to the east of Suq Al Khamis. The eastern third of the area is an interior drainage basin formed by the above mentioned mountains and the escarpment east of the report area. Relief in the drainage basin is moderate to rugged.

Drainage, exclusive of the interior basin, flows from east to west. In places the drainage pattern suggests rejuvination and that former drainage may have been in an easterly direction.

Although the area is extremely arid, the water table in the central and eastern parts is fairly shallow and the major wadis contain a few small pools. Flowing wells which are located in the wadis are less than 6 meters deep.

Acknowledgements

Acknowledgement is due to the Minister of Petroleum and Mineral Resources and his assistants for providing logistic support and encouragement. The author also wishes to acknowledge the cooperation and warm hospitality of officials and other inhabitants of the area.

General geology

The rocks in the area are comprised of an eugeosynclinal assemblage of volcanic and sedimentary rocks which are metamorphosed to the greenschist-amphibolite facies and intruded by granitic rocks of at least two ages. Quartz veins and ophitic dikes are widespread, and simple pegmatite dikes which appear to be related to the later granite were observed in the vicinity of the intrusives. The rocks are inferred to be of Precambrian age. Relatively minor outcrops of Tertiary(?) sedimentary and volcanic rocks are exposed in the western part of the area. Unconsolidated surface debris, including mobile eolian sand, covers large segments of ground in the coastal region and in areas of weathered intrusive rocks.

The general strike of rock foliation, which appears to parallel bedding and flow banding, is north. Rocks dip to the east and west at moderate to high angles. Broad to tight and intricate folds with north-striking fold axis are common. The most prominent faults and shear zones strike north and dip vertical to parallel to rock foliation. These displace a lesser but conspicuous set of faults which strike northwest to west and dip at high angles. Normal faults are probably dominant; however, insufficient data were collected to permit general classification of the fault systems. The west-striking faults most often display right-handed separation. A north-striking fault near the village of Suq Al Khamis appears to be terminated by the later granite. It is inferred that the north-striking faults to the east belong to the same system. Thus these faults, along with the west-striking faults which they displace, are most probably of Precambrian age. A north-striking fault 22 kilometers west of Suq Al Khamis displaces and brecciates sediments of probable Tertiary age. The latest movement in this fault is therefore relatively recent and may be related to movement along the Red Sea Rift.

Minor to intense shearing is prevalent throughout the metavolcanic and metasedimentary series. The most intense shearing parallels the foliation of the layered rocks. Quartz veins commonly occupy shear zones parallel to and transecting foliation.

Jointing is in evidence throughout the area. Patterns are multi-oriented and have not received detailed study. The most conspicuous joints are tension fractures which develop normal to foliation in folded nonelastic rock units. Near the upper limits of the volcanic sequence near Suq Al Khamis these joints often contain heavy iron oxide selvage material.

All rock units which predate the latest granite intrusive display effects of low-rank to medium-rank regional metamorphism. Dynamic metamorphism typically characterized by silicification and the reversion of amphibolite to chlorite schist can be observed in zones of intense shearing.

Regional metamorphic grade appears to increase slightly from west to east from the upper greenschist facies to the amphibolite facies. Rocks in the extreme eastern part of the area in the vicinity of the Wadi Yiba copper prospect are metamorphosed to the greenschist facies. The siliceous dolomite part of the copper-bearing formation shows no obvious metamorphic effects; however, 20 kilometers to the northwest in the vicinity of the Muckahal mine the siliceous carbonate beds are converted to marble.

The effect of metamorphism on sulphide mineralization is not yet fully understood. It appears that dynamic and possibly regional metamorphism has resulted in remobilization of sulfide minerals along shear planes and planes of foliation. In the thickest part of the pyroclastic unit 13 kilometers west of Suq Al Khamis, large, elongated, oxidized pyrite cubes attain dimensions of 3 or 4 centimeters. The large size, which appears to be the result of recrystallization, and the deformity are most likely due to metamorphism.

The earliest granite intrusive in the region is gneissic; the later granite, however, does not appear to be affected by metamorphism. Thus the date of regional metamorphism can be established as Precambrian.

Sulfide mineralization

Sulfide minerals or their oxidized products were observed in rock outcrops or detected by chemical analysis in samples from (1) volcanic transition zones, (2) sediments above volcanic piles, (3) quartz veins and shear zones, and (4) selvage joints near the top of the volcanic pile. Supergene copper minerals were observed in the Wadi Yiba copper belt and in quartz veins. The most conspicuous supergene mineral is chalcocite which occurs sparingly as a dull, black, sooty mineral with malachite in siliceous dolomite and interbedded schist, and as a black to gray metallic mineral in quartz veins. The chalcocite in quartz veins often retains a core of chalcopyrite and contains associated copper carbonate.

Primary sulfides are rare because of the extensive oxidation. In some places compact siliceous rocks have protected primary minerals such as pyrite, chalcopyrite, and perhaps minor sphalerite from weathering, Galena, being more resistant to oxidation, can be seen in surface outcrops in the carbonate beds west of Suq Al Khamis and at the ancient Al Muckahal mine northwest of the Wadi Yiba copper prospect.

Gossans in the area are minor in both size and number. Most of the sulfide mineralization observed appears to be the disseminated type which does not form conspicuous iron cappings. A peculiar weathering feature of the carbonate bed in the Suq Al Khamis area often results in the formation of false gossans. This bed contains minor sulfide minerals; however, the tan limonitic weathering product is not due to the oxidation of sulfides. The weathering product likely results from a minor iron content in the carbonate.

Copper is the most abundant base metal found in the area. Significant amounts were found in several localities. Perhaps the most important occurrence of copper is the Wadi Yiba copper prospect (fig. 5).

Relatively minor occurrences of galena were observed in quartz veins and carbonate beds. The largest occurrence is at the ancient Al Muckahal mine.

Zinc constitutes a minor element but perhaps an important one in the cupriferous rocks of the Wadi Yiba copper prospect. Anomalous values of zinc were also detected near the north-striking fault in the extreme western part of the map area and at the Al Muckahal mine.

Molybdenum values of all the rock samples collected average from 5 to 10 parts per million (ppm). Two areas were found which deviate sharply from this background value. These are (1) near the top of the volcanic pile northwest of the village of Suq Al Khamis and (2) the southern part of the Wadi Sishah copper prospect in the eastern part of the Suq Al Khamis map area. Molybdenum was previous reported from the Al Muckahal mine; however, only one of five samples collected by the author contained more than 5 ppm.

A soil sample survey conducted by Allcott disclosed a very high nickel anomally in the vicinity of the north-striking fault in the extreme western part of the Suq Al Khamis map area. This locality, which is nominally called the West Gossan, is also anomalous in copper, and geochemical results suggest an inverse relationship between the two metals.

Analysis of gold and silver is not complete upon preparation of this report. The highest gold values obtained thus far are from the cupriferous rocks in the Wadi Yiba copper prospect. The analysis data from some of the samples collected in this mineralized zone indicate that gold may occur in economically important amounts. A single sample of quartz vein material included in the thickest part of the pyroclastic pile 13 kilometers west of Suq Al Khamis contained 0.4 ounces of gold per ton. Silver values of commercial grade from the Al Muckahal mine were previously reported by Brown (1967); however, of the samples collected by the author the highest assayed only 0.88 ounces of silver per ton. This corresponded to the highest lead value (8 percent) obtained. Recoverable amounts of silver may occur in shear zones and in zones of supergene enrichment in the Wadi Yiba copper prospect.

The most extensive and therefore the most important sulfide occurrences found in the area appear to be stratigraphically controlled. Favored horizons appear to be tuff beds within the volcanic pile, rhyolite and siliceous pyroclastics at the top of the volcanic pile, and shallow water marine and tuffaceous sediments stratigraphically above or between volcanic rock sequences. Sulfide mineralization in shear zones and selvage joints most frequently occurs where these tectonic features transect or parallel favored stratigraphic horizons. Faulting and particularly folding exert strong influences on localization of sulfide minerals within favored stratigraphic horizons.

