UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Saudi Arabia Investigation Report
(IR) SA-50

RECONNAISSANCE MINERAL AND GEOLOGIC INVESTIGATIONS IN THE AL BAD' QUADRANGLE, AQABA AREA, SAUDI ARABIA

by

Virgil A. Trent and Robert F. Johnson
U. S. Geological Survey

1968

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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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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Exploration - 50

RECONNAISSANCE MINERAL AND GEOLOGIC INVESTIGATIONS IN THE AL BAD' QUADRANGLE, AQABA AREA, SAUDI ARABIA

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Contents

Abstract

A reconnaissance mineral and geologic survey of the Al Bad' quadrangle, Aqaba area, was completed during 28 man-days of field work. The work partially fulfills an agreement between the Directorate General of Mineral Resources, Ministry of Petroleum and Mineral Resources and the U. S. Geological Survey to evaluate the mineral potential of Western Saudi Arabia.

Intrusive rock contacts, faults, and light or dark colored rocks were examined while driving up most of the accessible wadis. Wadi sand samples were collected for spectrographic analysis and the trace element content for copper, zinc, and molybdenum is presented on the map.

Most of the rocks are Precambrian in age. Cambrian and Ordovician sandstone crop out in the eastern part of the quadrangle and unconformably overlie the older rocks. Tertiary rocks are limited to small exposures in the western mapped area. Intrusive rocks are abundant; granite of at least two and probably three ages crops out and their age relations pose the outstanding geological problem. Bedded rocks also are common, the oldest being at the greenschist facies of metamorphism.

Folding is locally tight but in general not complex. Major northwest -, northeast -, and east-striking faults are prominent structural features. Dikes and dike swarms are abundant and varied in composition.

No mineral deposits of economic value were located in the quadrangle. Small, local occurrences of sulfide minerals were found north of Jabal Rawa and southeast of Shaib as Siq. At the latter locality gossan is developed in quartz veins and pegmatite near the contact of diorite and granite. Spectrographic analysis of one sample, 4053, shows 1 percent copper, 500 parts per million (ppm) molybdenum, and 200 ppm zinc.

Banded iron formation, jaspilite type, crops out in small, scattered areas in the quadrangle. These deposits are not of economic interest in themselves.

Beds of gypsum up to 1 meter thick are interbedded with shales in the Raghama

formation of Tertiary age near Al Bad'. Aeromagnetic data indicates no near surface basement rock in the Al Bad' - Al Lisan Tertiary basin. It may be a favorable structure for accumulation of petroleum.

First priority recommendations for further work are: a) make a definitive study of marginal iron formation resources and b) field check the copper zone at sample location 4055 and collect additional samples for spectrographic analysis. Several areas of low priority study are indicated.

Introduction

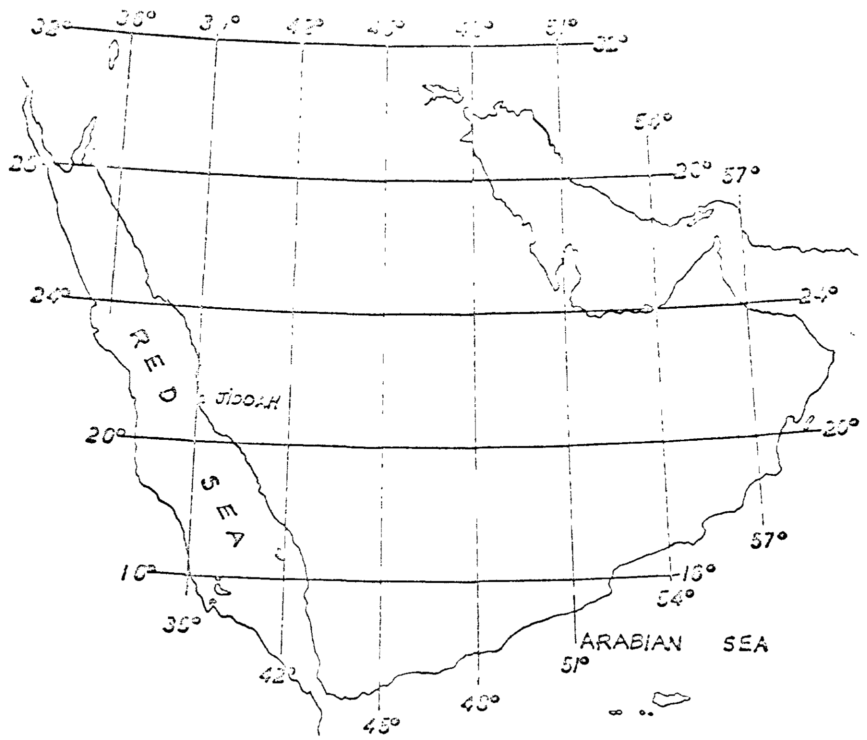
Geographic setting.

