UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Saudi Arabia Investigation Report
(IR) SA-129

RECONNAISSANCE GEOLOGY OF THE PRECAMBRIAN ROCKS IN THE WADI MAHR.GHAH QUADRANGLE KINGDOM OF SAUDI ARABIA

by

William C. Overstreet and Jesse W. Whitlow

U. S. Geological Survey
OPEN FILE REPORT 72-280

1972

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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian government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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RECONNAISSANCE GEOLOGY OF THE PRECAMBRIAN ROCKS IN THE WADI MAHRAGHAH QUADRANGLE, KINGDOM OF SAUDI ARABIA

by

William C. Overstreet and Jesse W. Whitlow

ABSTRACT

The Wadi Mahraghah quadrangle covers an area of 2863 sq km at the eastern edge of the Precambrian Shield in Saudi Arabia. Precambrian rocks are exposed in the western quarter of the quadrangle. To the east the Precambrian rocks are overlain by limestone of Permian age and by Quaternary sand and gravel.

The Precambrian rocks consist of granites intruded by a swarm of andesite dikes. These igneous rocks are overlain by sedimentary formations of the Precambrian Murdama Group comprising conglomerate of the Z'reiba Formation which grades upward into graywacke of the Abt Formation. Rhyolite dikes intrude the Abt. Possibly owing to these rhyolite dikes, or possibly as a result of weak mineralization along west-northwest- and east-trending faults related to the Najd fault zone, the area underlain by graywacke and conglomerate is characterized by threshold or anomalous amounts of beryllium in samples of wadi sand. Samples of sand from granitic areas contain threshold amounts of barium and lanthanum, but none is anomalous. No ancient mine nor other megascopic evidence of mineralization was found; however,

further examination might be given to the beryllium anomaly in the trough of a syncline in graywacke near the northwestern corner of the quadrangle, and to the scheelite-bearing locality in a possible northwest-trending shear zone in gray hornblende-biotite granite.

INTRODUCTION

Location

The Wadi Mahraghah quadrangle covers an area of 2863 sq km in the central part of the Arabian peninsula (fig. 1) at the eastern edge of the Precambrian Shield. Precambrian rocks are exposed only in the western quarter of the quadrangle; they are overlain along their eastern edge by marl, shale, and limestone of the Permian Khuff Formation.

Altitudes in the area are between 700 m and 800 m (Bramkamp and others, 1956). The drainage is internal toward the broad depression underlain by the Khuff Formation.

A main unpaved road crosses the northwestern quarter of the quadrangle, but light trucks and four-wheel drive vehicles can reach most places by travelling across country.

There are no permanent settlements owing to the dearth of potable water, but a small community known as Sulayyimah is about 5 km east of the center of the eastern edge of the quadrangle. The well at Bi'r Mahraghah in the northwestern quarter of the quadrangle is dry. No other wells were seen in the area underlain by Precambrian rocks.