Lead isotope age dating of galena from one sample in the western part of the area indicates that the mineralization is of late Precambrian or Early Paleozoic age. Galena samples submitted from the Al Muckahal mine in the eastern part of the area gave comparable results (table 1). Metamorphic effects on sulfide minerals indicate that the mineralization predates the latest metamorphism, which can be reasonably established as Precambrian. Most of the sulfide mineralization appears to be stratigraphically controlled and has other characteristics which indicate a possible syngenetic origin.

SUQ AL KHAMIS AREA

Location

The Suq Al Khamis area (Fig. 4) begins about 17 kilometers east of Al Qunfidhah and extends 32 kilometers east to the mountains. It is bounded by Wadi Sishah to the north and Wadi Yiba to the south, and it encompasses about 600 square kilometers.

Scope and purpose

The geology of the area is complex due to folding, faulting, metamorphism, and intrusive activity. The resolution of complex geological problems was beyond the scope of the reconnaissance investigation. It was the intention of the investigators generally to define rock types, prospect for valuable minerals, and to establish general relationships of mineralization to rock types and structural features. Rock types and mineral descriptions are based on megascopic examinations in the field. In some cases these descriptions are refined as a result of spectrographic data.

Sampling

A total of 180 grab samples were collected from outcrops. A majority of these samples contain obvious mineralization. Because they are best described as character samples, the reader should not interpret the analysis data from these

Table 1. Isotopic Composition of Lead Samples (Age dating by B. Doe and Al El-Jawad, U. S. Geological Survey, Denver, Colorado, 1967).

Sample No.	Location	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
B-7	Al Muckahal Mine.......	17.862	15.612	37.584
B-8	" " "	17.89	15.69	37.86
37214	Western part of Suq Al Khamis Area........	17.72	15.60	37.57

Age of the galena mineralization is believed to be 580 to 750 m.y.

Samples B-7 and B-8 submitted by Brown, March 1967

Samples 37214 submitted by Earhart, June 1967 samples as being representative of the area in which the sample was collected. The samples are selective only in the sense that from an extensive zone of mineralization, both the highest grade and lowest grade of mineralized material observed were sampled. Sample locations and data are presented on figure 4.

Modal data cannot be established from the small number of samples which were discriminately collected. Therefore, only analysis values which are several times greater than what could be normally expected are considered to be anomalous high values. Values which are considered to be anomalous are therefore arbitrary but conservatively arbitrary.

The samples were analysed in the USGS laboratory in Jeddah by either wet chemical or spectrographic methods. Many of the base metal determinations were made by both methods, and significant discrepancies were reassayed by wet methods. Gold and silver determinations were made in the fire assay laboratory of the Ministry of Petroleum and Mineral Resources.

Geochemical samples of stream beds and soils were collected by Allcott over selected areas.

Stratigraphy

Metasedimentary rocks I

The oldest rocks exposed appear to be the metasediments which crop out west of the volcanic rocks in the western part of the area (fig. 4). These rocks which consist chiefly of quartzite and quartz-rich schists, received only superficial examination and were not lithologically differentiated from the nonvolcanic metasediments which overlie the argillite above the volcanic sequence.

Metavolcanic and pyroclastic rocks

Metavolcanic and pyroclastic rocks with an estimated average true thickness of 1500 meters overlie metasedimentary rocks. The volcanic rocks are basic to intermediate at the base of the section and grade to acidic members toward the top. There is, however, some interlayering of volcanic rocks of contrasting compositions throughout the section. The rocks vary in composition from basalt to rhyolite, and volcanic rock of dacitic composition is probably the dominant rock type. Pyroclastic rocks are found interlayered throughout the volcanic sequence but are most abundant towards the top. Siliceous pyroclastic rocks are probably most common.

The basic to intermediate volcanic rocks in the western part of the area chloritic. Approximately 13 kilometers west of Suq Al Khamis, they are metamorphosed to the chlorite-epidote subfacies, and in the vicinity of Suq Al Khamis they are metamorphosed to the lower amphibolite facies.

A zone of soft chlorite schist 2 kilometers north of Suq Al Khamis constitutes a mappable unit and determines the course of Wadi Sishah for 4 or 5 kilometers. This schist is included in a zone of intermediate volcanic flow rocks and is probably of puroclastic origin. Similar chlorite schist zones of lesser extent occur throughout the basic to intermediate volcanic rocks.

The silicic volcanic rocks are converted to porphyritic quartz-sericite schist. To the west these rocks contain some kaolin which suggests incomplete seritization of feldspar. In the vicinity of Suq Al Khamis, kaolin is rare in the siliceous volcanic rocks. Rounded quartz phenocrysts are commonly preserved where siliceous volcanic rocks were observed. Chloritized mafic minerals usually comprise less than 5 percent of the rock mass. Rocks suggesting trachytic composition or structure are rare. It is often difficult or impossible to distinguish siliceous flow rocks from siliceous pyroclastic rocks where they are highly sheared.

Volcanic flow structures are not well preserved. Poorly developed pillow structures were rarely observed in andesitic rocks, and flow banding in rhyolite was noted at several localities.

Siliceous dolomite(?)

A siliceous carbonate bed, perhaps of dolomitic composition, overlies rhyolite or siliceous pyroclastic rocks and is approximately 10 meters thick. This bed appears to lie beneath the rhyolite near Suq Al Khamis; however, this relationship is probably structural and not stratigraphic. This rock unit is light gray or uncommonly medium gray but weathers to bright tan or buff and often forms false gossans. This characteristic color makes it particularly useful as a marker horizon for airborne reconnaissance. Near Suq Al Khamis it is converted to marble; however, it does not possess any obvious metamorphic effects in the western part of the area. Indications of sulfide mineralization were observed locally in the carbonate and adjacent beds.

Pyroclastic rocks

Siliceous pyroclastic rocks which range from 0 to 700 meters thick occur above the siliceous dolomite(?) in the western part of the area. This unit consists of tuff, agglomerate, volcanic conglomerate and may include siliceous, altered flow rocks. The maximum thickness occurs 13 kilometers due west of Suq Al Khamis where the rocks are highly pyritic.

Argillite

Argillite overlies rhyolite in the vicinity of Suq Al Khamis. The thickness ranges from approximately 10 to 20 meters, and the rock is dark gray to black. Locally it contains sandy lenses and locally it is graphitic. The strike extent of the argillite is not well known.

Metasedimentary rocks II

A considerable thickness of metasedimentary rocks overlies the argillite. These rocks are poorly exposed and were not studied. Outcrops from this sequence of rocks were observed in Wadi Sishah and in Wadi Yiba. These outcrops consist of highly competent quartzite, graywacke, and quartz-amphibole schist. The lack of exposrues would suggest that most of the sequence consists of less competent rocks. The maximum thickness of this rock sequence is possibly 2000 meters in the northern part of the area. To the south the metasedimentary rocks, except for approximately 100 meters of predominantly quartz-amphibole schist are intruded and assimilated by peralkalic granite.

Other metamorphic rocks

A highly sheared complex of predominantly metavolcanic rocks crops out east of the metasedimentary rocks. The stratigraphic relationship of these rocks to the metasedimentary and metavolcanic rocks to the west is not known. The dominant rock type in the west part of this zone is amphibolite which has, to a large degree, been reverted to chlorite schist. Pillow structures are suggestive in the amphibolite. Siliceous and limey metasedimentary rocks are most abundant in the central and eastern part of the complex. Silicified rocks of questionable origin and migmatite zones are included in the rock complex. In the vicinity of Wadi Sishah the thickness is approximately 700 meters. It thickens rapidly to the north, and volcanic rocks become increasingly abundant. To the south the rock sequence thins out and probably does not extend south of Wadi Yiba.

Quartz and quartz-carbonate veins occupy prominent north-striking shear zones in the western part of the zone described above. In the vicinity of Wadi Sishah, several of the veins contain malachite, chalcocite, and chalcopyrite. Sulphide mineralization shows preference to veins that are incompletely filled and contain terminated quartz crystals. This mineral occurrence is referred to as the Wadi Sishah copper prospect and is described under the following section on Mineralization.

Vein type rocks

Metamorphosed ophitic dikes which are highly mafic and chloritic were observed locally in mafic volcanic rocks. It is usually difficult to make a mineralogic distinction between them and the volcanic rocks which enclosed them, and they are most probably closely related to the volcanic rocks.