A highland belt of largely crystalline rocks known from antiquity as the "Land of Midian" extends from 28°N. to 29°30'N. and between 34°30'E. and 36°E., east of and adjacent to the Gulf of Aqaba. This highland has been a route for pilgrims, caravan trade, armies, and pastoral peoples over the centuries. While searching here for minerals of value our attention was often called to the areas 'rich and colorful history; similar prospecting trips have been made here since the days of King Solomon's mines.

Roads are unsurfaced and not maintained. The coast road along the western margin of the quadrangle, passes five villages of which Al Bad' is the largest. The only other road crosses the northeastern part of the Al Bad' quadrangle to connect Tabuk and Haql, which are outside the mapped area.

Much of the quadrangle (located on figure 1) is mountainous. The large sand plain of Wadi Ifal lies within the Al Bad' - Al Lisan Tertiary basin (Kahr and Agocs, 1962, p.p. 14-15). East of thisplain there is fairly good access to the interior by primary and tributary wadis. Along the eastern map border the high, plateau-forming Paleozoic sandstones, the Hisma, are in contact with topographically subdued Precambrian rocks.

Vegetation is sparse but acacia trees, desert shrubs, bushes, and wild flowers are common. Date palms are cultivated near the villages. The climate is cool in the winter and hot in the summer with little rain during the year.



INDEX MAP OF ARABIAN PENINSULA
SHOWING LOCATION OF QUADRANGLE

FIGURE 1

Previous Investigations

Captain Richard F. Burton explored parts of this area in 1877 under sponsorship of the Viceroy of Egypt. His party spent seven days in the area of the Al Bad' quadrangle where he observed a vein containing some tin metals at Jabal al Abyad, about 20 kilometers northeast of Ash Sharma (Burton, 1878, pp. 216-219). He also described in considerable detail ancient villages, forts and smelting sites at Aynunah and Ash Sharmah, which he thought were the base locations of mining communities operating in the interior.

The next record of work in the area was in 1953 when Richard G. Bogue, U. S. Geological Survey, and H. St. J. B. Philby, advisor to the Arabian government, examined the Wadi Sawawin iron deposits and many of the ancient gold mines in the vicinity of Al Wajh. They checked the white quartz hills known to Burton as Jabal al Abyad and found the veins are irregular masses barren of gold. Bogue found the small vein of magnetite which Burton had located years ago (Bogue, 1953, pp. 24-25). Bogue used the local name Abal Maru for this prospect. This name is spelled Abu Marw on the accompanying map and map I-200A (Brankamp and others, 1963). Five kilometers south of Jabal Kharis they found iron formation outcrops in isolated hills.

Dr. H. R. von Gaertner and Dr. H. Schurenberg of the Amt fur Bodenforschung, Hannover, Germany, visited this area as part of a regional geological and mineral resources survey in 1954. They noted thin lenses of iron formation in greenstone northeast of Ash Sharma, and large crystals of feldspar near the white quartz hills of Jabal al Abyad. They described a vaguely located mine called Safra, with small outcrops of iron formation nearby.

A geologic map of this area, scale 1:500,000 (Brankamp and others, 1963), provided us with a good geological framework and guidelines for minerals exploration. We found in field checking the map that the contacts are generally well located but some of the rock types are incorrectly labelled. Dr. Glen F. Brown, U. S. Geological Survey, compiled the data for the portion of the map in the Aqaba area from field notes and reports of R. G. Bogue, H. R. von Gaertner, and H. Schurenberg and from air photo interpretation.