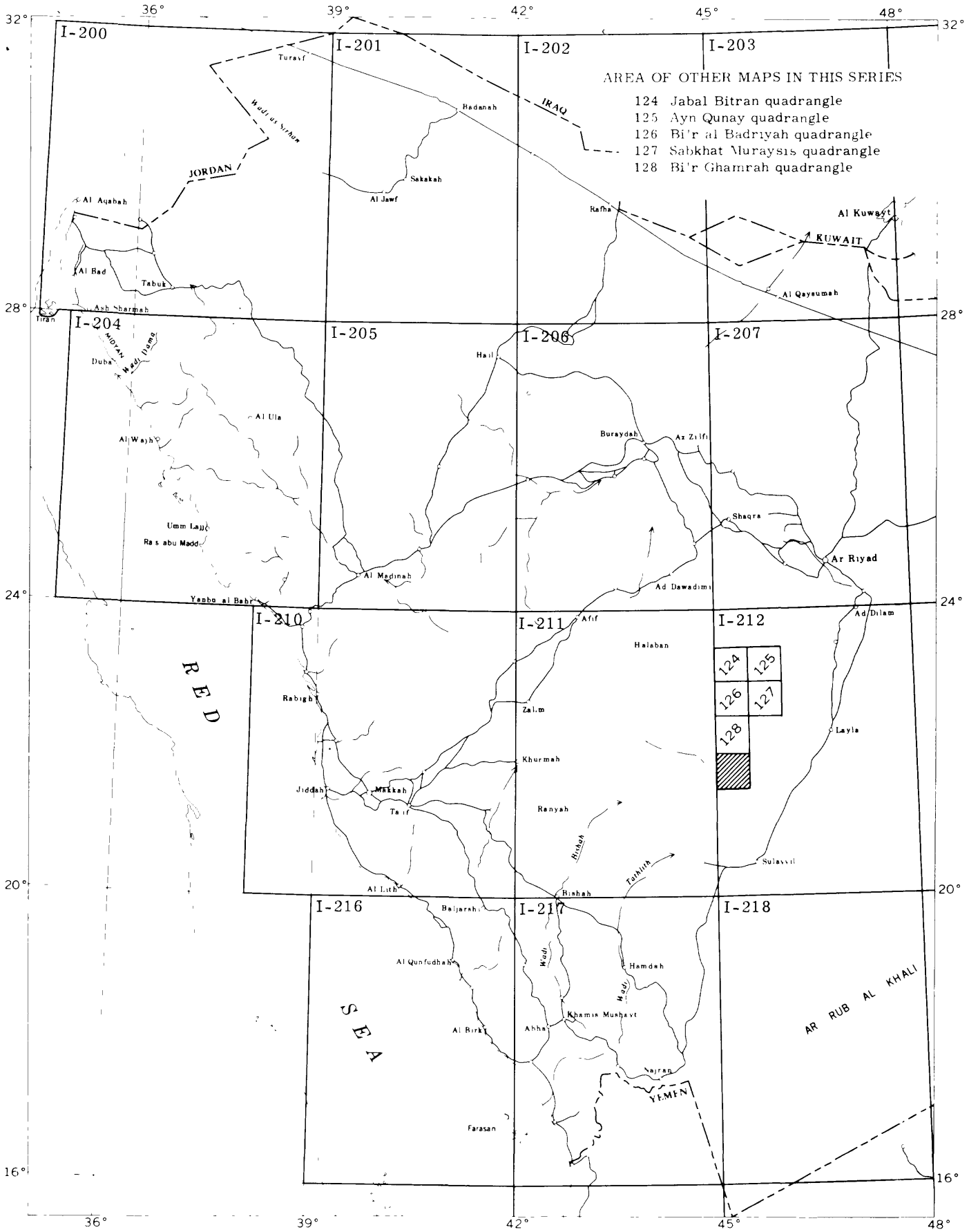

Figure 1. - Index map showing the location of the Wadi Mahraghah quadrangle

Previous investigations

The rocks of the Wadi Mahraghah quadrangle (plate 1) are shown as a small part of the 1:500,000-scale geologic map of the Southern Tuwayq quadrangle (Bramkamp and others, 1956). No other previous investigation of the Precambrian part of the Wadi Mahraghah quadrangle is known to the writers.

Present work and acknowledgments

The Precambrian rocks of the Wadi Mahraghah quadrangle were examined by the writers in the period May 29 to June 1, 1964, during a search for ancient mines and other indications of ore deposits, but the study of the regional geology was subsidiary to that work. The investigation was conducted as partial fulfillment of the agreement of September 1963 between the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the United States Geological Survey to explore the mineral potential of the Arabian Shield. The writers wish to express their appreciation to officials of the Ministry and of the Directorate General of Mineral Resources, Kingdom of Saudi Arabia, for their support in this investigation.

GEOLOGY

Rock types and stratigraphic succession

Older granites

Gray hornblende-biotite granite.-- The unit here called gray hornblende-biotite granite is the oldest rock in the Wadi Mahraghah quadrangle. It consists dominantly of medium- to coarse-grained

hornblende-biotite granite which grades into hornblende granodiorite in the northwestern part of its area of exposure and into gray biotite granite in the southwestern part. West of the plug of diorite and gabbro, the unit consists of gray coarse-grained pyroxene granite with minor biotite. About 4 km southwest of the plug, biotite becomes common and the rock is a pyroxene-biotite granite. Farther south, biotite is the only mafic mineral. All varieties of the granite are generally epidotized and massive.