Rhyolite dikes may occur in the area. The rhyolite in which the West Gossan (the only true gossan in the area) is formed is possibly an intrusive rock. This rhyolite differs from other rhyolites in the area by its stratigraphic position and relatively high carbonate content.

Two or possibly three types of quartz veins were observed in the area. Type I is widely distributed in all the rocks which predate the peralkalic granite. Pegmatitic quartz veins are found in and near the border facies of the peralkalic granite and constitute the second type.

Type I is commonly milky white, massive, and barren of metallization. Where these veins are included in volcanic or pyroclastic rocks they sometimes contain copper carbonates and sulfides. With the possible exception of the Wadi Sishah copper prospect, these mineral occurrences are not economically important. They do, however, provide an important clue as to what stratigraphic horizons merit prospecting.

The quartz veins are oriented both parallel and crosscutting to rock foliation. Where they are parallel and the rocks are folded, the brittle quartz forms tension fractures normal to the strike. These fractures are sometimes filled with heavy iron oxide material and result in selvage joints.

The quartz veins in the Wadi Sishah copper prospect differ from those just described in that they contain well-terminated quartz crystals, abundant carbonate, and usually more sulfide mineralization.

Except for pegamtitic quartz veins which appear to be related to the peralkalic granite, none of the quartz veins are spatially related to the intrusive masses. Field evidence indicates that they are older than the peralkalic granite.

Diorite and granodiorite dikes which strike north crop out a short distance east of the mapped area. A dike belonging to this system persists for many tens of kilometers to both the north and south of the mapped area and forms a conspicuous geologic feature in the region.

Granite gneiss

Gray gneissic granite crops out in the extreme eastern part of the mapped area. This granite appears to be the same as the granite gneiss described by Brown and others in various parts of the Arabian Shield (Brown and others, 1958).

Rubidium-strontium isotope age dates indicate that equivalent granite is about 1000 million years old. Brown believes that this granite is largely derived from granitization of schists and volcanic rocks (Brown and others, 1958).

Peralkalic granite

Pink to gray peralkalic granite occupies an oblong area in the central and southeastern part of the mapped area. It is of the type described by Brown and others in various localities throughout the Arabian Shield (Brown and others, 1958). Rubidium-strontium isotope age dates indicate that equivalent granite is about 535 million years old (Brown and others, 1958).

This granite intrudes the top of the volcanic sequence about 2.5 kilometers southwest of Al Khamis and appears to cut deeper into the volcanic rocks to the southwest. The granite intrudes and assimilates the metasediments which overlie the volcanic sequence in the southeast part of the mapped area. Xenoliths of metavolcanic and metasedimentary rocks are common and range in size from a few centimeters to several hectometers. Contact rocks and xenoliths display little to no thermal effects from the intrusive.

Tertiary(?) rocks

Near Wadi Qanunah in the extreme northwest of the mapped area shale, conglomerate and silty lacustrine limestone overlie metavolcanic and metasedimentary rocks with angular unconformity. The same silty limestone overlies tertiary(?) lava flows north of the mapped area. The shale is soft and friable, dark gray, and carbonaceous. The conglomerate is comprised entirely of quartz pebbles and cobbles in a sandy, rusty matrix and includes lenses of gritstone. The limestone is gray to tan and is thin bedded. Both the limestone and the conglomerate are brecciated by the north-striking fault in the extreme western part of the mapped area.

Tertiary(?) basalt lava flows are exposed in the southwest of the mapped area.

Recent unconsolidated sediments

Recent deposits of pediments, fluvial, and other unconsolidated sediments including mobile eolian sand cover a large part of the area.

Mineralization

Four zones which contain economic minerals are discussed in the following paragraphs. From east to west these zones are (1) the Wadi Sishah prospect (2) the upper part of the volcanics at Suq Al Khamis (3) the pyroclastic rocks 13 kilometers west of Suq Al Khamis and (4) the West Gossan. Of these, the West Gossan and the pyroclastic rocks may offer the greatest economic potential. The West Gossan is only briefly mentioned here because an evaluation of this prospect includes detailed presentation of geochemical data collected by Allcott. It is therefore the subject of Technical Letter 98 being prepared jointly by Allcott and the writer.

Wadi Sishah prospect

Description.-- The Wadi Sishah prospect is near the eastern edge of the map area at latitude 19°14'N. and longitude 41°33'E. (fig. 4). Copper mineralization consisting of malachite, chalcocite, and chalcopyrite in north-striking quartz-carbonate veins was discovered early in the reconnaissance program. The veins are 2 cetimeters to 1 meter wide and are included in the footwall portion of east-dipping high-rank metamorphic rocks which are principally of volcanic origin but also include siliceous and calcareous metasedimentary rocks. The veins pinch and swell and occupy shear zones which parallel the schistosity of the adjacent rocks. They are separated by 3 to 50 meters of country rock over a stratigraphic width of 150 to 200 meters. Copper mineralization in the veins occurs intermittently along strike for approximately 1 kilometer. The veins are unique in the area in that they are cavernous and contain terminated white to clear quartz crystals and calcite. Calcite is locally the dominant vein mineral. Malachite, chalcocite, chalcopyrite, and pyrite occur as cavity or void fillings and are erratically distributed. Where metallization is most abundant these minerals comprise up to 10% of the rock. Rarely, mineralized zones are continuous along strike for 40 or 50 meters. Quartz crystals of optical quality are found in the veins but are not common. Copper minerals were not observed on the traverse across the strike of the veins south of Wadi Sishah; however, two of the eight samples collected over this traverse were anomalous in molybdenum. The highest value obtained was 2300 ppm. The area to the north of the strike projection of the mineralized zone was also traversed and sampled, but only minor amounts of malachite were detected. Malachite is found both in place and as transported material. It is megascopically detectable in samples that assay as little as 20 ppm copper. Analysis data indicate that the veins do not contain economically important amounts of gold and silver.

Several samples of wall rock material were collected. Assay results indicate that the copper and molybdenum values are not anomalous. One sample of chlorite schist contained ore grade copper; however, this sample includes some secondary quartz.

Of 43 samples collected in the 1-kilometer strike zone which includes copper mineralization, 31 were taken from quartz veins. Eleven samples of quartz vein material contained significant amounts of copper which ranged from 800 to 23,00 ppm and averaged 8700 ppm. Four of these samples contained 15,000 ppm or better.

The primary copper mineral is chalcopyrite. Usually it is completely replaced by chalcocite as a result of supergene enrichment. Often a small core of chalcopyrite persists and occasionally a small dissemination of unenriched chalcopyrite can be observed. Supergene sulfides on the oxidized surface are likely the result of more than one cycle of enrichment caused by fluctuations in the water table or recessation of the water table that has greatly exceeded the rate of oxidation.

Conclusions and recommendations.-- The copper-bearing quartz-carbonate veins occupy zones of intense shearing. All the elements found in the quartz veins can be detected in lesser amounts in the adjacent rocks.

Boyle (1962) presents convincing arguments that in the Keno Hill-Galena Hill area of Canada all the vein minerals are formed by diffusion processes in dilatant zones which result from intense shearing. He believes that the source of all the vein materials is the country rock. The veins, including the sulfide minerals, in the Wadi Sishah prospect may be of similar origin. The diffusion process may not have continued to an end stage which would explain the cavernous character of the veins.

The sparsity of economic sulfides beyond the limits of the quartz-carbonate veins and the apparent lack of precious metals in the veins detract from the economic potential of this prospect. It does merit further investigation, however, because of the widespread occurrence of supergene chalcocite within the vein ystem and the limited occurrence of molybdenum. Supergene minerals may be more abundant near or beneath the base of the oxidation zone, and dilatant zones caused by shearing and cavities in the quartz-carbonate veins are ideal recepticals for the accumulation of enriched copper oxides within the oxidation zone. Therefore two diamond drill holes should be planned on a section where the outcrops indicate that copper mineralization is most abundant. This location is by Wadi Sishah where the wadi course changes abruptly to the north. Because the veins dip steeply east, the holes should be drilled at 45° due west. The topographic setting would make this drill hole orientation extremely difficult, but the desired horizons could be transected by drilling the holes at 30° due east. This orientation would require a depth of 325 meters on the first hole, which should transect the copper bearing veins in the oxidation zone. The depth of the second hole would necessarily be dependent on results from the first hole, but it would probably not exceed 400 meters. Should encouraging data result from these holes, additional drilling will be required, this is recommended as a low priority drill target.