Dr. Viktor P. Kahr, Senior Geologist, and Mr. W. B. Agocs, Chief Geophysicist of the Directorate General of Mineral Resources, Ministry of Petroleum and Mineral Resources, mapped a portion of the Al Bad' quadrangle at 1:100,000 scale in late 1961 as part of a reconnaissance geologic and magnetic survey of the Wadi Sawawin iron formation, exposed to the south in the Wadi as Surr quadrangle (Johnson and Trent, 1966).

Present work.

The purpose of this study was to search for, assess, and submit recommendations regarding mineral deposits; check and revise in so far as necessary the existing geologic map of the area (Bramkamp and others, 1963); and to assist in training counterpart personnel and helpers in geological studies and mineral prospecting. A total of 28 man-days were spent in the Al Bad' quadrangle (Trent and Johnson, 1966 Tech. Letter 41). We found no mineral deposits of immediate economic value but scattered, small, low grade deposits of iron formation were observed and anomalous copper values were found. Other than these targets the work does not indicate a need for additional detailed studies of a first priority nature.

The plan of the work was to drive up most of the accessible wadis using aerial photographs to lay out the daily traverses. Intrusive rock contacts, light-or dark-colored rocks, faults, and rock types were examined. Samples of wadi sediment were collected to test some definite contact or structure and in places to test a large drainage basin. Spot checks for radioactivity were made. Old mines and prospects were located and examined where possible .

A photomosaic base at a scale of 1:100,000 was used for map compilation.

Acknowledgements.

The present work was done under the auspices of the Directorate General for Mineral Resources, Ministry of Petroleum and Mineral Resources and the U. S.

Geological Survey as partial implementation of an agreement to make a regional economic mineral survey of the Precambrian rocks of Western Saudi Arabia.

We wish to acknowledge the assistance and guidance given us by numerous officials and employees of the Directorate General of Mineral Resources, Ministry of Petroleum and Mineral Resources, and the Emir of Al Bad'. Mr. Shattah Kattieb, geologist with the Ministry, accompanied us during the first two weeks of our work in the Al Bad' quadrangle.

Geologic setting

Most of the rocks in the Al Bad' quadrangle are of Precambrian age. Plutonic rocks predominate, but sandstone of Cambrian and Ordovician age crops out in the eastern part of the area where, the Hisma plateau is deeply dissected. Tertiary rocks are limited to the vicinity of Al Bad', north of Aynunah, and a small basin 5 km northeast of Ash Sharma. The oldest rocks in the area, greenstone and the Silasia formation, are largely at the greenschist facies of regional metamorphism, and contact metamorphic effects are common adjacent to bodies of granite. At least two and probably three ages of granite are present. Their age relations pose the largest geological problem in the region.

Rock types.

Greenstone:-- The Greenstone unit (gd) is the oldest rock and provides the fabric of the area. The greenstone consists mostly of metandesite with some metabasalt and metarhyolite flows. The flows are locally porphyritic. Sporadic, thick sections of metasedimentary rocks including slate, wacke and iron formation are interbedded with the volcanic rocks. Thin lenticular beds of magnetic iron formation crop out in greenstone near the head of Wadi Al Arnab. Some rocks of the greenstone unit are metamorphosed to amphibolite and hornfels along the margins of granitic plutons such as Jabal Rawa. Greenstone bordering the Jabal Rawa intrusion on the south and west, and the greenstone area 11 kilometers to the west contain some Hadiyah formation and granitic rocks. Granite intrusives of three probably different ages cut the greenstones. A single sample of greenstone dated by radioactive methods indicates this rock is about 615 million years old.

Silasia formation:-- Folded green slate, calcareous schist, arkosic sandstone, conglomerate and minor marble constitute the Silasia formation. Jaspilite iron formation is interbedded in the upper half of the Silasia formation. It ranges from 1/2 to 20 meters in thickness and consists of interlayered jasper and hematite with sparse magnetite. Remnants of iron formation crop out in small, scattered inclusions in granite (gg and gm) east and southeast of Wadi Aynunah.

The relations between the greenstone unit and the Silasia formation are obscure in this area. It is possible that there are two units of iron formation - one in the greenstone and one in the Silasia. In addition, this thick metasedimentary section may actually be equivalent to the metasedimentary rocks within the greenstone unit. The relative ages and relations of the Silasia formation and the Greenstone unit are not clearly understood.