Gray, quartz-rich, massive hornblende-biotite granite, exposed north of the plug of diorite and gabbro contains inclusions of fine-grained dark rock which are spindle-shaped, spherical, and possibly cognate. Similar inclusions are also present in the red biotite granite. The presence of similar, possibly cognate, inclusions in both rocks suggests that these granitic rocks are separated by only a short span in geologic time. They are inferred to be successive differentiates from the same magma.

The other igneous rocks in the Wadi Mahraghah quadrangle intrude the gray hornblende-biotite granite; thus, it is older than the other intrusives.

Detrital fragments of epidotized and non-epidotized hornblende-biotite granite and granodiorite are common in the conglomerate of the Z'reiba Formation which rests unconformably on the granite.

The gray hornblende-biotite granite is described by Bramkamp and others (1956) as being younger than the diorite and Precambrian

sedimentary rocks. Strong field evidence shows that in the Wadi Mahraghah quadrangle the granite is the oldest of the three. In the Southern Najd quadrangle to the west, Jackson and others (1963) mapped a unit of granite and granodiorite that is an extension of the gray hornblende-biotite granite and red biotite granite. This unit of granite and granodiorite is shown by them as being unconformable below their Halaban and Murdama Formations; therefore, it occupies the same stratigraphic position as we have observed for the gray hornblende-biotite granite and red biotite granite in the Wadi Mahraghah quadrangle. Although Jackson and associates (1963) did not distinguish another granite just west of the Wadi Mahraghah quadrangle, they noted that regionally the granite and granodiorite unit is intruded by gray and pink calc-alkalic hornblende granite which also lies unconformably below their Halaban and Murdama Formations. This is the same unit as the one we designate red biotite granite in this report. The geological relations of the two older granites in the Wadi Mahraghah quadrangle conform to the relations described by Jackson and others (1963) for the granites in the Southern Najd quadrangle, and therefore, these two granitic rocks in the Wadi Mahraghah quadrangle are correlated with those granites as mapped in the Southern Najd quadrangle by Jackson and others. However, the position of the gray hornblende-biotite granite, the red biotite granite (described below) is uncertain, and the presence of a

pyroxene-bearing phase in the hornblende-biotite granite contributes to this uncertainty. The possibility exists that these granites and the rhyolite are somewhat younger; that is, that the granites are the equivalent of the biotite-hornblende granite of the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) and the rhyolite is the equivalent of the rhyolite equal in age to the upper part of the Bi'r Khountina Group.

Red biotite granite.-- Under the term red biotite granite several varieties of calc-alkalic granitic rocks have been separated from the older gray hornblende granite phase and are shown separately on the geologic map (plate 1). The rocks are red, medium-grained, massive to faintly gneissic biotite granite; red gneissic granite with cataclastic foliation; pink massive biotite granite, locally quartzose; pink felsitic biotite granite; red quartz-rich biotite granite; red quartz porphyry with round grains of quartz; pink fine-grained hornblende-biotite granite; red coarse-grained biotite-hornblende granite; and pink felsite. Quartz-orthoclase pegmatite dikes are present but they are exceedingly rare. These rocks intrude the gray hornblende granite and contain inclusions of the gray granite. Dikes and stringers of red biotite granite cut across large inclusions of gray granite, and similar dikes extend out from the red granite into the gray granite. The red granite is, therefore, younger than the gray granite. Detrital fragments of the red granite are in the conglomerate of the Z'reiba Formation, thus showing that it is older than the conglomerate.

Spindle-shaped to round cognate inclusions of fine-grained mafic rocks are present in the red biotite granite. They are more common in the northern parts of the exposed areas of red granite than in the southern part. An inclusion of quartzite on the northeastern side of the arcuate mass of red granite suggests that an earlier cycle of sedimentation and metamorphism took place in this part of Saudi Arabia than is represented by the rocks mapped in the Wadi Mahraghah quadrangle.

The red biotite granite is strongly jointed. The joints are open and unhealed although they are commonly coated with epidote. Persistence of the open and unhealed joints may be evidence that fluids were very sparse in these rocks.