Suq Al Khamis

Description.-- Minor amounts of malachite were observed near the top of the volcanic sequence immediately west of Suq Al Khamis. This zone was extensively sampled, and the analysis results suggest anomalous conditions for both copper and molybdenum. A light-green zone of chlorite schist within the zone of intermediate volcanics also contained samples with weakly anomalous copper values.

The rocks near Suq Al Khamis are broadly folded, and the higher copper values are mostly derived from samples near the fold axis in rhyolite and near the contact with overlying argillite. A few samples from rocks of dacitic to rhyolitic composition included in the underlying intermediate volcanics are weakly anomalous in copper. Two samples from quartz vein selvage joints contain anomalous values of copper. These selvage joints appear to be peculiar to the upper part of the volcanic sequence. West of the rhyolite copper zone and on the same general strike, five samples of rhyolite contained anomalous amounts of molybdenum.

The rhyolite is highly siliceous and is metamorphosed to porphyritic quartz-sericite schist. It is weakly to moderately limonitic. The limonite is chiefly derived from pyrite. Rarely, fresh pyrite can be observed. The distribution of the anomalous values of chalcophile elements and the limonite observed in outcrops indicate that sulfide mineralization is conformable to the enclosing rocks.

The entire volcanic sequence was traversed in this area, and 49 grab samples were collected. A large majority of these samples were collected from the upper siliceous part where indications of sulfide mineralization are more suggestive. Six samples which were taken from the rhyolite over a strike distance of 1200 meters contain anomalous amounts of copper. The highest values obtained were from two samples, each of which contain 4600 ppm. Several other samples from this same zone contain higher than normal background amounts of copper and may or may not be considered anomalous. Five samples were collected to the west over an 800-meter strike length continuous to the anomalous copper zone. These samples contain molybdenum values which are 4 to 12 times greater than the normal value for the general area. The average value of these five samples is 45 ppm molybdenum. Samples anomalous in molybdenum are not anomalous in in copper.

Conclusions and recommendations.-- Analysis data and surface observations indicate that sulfide mineralization is sparse in this zone. Therefore, no further work is recommended. The data collected here aré highly significant in thay indicate the distribution of chalcophile elements in the volcanic sequence. These data enhance the economic possibilities of the next mineralized zone discussed which is at the top of the volcanic pile in pyrocalstic rocks.

Sulfide deposits at or near the tops of volcanic piles or between volcanic rocks of contrasting composition and which conform to the volcanic stratigraphy have been recognized by geologists in many localities throughout the world (Kinkel 1966), and many of these deposits have been the subject of detailed study. The sulfide minerals in this type of deposit probably are emplaced prior to the deposition of overlying rocks under surface or submarine conditions and are derived from a volcanic source. The sulfide minerals or their oxidized products in the upper part of the volcanic rocks in the Suq Al Khamis area may be of similar origin. If so, the upper part or top of the volcanic sequence may be worthwhile prospecting horizons in other parts of the area.

Pyroclastic rocks 13 kilometers west of Suq Al Khamis

Description.-- Pyroclastic rocks of this locality consist of siliceous tuff, agglomerate, volcanic conglomerate and may include siliceous volcanic flow rocks. To the west they are separated from schists of rhyolitic composition by a bed of siliceous dolomite (?) which measures about 10 meters across strike. The rock types are the same as at Suq Al Khamis where the top of the volcanic sequence can be positively identified; however, the pyroclastic rocks were not observed at Suq Al Khamis. A few exposures of intermediate volcanic rocks appear to lie stratigraphically above the pyrocalstic rocks to the east. It is not known if these are equivalent to the intermediate volcanic rocks beneath the rhyolite to the west or if they comprise the basal part of another volcanic sequence. The same stratigraphic sequence which includes the pyroclastic rocks can be observed in the southern part of the area. Twenty samples were collected from this locality and of these only four contain anomalous values of copper. One sample taken from a quartz vein which cuts the pyroclastic rocks assayed 12,000 ppm copper and 0.40 ounces of gold per ton. The highest copper value obtained from the pyroclastic rocks is 1600 ppm. One sample from a quartz vein contains anomalous amounts of zinc.

The zone 13 kilometers west of Suq Al Khamis comprises the thickest sequence of pyroclastic rocks and the most abundant sulfide mineralization found in the area. By far the most common sulfide mineral observed is oxidized pyrite; it occurs as disseminated cubes that vary in size from a few millimeters to 3 or 4 centimeters and are frequently deformed and elongated. Fresh, unoxidized pyrite is rarely observed. The pyritiferous zone was not studied in detail, but the wide distribution of pyrite suggests that this zone may extend over the entire width of the pyroclastic rocks. The maximum true width is approximately 700 meters. Where observed, the pyrite is continuous along strike for about 2 kilometers. It is not known if the pyrite is more highly concentrated along particular horizons within the pyroclastic rocks. Minor amounts of malachite were observed in pyroclastic rocks locally, and copper sulfide minerals were found in included quartz veins.

Geophysical reconnaissance with the EM vertical coil equipment was conducted over the siliceous dolomite (?) at the base of the pyroclastic rocks. One crossover which indicated a possible electromagnetic conductor was found during the course of this work, but other geophysical results were negative. This survey included only a small part of the base of the pyroclastic sequence of rocks (W.E. Davis, oral commun., 1967).

Conclusions and recommendations.-- The merit of this zone is based on the physical aspects of the rocks rather than the analysis data from the rock samples. The thickest part of pyroclastic piles which overlie predominantly volcanic flow rocks indicate a possible effusive center. It was suggested in the conclusions and recommendations under the mineral occurrence at Suq Al Khamis that sulfide deposits occur near the upper limits of volcanic piles or between intermediate and siliceous volcanics. In addition to this, the valuable sulfide minerals in sulfide deposits which appear to be related to volcanism are reported to be found most often near the effusive source (Kinkel, 1966). Geological reconnaissance results indicate that the zone described contains widespread sulfide mineralization and in addition to this it may be near an effusive center. More detailed investigations are therefore recommended.

The pyroclastic rocks described are well exposed. The area should be mapped on a scale of not less than 1:5000. Mapping on this scale will provide detailed information on the pyroclastic stratigraphy and may indicate a preferential distribution of sulfide minerals.

Rock samples from outcrops should be collected every 10 meters along a grid system with a 50-meter line spacing. This sampling may indicate an elemental distribution. Where outcrops are lacking, soil samples should be collected even though the two types of samples cannot be directly related.

The pyroclastic rocks are completely covered with overburden to the north of the zone described. The thickest part of the pyroclastic rocks could possibly lie to the north. Sulfide mineralization in this part of the zone could perhaps be located by geophysical techniques.

Although massive sulfides were not observed in outcrop, there is a possibility of buried deposits of massive or highly disseminated sulfide minerals. An electromagnetic or induced polorization survey over the outcrop zone may indicate sulfide zones which do not extend to the surface.

A geophysical survey over an area of 24 square kilometers is therefore recommended. This survey would include the unexposed north strike projection of the pyroclastic rocks. A helicopter EM-MAG survey which is reported to provide results equivalent to a ground horizontal coil survey has been proposed for the Wadi Yiba copper belt. It would be convenient to include this area under the same geophysical program. About 240 additional line kilometers would be required at a cost of $10 per kilometer.

Diamond drilling would be contingent upon the results from the compilation of the other detailed work recommended.

The West Gossan

The West Gossan zone is in the extreme west of the mapped area at latitude 19°08'N. and longitude 41°18'E. It is the only true gossan found in the area and has no obvious relationship to the other zones of mineralization described in this report. The gossan was located during the helicopter reconnaissance survey, and minor copper and zinc minerals were tentatively identified within the gossan zone. The gossan and adjacent rocks were then mapped on 1:1000 scale, while at the same time Allcott collected soil samples over closely spaced intervals and geophysical measurements were made.