Hornblende diorite:-- Hornblende diorite crops out in a small area 8 kilometers southeast of Jabal Rawa, east of Jabal ash Shati and in the southeastern map area. Locally the hornblende diorite includes some amphibolite and quartz diorite. South of the head of Wadi al Arnab the diorite grades into a diorite complex in the adjacent quadrangle.

Granite and granodiorite:-- The oldest granitic rock is light, medium-to coarse grained granite and granodiorite (gg). It is locally schistose and contains zenoliths of older volcanic and sedimentary rocks. In addition, it contains abundant felsite and lamprophyre dikes. Locally, dark talus material from mafic dike swarms mask the light granite almost completely. This rock unit crops out in a north-northwest-trending belt adjacent to the Paleozoic sandstone and also west of Jabal ash Shati. It was described by Bogue as cave granite and by von Gaertner as coast granite.

Hadiyah slate:-- Hadiyah slate crops out north of and adjacent to Jabal Rawa. The slate is composed of a variety of clastic sedimentary and metasedimentary rocks and intraformational breccias. Probably the most extensive unconformity in the Al Bad' quadrangle is found at the base of this formation. Ten kilometers north of Jabal Rawa a thick section of the Hadiyah is tightly folded and offset about 2 kilometers on a cross fault. The unit has been traced far to the south to the Wadi Al 'Ays area of Map I-204a by Brown and others (1963).

Gray biotite granite, red alkalic granite, and dark hornblende granite:-- The granites labeled gb, gr, and gh are regarded here as being genetically related and essentially the same age. The gb granite is a fine-grained, light colored biotite granite located in the core of a ring structure within greenstone 10 km south of Jabal Rawa. Red, medium to coarse-grained alkalic biotite granite, gr, is porphyritic in part and contains sphene, apatite and magnetite as the main accessory minerals. Characteristically it weathers to massive, rounded hills and crops out in large areas in the northwestern part of the quadrangle. The dark alkalic hornblende granite, gh, was possibly introduced during the late stages of intrusive activity. This unit may partly include some younger granite and acid, hypabyssal rocks.

Intruded along joint sets in the granites are at least two ages of dikes. The oldest and most common dike rocks are diabase, andesite, and basalt. The youngest dikes are rhyolite, dacite, and microgranite.

Calc-alkalic granite:-- The calc-alkalic biotite granite labeled gm is equivalent to the central granite of von Gaertner and the massive granite of Bogue. It forms a series of high peaks such as Jabal ash Shati that extend both north and south of the mapped area. Little reaction has taken place between this granite and it's host rocks other than local conversion of the host to hornfels. The relations of the gm granite to the Shammar rhyolite are not known.

Shammar rhyolite:-- Unmetamorphosed volcanic flows and interbedded sedimentary rocks of the Shammar rhyolite crop out in a northwest-trending belt in the southeast corner of the area south of Shaib as Siq. The Shammar underlies the Siq sandstone of Cambrian age and lies unconformably on diorite and gg type granite. Farther north on the southwest side of Wadi ar Rayt unmetamorphosed Shammar rocks unconformably overlie the Hadiyah formation and metavolcanic rocks. Northeast of Wadi ar Rayt the relations are more obscure. Siliceous flow rocks mapped as Shammar rhyolite by Bramkamp and others (1963) are slightly metamorphosed and have been intruded by granite. The rocks are shown as Shammar (?) on our map, but they may be older.

Hypabyssal siliceous intrusive rocks:-- Siliceous dikes and hypabyssal intrusive rocks (da) represent the last major stage of igneous activity in the area. Rhyolite, aplite and dacite are common; most of these felsic dikes are too small to show on the map.

Sandstone of Paleozoic age:-- Unmetamorphosed, gently dipping sandstone of Paleozoic age lies unconformably on the Precambrian rocks in the eastern part of the quadrangle. The relations and names of the units are shown in the explanation.

Sedimentary rocks of Tertiary and younger age:-- The Raghama formation near Al Bad' consists of thin layers of gypsum interbedded in shale, fossiliferous limestone, sandstone, and conglomerate. The conglomerate is very coarse and poorly sorted. These outcrops and exposures in a small basin northeast of Ash Sharma form a part of a large Tertiary basin (Kahr and Agocs, 1962, pp 14-15).

Poorly indurated sedimentary rocks striking northeast with low dips to the southeast occupy the mountain front east of Al Lisan. These rocks are probably of late Tertiary age or possibly Quaternary age and are truncated by a boulder pediment surface with several levels sloping gently seaward.