Older rhyolite

Dikes of red rhyolite in the extreme southwestern part of the quadrangle are part of a unit here called older rhyolite. The best evidence for the presence of an older rhyolite is the pebbles, cobbles, and boulders of red rhyolite, red rhyolite porphyry, epidotized rhyolite, and gray rhyolite which are among the most common coarse clastic debris in the conglomerate of the Z'reiba Formation. Similar detrital rhyolite occurs in intraformational conglomerate in overlying graywacke of the Abt Formation. The sources of these fragments of rhyolite have not been positively identified in the Wadi Mahraghah quadrangle, and epidotized rhyolite was not found in place. This

detrital rhyolite is regarded as having come from rhyolite older than the dikes that intrude the Abt Formation in the northeastern part of its area of exposure. Probably this older rhyolite, represented by the detrital fragments in the conglomerate, is genetically related to, and penecontemporaneous to slightly younger than the red granite and red granite porphyry intrusive into the gray granite.

Rhyolite dikes are shown by Bramkamp and others (1956) as being younger than the granite and Precambrian sedimentary rocks. Probably only a few rhyolite dikes in the Wadi Mahraghah quadrangle are younger than the Precambrian sedimentary rocks, but all are younger than the two granites. The possibility exists, as mentioned above, that the older rhyolite and older granites are equivalent in age to the upper part of the Bi'r Khountina Group in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972).

Bi'r Khountina Group

Badrīyah Formation.-- A body of andesite at the southwestern edge of the Wadi Mahraghah quadrangle is here thought to be genetically related to, but possibly older than, a small plug of diorite and gabbro in the west-central part of the quadrangle and a prominent swarm of andesite dikes in the same area as the plug. The extrusive andesite is tentatively correlated with the Badrīyah Formation of Bi'r Khountina Group named in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972).

The andesite of the Badriyah Formation in the Wadi Mahraghah quadrangle is inferred to be older than the conglomerate and graywacke exposed farther north and to be younger than the red biotite granite, but marble and conglomerate of the older formations of the Bi'r Khountina Group do not underlie the andesite; thus, the possibility exists that the andesite is a septum in the granite. Where the andesite is intruded by dikes of pink alkalic granite(?) local hardening of the andesite has taken place. This is the only metamorphic effect observed in the andesite. From relations in the Bi'r Ghamrah Overstreet and Whitlow, 1972) and Bi'r al Badriyah (Overstreet, Whitlow, and others, 1972) quadrangles, this andesite is thought to be younger than the Halaban Formation of Jackson, Bogue, Brown, and Gierhart (1963).

Diorite and gabbro

A plug of medium-grained diorite grading locally to gabbro intrudes the gray hornblende-biotite granite and red biotite granite in the west-central part of the quadrangle. The diorite and gabbro appear to be genetically related to the dike swarm of andesite and andesite porphyry in this area, but the plug is a little older than the dikes, because andesite dikes intrude it. Possibly the plug and dikes are penecontemporaneous, because diorite dikes occur with andesite dikes in the extreme southwestern corner of the quadrangle, and these diorite dikes have fine-grained margins which resemble the andesite.

Pebbles and cobbles of diorite and gabbro identical in appearance to the rocks in the small plug are among the detrital components of the conglomerate of the Z'reiba Formation. The diorite and gabbro is, therefore, older than the conglomerate.

Diorite is not shown in this area by Bramkamp and others (1956), but for the region as a whole, they show diorite as being older than the granite and younger than the Precambrian sedimentary rocks. Field relations in this area show the reverse stratigraphic succession.

Andesite dikes

A swarm of west-northwest-trending andesite dikes intrudes gray hornblende-biotite granite at the west-central edge of the quadrangle. These andesite dikes also cut across red granite, red granite porphyry, red rhyolite, diorite, and gabbro. Apparently identical andesite occurs as detrital fragments in the conglomerate of the Z'reiba Formation. Therefore, the andesite dikes are here interpreted to be older than the conglomerate, and younger than the hornblende-biotite granite, red granite, and old red rhyolite. The andesite dikes are penecontemporaneous with, to younger than, the diorite and gabbro.