Results from Allcott's work (written commun., 1968) indicate a highly anomalous zonal distribution of nickel values which extend beyond the limits of the gossan. Anomalous amounts of copper were also found in the soils. Additional detailed investigations are recommended for this zone.

WADI YIBA COPPER PROSPECT AND SURROUNDING AREA

This area comprises the eastern third of the area under investigation. Reconnaissance work was concentrated over 15 square kilometers in the extreme southeast where disseminated copper mineralization was observed in sedimentary rocks over a strike distance of several thousand meters (fig. 5). This work consisted of geological, geochemical, and geophysical preliminary investigations. Prior to these investigations, copper carbonate had beeen observed in volcanic rocks which lie a short distance to the east of the report area. Davis called the author's attention to this occurrence and the locality was visited.

Al Muckahal, an ancient lead-silver(?) mine, is located in the northern part of this area. The few workings in this vicinity are the only indications of former mining activity which were observed during the course of the investigations.

Geological setting

The Wadi Yiba area is separated from the Suq Al Khamis area by a north-trending mountain chain which consists mainly of granitic rocks. Brown believes that the axis formed by the mountains defines the axis of a large anticlinal fold (oral commun. 1967). His opinion is substantiated by structural observations made during the reconnaissance investigations. To the east of the anticline the rocks are folded into a large north-plunging syncline which is the main structural feature in the eastern third of the report area. In detail, the structure is highly complicated by numerous faults and secondary folds. The fault pattern is the same as in the Suq Al Khamis area; the most conspicuous faults strike north and offset west to northwest striking faults. Folds are commonly isoclinal, and near the Al Muckahal mine they are locally recumbent.

General stratigraphic observations were made in the area surrounding the cupriferous rocks and at the Al Muckahal mine. The oldest rocks in the area appear to be intermediate volcanics which form continuous outcroppings to the east and on the up side of a north-striking major fault in the extreme eastern part of the mapped area. These rocks received only cursory examination, so their habit is not well known. Flight observations across the strike indicate that they continue for several thousand meters to the east, and it is probable that they constitute a thick volcanic pile. They strike to the north and dip moderately to steeply east. A wedge-shaped fault remnant of siliceous schists which strike north and dip to the west crops out to the west of the volcanic rocks in the northern part of the mapped area, and siliceous dolomite with interbedded chlorite-quartz schist lies to the west of the fault adjacent to the volcanic rocks in the southern part of the mapped area.

On the west limb of the syncline and in the western part of the mapped area, siliceous dolomite is underlain by highly competent dark-gray quartzite and limey quartzite. These rocks form a prominent northwest-trending fault or fault line scarp and strike to the northwest and dip to the east.

In the central and southern part of the mapped area, siliceous dolomite with interbedded chlorite-quartz schist and phyllite form the core and nose of a north-plunging syncline. The east limb strikes north and dips 30° to 50°W., and the west limb strikes northwest and dips at slightly lower angles to the east so that the fold is assymetric. These rocks comprise the stratigraphic unit of principal economic interest. Although they are exposed over a distance of 2 or 3 kilometers perpendicular to the strike, they are highly faulted and folded so that the stratigraphic thickness may not exceed 400 meters. Quartz veins and plugs are found throughout this series of rocks. Most of the veins parallel the strike of the wall rocks; however, some are crosscutting. They are normally less than a meter wide; although some measure several meters. A large quartz stockwork is indicated by outcrops and abundant quartz float on the west limb of the syncline. The stockwork parallels the limb of the fold and it is possible that it occupies a strike fault zone. The quartz is commonly white, massive, and barren of sulfide minerals. Locally, chalcopyrite, chalcocite, and malachite are found as cavity and fracture fillings and are commonly found in quartz veins near or in the mineralized sedimentary rocks.

In the northern part of the mapped area, the core of the syncline is occupied by volcanic rocks of dacitic to andesitic composition which overlie the siliceous dolomite and chlorite-quartz schist. The volcanic rocks extend to the north of the mapped area for approximately 3 kilometers forming a progressively wider outcrop pattern in the trough of the north plunging syncline. Two kilometers north of the mapped area the volcanic rocks are intruded by peralkaline granite stock which appears to offset the syncline axis to the west.

Time did not permit an investigation of the area between the granite plug and the Al Muckahal mine 13 kilometers to the northwest. The regional geology on the Tihamat Ash Sham quadrangle by Brown and others (1958) shows that the rocks in the vicinity of the Al Muckahal Mine are in the same stratigraphic unit as those at the Wadi Yiba prospect. This has not been verified in the field, however, stratigraphic and lithologic comparisons between the two areas indicate that these two widely separated mineralized zones are in the same stratigraphic unit.

In the vicinity of the Al Muckahal mine, marble, which may be the metamorphosed equivalent to the siliceous dolomite in the Wadi Yiba copper prospect area, is the dominant rock type and is host to lead-zinc-copper-silver-molybdenum mineralization in the mine workings. Near the mine the marble is overlain by siliceous pyroclastic rocks which are in turn overlain by intermediate volcanic rocks. The marble appers to be underlain by volcanic rocks 200 or 300 meters northeast of the mine area; however, this contact was not observed on the ground. The rocks in the vicinity of the mine are tightly folded and highly sheared. The main workings are located in fractures near the nose of a small anticlinal fold. This mine is further discussed under mineralization.

Low-rank regional metamorphism has affected all the rocks which predate the peralkaline granite. Although the siliceous dolomite shows no obvious metamorphic effects, the interbedded schists and the overlying volcanics appear to be metamorphosed to the lower greenschist facies. Chlorite and sericite are the metamorphic minerals identified in these rocks. Dynamothermal metamorphism of low to medium rank has affected the rocks where they are folded and faulted. The degree of metamorphism is dependent upon the intensity of the structural disturbance.

In the Wadi Yiba copper belt this has resulted in argillization along shear zones and perhaps a partial remobilization and concentration of sulfide minerals in the dilatant zones near the nose of the syncline and in fault and shear zones. Folding and shearing are more intense in the vicinity of the Al Muckahal mine. Thus, there is an increase in the metamorphic rank resulting in the conversion of siliceous dolomite to marble and more pronounced sulfide remobilization to dilatant zones.

The stratigraphic relationship between rocks of the Suq Al Khamis and Wadi Yiba-Al Muckahal areas is not well known. The siliceous dolomite in both areas appears to be very similar mineralogically and by the appearance of the weathered outcrops. In both areas the siliceous dolomite is underlain by volcanic rocks. Galena mineralization from both areas is of approximately the same age. Samples for lead isotope age dates were submitted by Brown from the Al Muckahal mine and by the author from the western part of the Suq Al Khamis area. The results indicate similar ages (table 1). Thus sulfide mineralization in both parts of the area may by of approximately the same age, and general lithologic comparisons suggest possible stratigraphic correlations.

Sulfide mineralization

Sulfide minerals or the oxidized products were observed in marble, siliceous dolomite, and in schists of possible pyroclastic origin. The minerals occur as disseminations or as concentrations in dilatant zones within these units. In shear zones the sulfide minerals are often associated with quartz and at the Al Muckahal mine with quartz-carbonate.

The sulfide occurrence of greatest economic importance is probably the Wadi Yiba copper prospect which is located 31 kilometers east of Suq Al Khamis and 76 kilometers east of Al Qunfidhah in the vicinity of latitude 19°10'N. and longitude 41°50'E. A road provides access to the prospect from both the north and south.

Disseminated copper carbonates and secondary sulfides occur in siliceous dolomite and interbedded chlorite-quartz schist on the east limb and in the nose of a north-plunging syncline. Copper minerals were observed along the same general stratigraphic horizon for a strike distance of over 4 kilometers. Mineralization is locally continuous for a few meters parallel to strike and as much as 8 meters perpendicular to strike. The long axis of the mineralized outcrops in the horizontal plane appears to parallel bedding and foliation of the host rocks. There is local discordance where mineralized beds are transected by shears or faults.