Alluvial fan deposits, surficial clay, silt, sand, and eolian sand of Quaternary age are common in the eastern and western parts of the quadrangle.

Structure.

Morphologically the most impressive features are the large granitic plutons of Jabals ash Shati, Az Zuhd and Rawa. Several sets of faults are evident of which the most prominent strike toward the northwest and east. The Wadi al Arnab fault is the best example of a major east-striking lineament. A northwest-trending fault set may be related to the large wrench faults further south. There are a few north-trending faults and also a northeast-striking set. Little is known regarding the movement on these faults and their age relationships.

Incompetent beds in the iron formation have been intricately folded, and local tight folds are present, as in the Hadiyah formation north of Jabal Rawa. However, in most of the area, the folding is not complex except near the large intrusive bodies.

In general the folding tends to parallel the major northwest and east fault systems.

Dikes and dike swarms are abundant, especially in the older granites and along close-spaced joints and faults.

In the east-central part of the area there is a small synclinal basin of Hadiyah metasedimentary rocks unconformably overlying greenstone and underlying the Shammar rhyolite.

The Al Bad' - Al Lisan Tertiary basin (Kahr and Agocs, 1962, pp. 14-15) lies beneath the sand plain of Wadi Ifal, in the western part of the quadrangle.

Geochemical reconnaissance

Procedure.

An integral part of the field investigations for mineral deposits was collecting samples of wadi sand, rock, and magnetite for trace element analysis in the laboratories of the Directorate General of Mineral Resources, Ministry of Petroleum and Mineral Resources, Jiddah, Saudi Arabia. Semi-quantitative spectrographic analyses for 27 elements were made by C. E. Thompson, U. S. Geological Survey, of each wadi sand sample using the modified method of emission spectrography employed by the U. S. Geological Survey. Each sample was also analyzed by Thompson and L. Al Dugiather for copper, zinc, and molybdenum using standard colorimetric techniques.

Wadi sand at the sample site was screened and that portion passing through a 30 mesh sieve and remaining on an 80 mesh sieve was retained for analysis. At the laboratory the sample was passed through a Jones splitter and divided into two parts. One part was used for analysis and the other part supplied the magnetite which was analysed for copper, zinc, and molybdenum. Analytical data for magnetite are not presented here.

Most samples are from wadis that drained intrusive contacts, dark rock outcrops, light or bleached rock areas, and faults; some samples are from wadis draining specific rock types. The samples are sparse considering the size of the area. However, from this reconnaissance sampling anomalous quantities of various elements were disclosed and are shown on the map, and rough background levels for several rock types were established.

Results.

The results of spectrographic determinations for copper, zinc, and molybdenum on 50 wadi sand samples are shown on the map. No large anomalies were found. The Hadiyah formation contains 50 parts per million (ppm) copper and 3 ppm molybdenum north of Jabal Rawa. This amount of copper constitutes a small positive anomaly because background for copper here is about 20 ppm. Similar results were obtained further south in the Wadi al 'Ays area where samples of wadi sand from the Hadiyah formation contain from 50 to 70 ppm copper (Johnson and Trent, 1966, p.6).

The spot anomaly of 300 ppm copper and 10 ppm molybdenum near Wadi Rawa, sample 4185, was from soil below a sulfide-bearing quartz vein 40 centimeters thick. The sulfides are completely altered to limonite that fills fairly large cavities in the quartz.

Six kilometers southeast of Jabal Rawa a serpentine dike about 20 meters thick crops out with some quartz-carbonate veins in metavolcanic rock. Sample number 4181 from a wadi draining the dike and veins has 5,000 ppm chromium and 1000 ppm nickel.

Background values:-- The results of the analyses of samples of wadi sand from various rock types show that samples from a particular mapped unit have a definite similarity in trace-element content. For example, five samples from red alkalic biotite granite (gr) in the northwestern portion of the map have similar abundances of characteristic elements. Specific elements and their range are: barium, 1000-1500 ppm; chromium, 50-100 ppm; lanthanum, 50-100 ppm; molybdenum, 2-3 ppm; nickel, 50 ppm; and strontium, 300-700 ppm. Iron formation contains higher than average zinc and molybdenum. Samples 4037 and 4175 each have 300 ppm zinc, and 15 ppm and 10 ppm of molybdenum respectively.