The principal economic mineral observed is malachite, and locally small concentrations of secondary chalcocite were found. Chalcopyrite is the only primary economic sulfide mineral observed and occurs sparingly in quartz veins as an unenriched core in chalcocite. Copper minerals were the only economic minerals positively identified in hand specimens; however, anomalous assay values of zinc were detected in all the chlorite-quartz schist samples. Only 1 of 11 siliceous dolomite samples contain a weakly anomalous zinc value, and this sample was collected near a schist contact. Pyrite cubes completely converted to limonite are found in schist horizons. Limonite occurs sparingly in the cupriferous part of the siliceous dolomite and appears to be transported. Limonite is most abundant in rocks adjacent to the copper zone and the distribution appears to be erratic.

Siderite is sometimes found in the siliceous dolomite where supergene chalcocite is most abundant; however, it also occurs in zones apparently lacking in copper mineralization.

Field investigations and analysis data indicate that there have been much solution and precipitation of copper and iron minerals in the zone of oxidation, and they have resulted in mineralogic changes and redistribution. Copper mineralization has retained a stfatigraphic relationship, so it would appear that in the leaching process, copper sulphate reacted quite rapidly with the carbonate host rock to form copper carbonate. Iron derived from the leaching of iron or copper-iron sulfides has apparently been mostly precipated as insoluble ferric hydroxide and transported as a colloid in the well-aerated waters of the oxidation zone. This has resulted in an erratic pattern of iron hydroxide distribution. Solutions of ferrous iron may have reacted with the host rock to form iron carbonate; however, most of the iron derived from sulfide leaching has most likely been transported in colloidal solutions and deposited some distance from its original depositional environment.

The analysis data on figure 2 suggest that the copper values may have a direct relationship to the calcium-magnesium ratios. In general, the highest copper values have the lowest Ca-Mg ratios. This relationship suggests that copper may have been originally deposited in a particular sedimentary environment and that it has not migrated a significant distance from the stratigraphic horizon where it was originally deposited.

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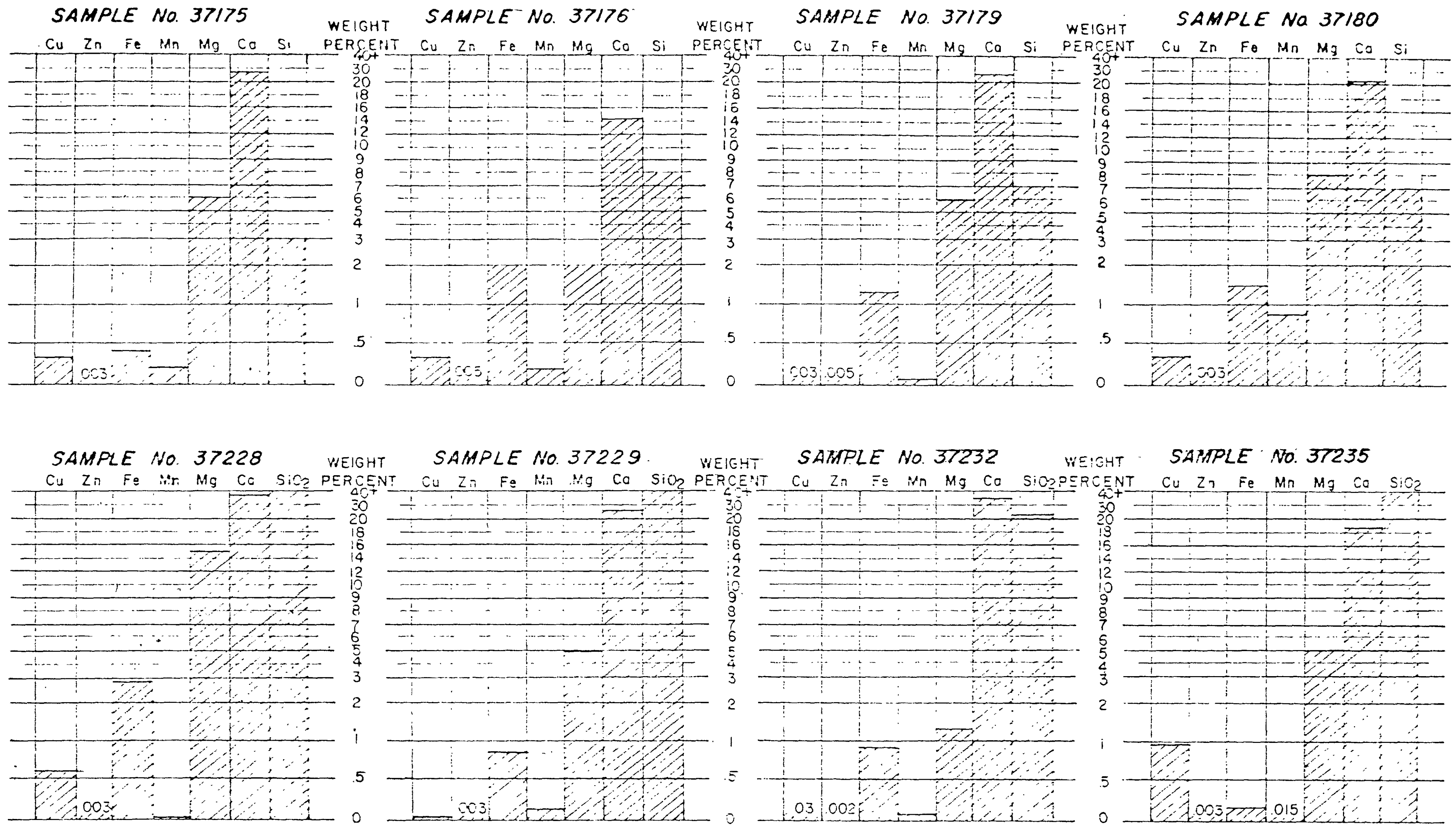
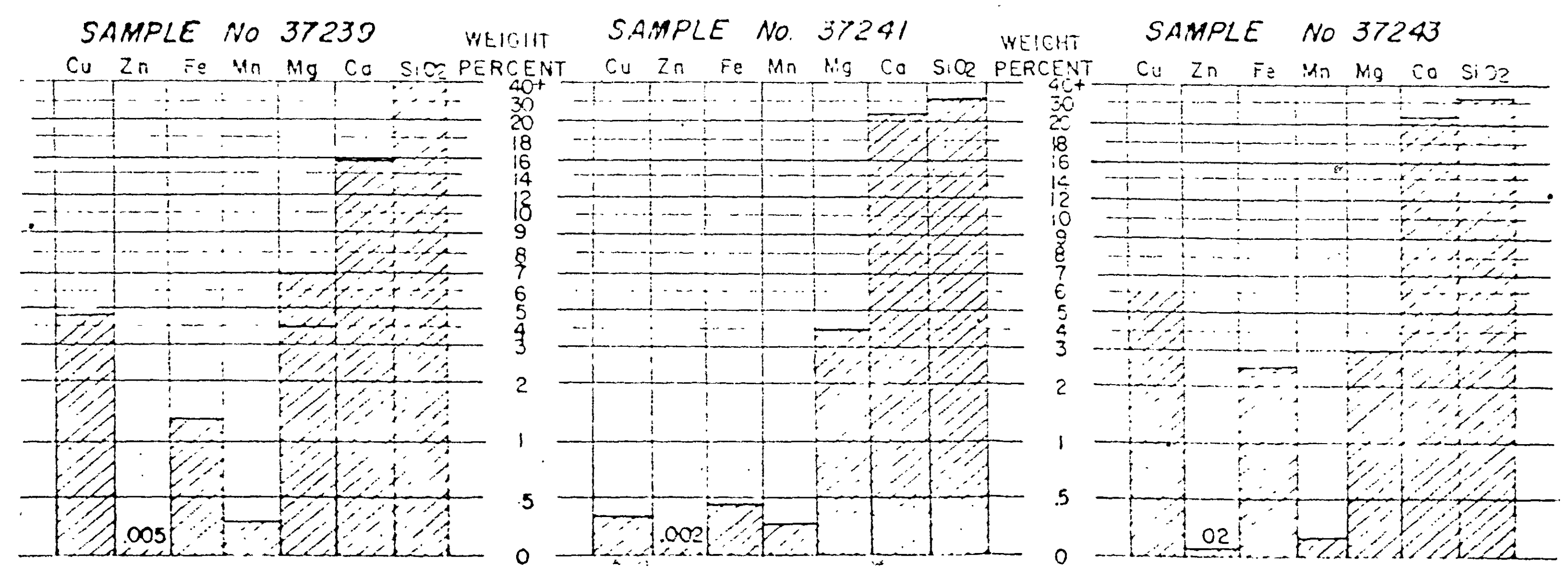
ANALYSIS DATA BAR GRAPHS - SILICIOUS DOLOMITE - WADI YIBA COPPER