Once background values are established for various rock types in an area it may be possible to use the data for correlation. In general, only a rough background was obtained for most of the rock types in this area.

Specific elements:-- Barium values are higher, in general, than in other areas due to the abundant felsic rocks; K-feldspar is the primary rock mineral source of this element (Hawkes and Webb, 1962, p.361). All the granites appear to be high in lanthanum and niobium, in particular the calc-alkalic biotite granite (gm).

Higher than average values for nickel and chromium are found in the diorite and on or near faults. The three anomalous samples on the west-northwest trending fault crossing Wadi Aynunah have average values of 200 ppm chromium and 50 ppm nickel. In addition, values for chromium and nickel of 200 ppm and 50 ppm respectively occur in samples taken close to the fault near the head of Wadi al Arnab. Other samples from faults also show anomalous values for chromium and nickel.

Lead is absent. Zinc values were less than or equal to the level of detection (100 ppm) in all samples.

The two samples 3 to 4 kilometers southwest of the Wadi Rawa ring structure each contain 1 ppm silver and higher than average molybdenum, titanium, barium, and manganese.

Mineral deposits

Ancient mines.

Bogue (1953, p.25) used the name Abu Marw for two hills at Jabal al Abyad that contain irregular masses and veins of white quartz. He located a few small pits and trenches but found no extensive workings. Small amounts of pyrite occur as well as a small vein of magnetite which Bogue estimates to contain from 75 to 100 tons. Magnetite does not crop out elsewhere in the area.

Von Gaertner and Schurenberg (1954, p.78) describe very large crystals of red feldspar that occur in a broad area in the westernmost part of the quartz hills. This is a localized quartz pegmatite area within the granite, but von Gaertner and Schurenburg thought that a survey should be made for mineable quantities of feldspar.

They also examined the ancient mine called Safra (exact location unknown) near Al Khuraybah. Some shallow pits, an inclined shaft, and a trench were found near the summit of a hill north of Wadi Gharr. The excavated material, within dolomite, averaged 1 to 2 meters in thickness. Malachite is common and also occurs in the wallrock. One sample contained 2.1% copper. They believe the mine was worked for gold as well as copper. A thin bed of iron formation crops out near the mine. They did not recommend further work at the mine but felt an area reconnaissance of the iron formation was warranted.

Mineralized areas.

A small area of secondary copper was found in conglomerate in the Hadiyah slate on the north boundary of the map. Spectrographic analysis of sample number 10,253 gave a result of 2,000 ppm copper. The copper appeared to be sparse and local.

Some cross fiber chrysotile asbestos with fibers as much as 1 cm long was found in a serpentinized dike about 6 km south of Jabal Rawa (sample locality No.4181). The quantity was very small; the area is not worthy of additional study for asbestos.

A sulfide-bearing quartz vein (sample number 4185) near Wadi Rawa is very small.

Surface coatings of malachite and chrysocolla occur in and adjacent to quartz veins and pegmatite ten kilometers southeast of Shaib as Siq. Gossan is developed on some quartz veins, and one vein contains a little chalcopyrite. The best displays of copper minerals are near the contact between diorite and granite. Veins are abundant in granite, but they lack copper minerals. Spectrographic analysis of sample 4053 shows 10,000 ppm copper (1%), 500 ppm molybdenum, and 200 ppm zinc.

Iron Formation.

The iron formation found within the Al Bad' quadrangle is the banded jasper-hematite-magnetite type. There are varying amounts of specular hematite and magnetite depending in part, on the degree of metamorphism and the proximity of faults. Roughly, the analysis of Bogue's chip samples collected at Wadi Kharis would apply to the other areas as well; that is, an average of 26 to 35 percent iron and 37 to 50 percent silica. The following paragraphs discuss the iron formation in the Al Bad' quadrangle.

Wadi ar Rayt:-- Northeast of Jabal Rawa small outcrops of Silasia iron formation as much as 10 meters wide can be traced for several hundred meters in a northwesterly direction.

Wadi Kharis:-- About 10 kilometers southeast of the Wadi Rawa ring structure there are several small hills with remnant outcrops of banded jasper-hematite iron formation with some magnetite preserved in the calc-alkalic biotite granite (gm). Bogue found sandstone and shale associated with these rocks and called them Silasia (Bogue, 1953, p.28). Several chip samples collected by him show the iron content ranges from 26 to 35 percent and the silica from 37 to 50 percent. Dark areas on the photographs which may contain iron formation have been identified with query on the map.

South of the ring structure (sample 4186) low grade, thin-bedded, intricately folded iron formation occurs in greenish slate.

Head of Wadi al Arnab:-- Low grade, sheared, magnetite-hematite-jasper iron formation is interbedded with Silasia metasediments and the greenstone unit (gd). The iron formation within the greenstone contains more magnetite and lacks the jasper of typical Sawawin banded iron formation. There are probably more outcrops of iron formation in this area. Helicopters would be particularly useful for scouting the surrounding rough terrain for iron formation.

South of Jabal ash Shati:-- Kahr and Agocs describe iron formation outcropping sporadically in a belt 11 kilometers long and 13 kilometers (?) wide near the junction of Wadis Smach and al Arnab, and extending southeastward. We located a few iron formation bodies south of Jabal ash Shati, and there may be others. Jasper has been recrystallized to fine-grained quartz and there is some massive specularite. It's quite possible that small bodies of iron formation do occur within the granite and granodiorite (gg) further northwest, but we doubt that aggregate totals of 108 million tons (Kahr and Agocs, 1962, p.35) can be located in this belt. The grade at the outcrops mapped south of Jabal ash Shati is somewhat better than at other areas.

East-southeast of Ash Sharma:-- In the southwest portion of the map 6 kilometers east-southeast of the village of Ash Sharma low hills and ridges of iron formation cap the granite outcrops. The rock is thin-banded jasper-hematite type (jaspilite) with some thin bands of magnetite. An apparent thickness of 40 meters in one place is probably due to faulting. Although locally there is somewhat more specular hematite in these outcrops than the other localities the rock generally has a high silica content. Johnson estimated that one of the larger bodies contained 1.2 million tons of this rock.

These deposits are much too small, isolated, and high in silica to be of economic interest in themselves. If the Wadi Sawawin iron deposits were developed then these occurrences would have a potential for exploitation. Beneficiation procedures would be necessary to upgrade the iron content, followed by some method of agglomeration or pelletizing. The initial investment costs for these procedures are very high.

Gypsum.

Some fairly pure beds of gypsum up to one meter thick are interbedded with shale in the Raghama formation near Al Bad'. This resource is discussed more fully in a report on the Maqna quadrangle (Trent and Johnson, 1966).

Al Bad' - Al Lisan basin.

Kahr and Agocs (1962, pp.14-15) describe a large structural basin centered in the Wadi Ifal area along the west margin of the map. They call this structure the Al Bad' - Al Lisan basin and believe it was one of several which formed marginal to the Red Sea coast during the Tertiary period. Possibly the necessary stratigraphic or structural traps exist in this basin for the accumulation of petroleum.

Hunting aeromagnetic survey maps of this area indicate there is no evidence of near surface basement around the mouth of Wadi Ifal (Don R. Maby, U.S.G.S., personal communication, 1964).

Recommendations

Two first priority recommendations can be made for further work in this quadrangle. A definitive survey of the marginal iron formation resources described in this and previous reports should be made concurrent with or subsequent to a detailed survey of the Wadi Sawawin deposits. The immediate goal would be to determine tonnages, grade, and extent of the deposits.

Additional field examination should be made of the anomalous copper zone along the contact between granite and diorite at sample location 4053. A more closely spaced geochemical sample net in this area is needed.

Several areas of low priority should be examined in the mineral exploration program.

The Jabal al Abyad pegmatite area should be studied for possible feldspar resources, as recommended by von Gaertner and Schurenberg (1954, p.78). At the same time it would be worthwhile to locate and sample the ancient Safra mine which we believe is in the greenstone (gd) belt near and east of Al Khuraybah.

Additional trace element studies of the ring structure south of Jabal Rawa would be of interest. Two samples southwest of the structure along the granite contact contain anomalous molybdenum (7 ppm) and silver (1 ppm). Trace amounts of silver may be an indicator of hydrothermal sulfide deposits (Hawkes and Webb, 1962, p.372). If other work was being done in this general area then a more detailed field examination and geochemical sample net of the ring structure, and the vicinity of sample 10,253 should be completed.

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