ANALYSIS DATA FROM MINISTRY OF PETROLEUM AND MINERAL RESOURCES LABORATORY, JEDDAH

GANGUE ELEMENTS DETERMINED BY ATOMIC ABSORPTION

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TL 97

FIGURE 2

The analysis data indicate that zinc was originally deposited in the interbedded schist and not in the siliceous dolomite (figs. 2 and 3). It is assumed that zinc was originally deposited as zinc sulfide. The absence of zinc in the siliceous dolomite indicates that there has been little to no interchange of zinc or copper between chlorite-quartz schist and siliceous dolomite. The schist is evidently an impervious barrier prohibiting the entry of ground-water solutions from the siliceous dolomite, and ground water in the schists apparently migrates downward to the water table along the planes of schistosity. This control on the migration of ground water may have important economic significance. If copper sulphate solutions derived from leaching of copper-bearing sulfides migrated from the schist to the siliceous dolomite, they would react rapidly to form insoluble copper carbonate and would reduce the chances of the formation of important supergene deposits below the oxide zone. The chlorite-quartz schist is relatively inert, however, so that copper sulphate solutions, restricted to this horizon on downward migration to the water table, may form important supergene enrichment zones below the zone of oxidation. This speculation is based on the assumption that primary copper minerals were deposited below the present zone of oxidation. This assumption is reasonable in view of the extensive strike distribution of mineralized outcrops. The most important zones of supergene sulfides are likely to occur in the schist below the zone of oxidation where the mineralized horizon is transected by shears. Such zones are likely to contain more abundant primary sulfides as a result of remobilization due to shearing and to cause depressions in the zone of oxidation which provide a greater reservoir of copper sulfides available to leaching processes.

ANALYSIS DATA BAR GRAPHS - CHLORITE SCHIST

WADI YIBA COPPER

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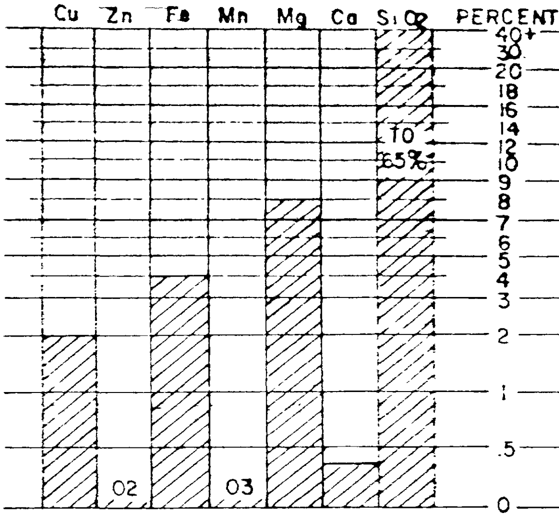

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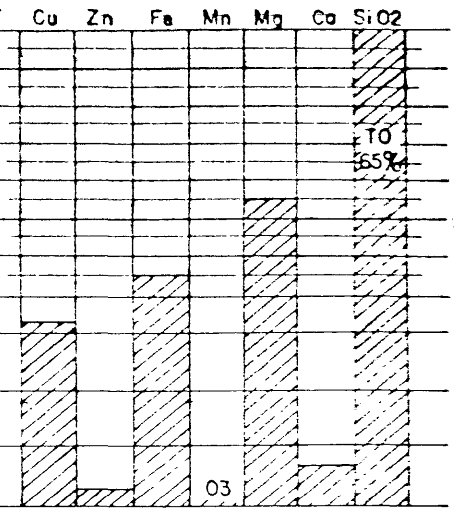

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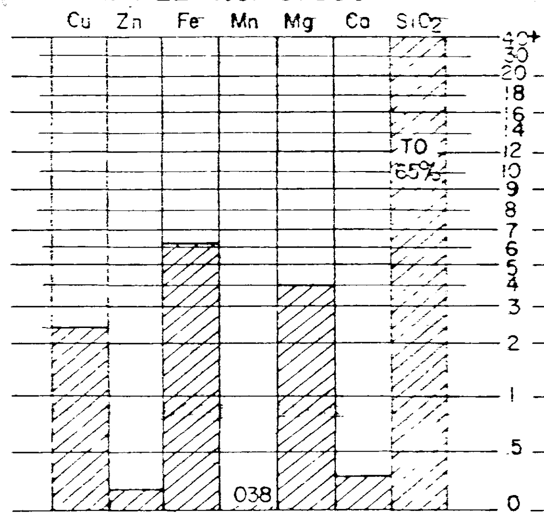

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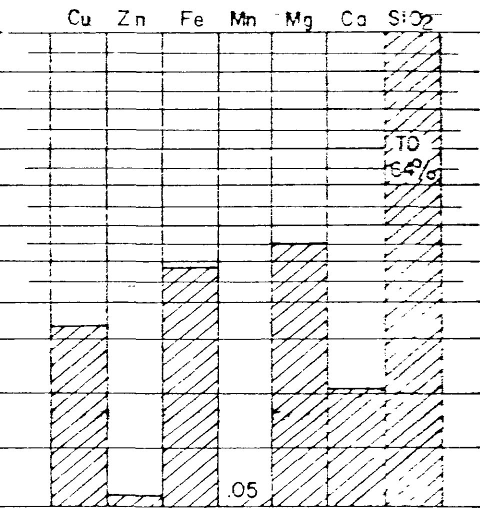

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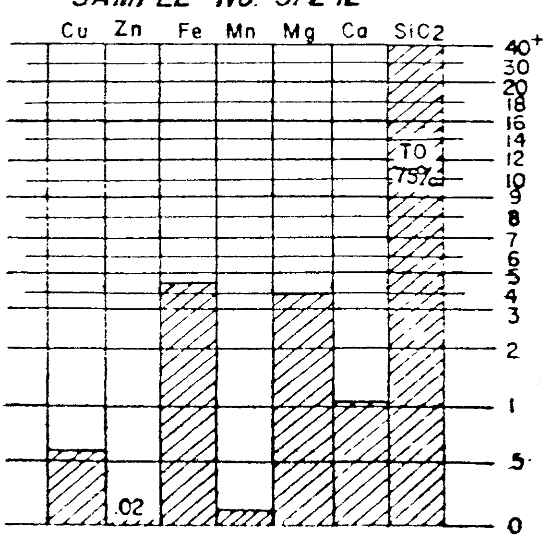

ANALYSIS DATA FROM MINISTRY OF PETROLEUM AND MINERAL RESOURCES LABORATORY, JEDDAH

GANGUE ELEMENTS DETERMINED BY ATOMIC ABSORPTION

Geophysical and geochemical surveys by Davis and Allcott in the copper zone support geological observations. Electromagnetic horizontal coil measurements were made along six traverses perpendicular to the strike of the copper mineralization and spaced over a total strike distance of about 2000 meters. Davis reports anomalous responses from each of these lines which may be indicative of disseminated sulfides (Davis and others 1969). The strike of the anomalous trend appears to correspond with the strike projection of copper-bearing outcrops. Geochemical samples of wadi sediments collected by Allcott are inconclusive but are being further evaluated (G. H. Allcott, oral commun., 1967). Soil samples collected by Allcott over the nose of the syncline where outcrops are lacking show a distinct copper anomaly near the strike projection of cupriferous outcrops. These data and the position of the geophysical sections are given on figure 5. Analysis data from the copper zone are also presented on figure 5.

Mineralization at the Al Muckahal mine chiefly consists of argentiferous galena. Small amounts of sphalerite and chalcopyrite are associated with galena, and one sample from the mine workings contained weakly anomalous amounts of molybdenum. Sulfide minerals occur as sparse disseminations in marble and as small massive pods in vertical fractures filled with quartz-carbonate. The fractures are confined to the nose of a small north-plunging anticline and parallel the axis of the fold. They are prominent but terminate rather abruptly 200 or 300 meters south of the nose. The veins are closely spaced and are a maximum of 1 meter wide. Sulfide mineralization is highly localized in the vein system. Sulfide minerals both in the vein system and in the marble are mostly unoxidized.

The main working consists of a vertical shaft which extends to a depth of 3 meters on the main vein. A drift extends from the bottom of the shaft to the south away from the nose of the fold. The first 10 meters of the drift were examined and the total length is not believed to exceed 30 meters. The analysis data from samples collected in the vicinity of the mine workings are given on table 2. Geophysical surveys over the vein system did not indicate conductive responses (W. E. Davis, oral commun., 1967).

The occurrence is not considered to be economically important; however, it indicates a possibility of locating other mineral deposits in the carbonate beds. Future investigations in the area should be directed along this stratigraphic horizon between the Al Muckahal mine and the Wadi Yiba copper prospect.

Near the Al Muckahal mine there is a greater concentration of sulfide mineralization in the fracture systems than at the Wadi Yiba copper prospect. This is best explained by the fact that the rocks are more highly metamorphosed at the Al Muckahal mine and consequently there has been more sulfide remobilization and concentration in dilatant zones. The different association of sulfide minerals between the two locations may be due to differential mobility caused by metamorphism which has resulted in selective sulfide concentrations, or it may be due to a primary zonal distribution of sulfide minerals within the stratigraphic unit.

Precious metals

Gold and silver values were determined by atomic absorption on 23 samples from the Wadi Yiba copper prospect. Analysis results are given in figure 5.

Table 2. Assay results from Al Muckahal mine area (Assays from laboratories of Directorate General of Mineral Resources, Jeddah, 1967).

(Values in ppm except Silver in ounces per ton)

Sample No.	Description	Cu	Pb	Zn	Mo	Ag	Au
37106	Light gray marble with traces of pyrite and malachite............	20	25	25	5	.48	Nil
37107	Sandy, ferruginous tuff...........	800	25	50	5	.32	Nil
37108	Quartz-carbonate vein material with minor galena, malachite, and smithsonite (?)................	115	300	1000	5	.52	Nil
37109	Slag............................	460	4000	100	5	.04	Nil
37110	Quartz-carbonate and marble with richly disseminated galena......	20	80,000	125	160	.88	Nil

Gold was detected in seven samples. In general, the gold values were obtained from samples which contain appreciable amounts of copper. The highest gold value is 0.11 ounces per ton and was taken from an argillized shear zone near the syncline axis. Siliceous dolomite and quartz veins also contain gold values of possible economic importance. Small amounts of gold were detected in samples of chlorite-quartz schist.

Significant amounts of silver were found in two samples. The highest value is 4.0 ounces of silver per ton and corresponds to the highest gold value obtained. A copper-bearing quartz vein sample, which was collected on the west limb of the syncline, contains 0.97 ounces of silver per ton. Minor silver values were detected in samples of siliceous dolomite and chlorite-quartz schist.

The precious metal analytical results indicate that economically important amounts of gold may occur in the copper bearing formations. Recoverable amounts of silver may occur in shear zones and in zones of supergene enrichment.

Many sulfide geologists believe that sulfide deposits from volcanic emanations are a common type and the reader is referred to selected references contained at the end of this paper. It is suggested that iron, copper, and zinc sulfides in the chlorite-quartz schist in the Wadi Yiba area are of volcanic origin.

Sulfur isotope studies could possibly contribute to a better understanding of the genetic processes, but regardless of the processes involved it would seem that there is a close genetic relationship between sulfide mineralization and volcanism.

Conclusions and recommendations

Copper mineralization which is stratigraphically controlled is exposed intermittently along strike for over 4000 meters. The host rocks are siliceous dolomite and chlorite-quartz schist. The prospect is enhanced by the presence of supergene copper minerals in both the siliceous dolomite and chlorite-quartz schist and by anomalous zinc values found exclusively in the chlorite-quartz schist.

Systematic surface sampling may help to define the limits of mineralization. The zone is highly oxidized, and there is evidence of much solution and precipitation of iron and copper minerals so that it will be necessary to obtain subsurface data before estimates of grade and character of the copper mineralization can be made.

The favorable host rocks are believed to have a minimum strike extent of 75 kilometers. Continued investigations should include reconnaissance geology and prospecting of this stratigraphic unit.

Preliminary work indicates that the mineralized zone is responsive to geophysical and geochemical techniques. These methods should therefore be applied in the future work.

Analytical data indicate that there may be a difference in the character of the mineralization between the siliceous dolomite and the chlorite-quartz schist. It is, therefore, important to map these rock units on a scale large enough to permit differentiation. This could best be done by the plane-table and alidade method, and the scale should not be smaller than 1:1200.

SUMMARY OF CONCLUSIONS AND FUTURE PLANNING

Reconnaissance investigations in the Al Qunfidhah area have indicated that the rocks at several localities contain anomalous amounts of sulfide minerals. The area may contain economically important deposits of copper and nickel. Mineralization is principally of the disseminated type and is found in volcanic rocks, pyroclastic rocks which overlie volcanic piles, and in shallow water marine sedimentary rocks. There appears to be a close relationship between sulfide mineralization and volcanism.

In addition to locating specific exploration target zones, the reconnaissance work has indicated particular stratigraphic horizons which should be included in future regional investigations. Stratigraphic relationships between the east and west parts of the area are not well understood. The major structural pattern indicates a possibility of stratigraphic repetition, and both stratigraphic and lithologic similarities were observed. Stratigraphic relationships may have economic implications, and attention to this problem should receive high priority. It is, therefore, recommended that the area be mapped geologically and that an attempt be made to gather geochronological data from the greenstones.

The most important zone is the Wadi Yiba copper prospect. Detailed work plans involving mapping, geophysics, geochemistry, prospecting, and diamond drilling have been submitted to the Minister of Petroleum and Mineral Resources. An important part of this work will be continued reconnaissance along strike to the north and south of the copper zone.

The nickel occurrence in the west part of the area may also be a deposit of primary importance. This is especially true in view of the close proximity of this occurrence to the Red Sea port. It will be necessary to continue detailed mapping and geochemical prospecting in this zone before subsurface exploration can be planned. Both the geochemical survey and geological mapping terminate in the most highly anomalous part of the zone which has yet been discovered. Soil samples in this part of the zone contain a maximum of 0.25 percent nickel. Parts of the zone are anomalous in copper, and zinc may be a minor ore mineral. In addition to the geological and geochemical work planned, the area should be included in the helicopter EM survey which has been proposed for the Wadi Yiba copper belt.

Perhaps the most abundant sulfide mineralization found in the area is in the thickest part of the pyroclastic pile 13 kilometers due west of Suq Al Khamis. The outcrops indicate that pyrite is the most abundant sulfide in this zone although minor amounts of copper carbonate were also observed and one sample contained ore grade gold values. Detailed mapping, sampling, and geophysics may indicate whether or not diamond drilling is justified in this area.

The cupriferous quartz-carbonate veins in the Wadi Sishah area are a low-priority drill target.

Drilling in the Suq Al Khamis area should not commence until the recommended surface work is completed on the principal prospects. This would allow better coordination of drill plans and will result in increased efficiency and lower costs.

A detailed exploration plan has been submitted to the Minister of Petroleum and Mineral Resources. This plan includes contracting 2500 kilometers of helicopter EM survey, 50 kilometers of ground EM survey, and 4500 meters of diamond drilling.

Diamond drilling should commence as soon as possible in the Wadi Yiba area, and the drilling program should be closely coordinated with the helicopter EM survey. Reconnaissance work has resulted in locating suitable drill targets, and data derived from rock cores will assist in the interpretation of geophysical results within and beyond the presently known limits of the copper zone. Also, a comparison of subsurface material with the highly oxidized surface outcrops may provide valuable data for continued geological reconnaissance in the belt of dolomitic rocks.

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