Most of the dikes are fine-grained andesite, but as the thickness of the dikes increases, the grain size also increases, resulting in dikes of andesite porphyry, diorite porphyry, and diorite. The dikes are locally and variably epidotized. Some coarse-grained dioritic dikes in red granite porphyry have strong gneissic structure and segregation banding parallel to their walls. Vertical lineation of

mafic minerals is pronounced in these gneissic dikes. Seemingly the gneissic structure, segregation banding, and vertical lineation are primary flow structures.

Dikes of pink, fine-grained alkalic granite(?) and aplite intrude across the dikes of andesite, diorite, and gneissic diorite at a few places. These dikes have not been shown on the map.

Locally the andesite dikes contain as much as 0.1 percent of scattered small crystals of pyrite and possibly a trace of chalcopyrite.

Andesite dikes are not shown in this area by Bramkamp and others (1956), but for the region as a whole they are said to be younger than the granite and Precambrian sedimentary rocks. In the Wadi Mahraghah area the andesite dikes are interpreted to be younger than the two units of granite and older than the Precambrian sedimentary rocks.

Murdama Group

Precambrian sedimentary rocks consisting of a basal conglomerate and an overlying thick sequence of graywacke are exposed in the northwestern corner of the Wadi Mahraghah quadrangle. In that area the sedimentary rocks are intruded by a few rhyolite and granite dikes, but their extension to the north in the Bi'r Ghamrah quadrangle is intruded and variably metamorphosed by coarse-grained igneous rocks (Overstreet and Whitlow, 1972).

On the geologic map of the Southern Tuwayq quadrangle (Bramkamp and others, 1956) these sedimentary rocks are called "sericite and chlorite schist", but in the Wadi Mahraghah area the rocks are largely

unmetamorphosed and are better described as graywacke and conglomerate. In the area west of the Wadi Mahraghah quadrangle, the equivalent of the conglomerate is called unit ha (Halaban Formation) comprising principally mafic rocks (Jackson and others, 1963), and the graywacke is called unit hc, consisting typically of felsitic andesite, agglomerate, conglomerate, quartzite, and graywacke with locally interbedded marble and rhyolite. Both units of the Halaban Formation of Jackson and others (1963) are shown to unconformably overlie granite and granodiorite.

The thick basal conglomerate and thick overlying graywacke in the Wadi Mahraghah quadrangle more closely resemble the Murdama Formation of Jackson and others (1963) than they do the sedimentary facies of the Halaban. In the Bi'r Ghamrah quadrangle to the north the term Murdama Group was introduced for this sequence of conglomerate and graywacke (Overstreet and Whitlow, 1972). In this report the conglomerate is correlated with the Z'reiba Formation of the Murdama Group, and the graywacke is correlated with the Abt Formation of the Murdama Group.

Z'reiba Formation.-- A unit of coarse conglomerate called the Z'reiba Formation and composed of boulders, cobbles, and pebbles set in a sandy matrix unconformably overlies gray granodiorite and gray and red hornblende granite in the northwestern part of the Wadi Mahraghah quadrangle. The matrix of the conglomerate consists of sand rich in detrital epidote, magnetite, pyroxene, and hornblende.

The boulders, cobbles, and pebbles are made up of epidote-rich hornblende granodiorite, gray hornblende granite, red pyroxene granite, red rhyolite, red rhyolite porphyry, gray rhyolite, andesite, andesite porphyry, diorite, gabbro, quartzite, conglomerate with rhyolite pebbles, epidote-rich sandstone, and dark red siliceous shale. Some rhyolite pebbles are epidotized and apparently were epidotized before they were reworked into pebbles, but locally both epidote and quartz coat the surfaces of joints in the conglomerate; therefore, there were several periods of epidotization in the area.

The detrital epidote, magnetite, pyroxene, and hornblende in the matrix of the conglomerate is a concentration of heavy minerals eroded from the granite, granodiorite, diorite, gabbro, and andesite dikes that formed the surface on which the conglomerate was deposited. Lower parts of the conglomerate were formed quite close to their source. The quantity of pebbles and cobbles of red granite and rhyolite decreases upward in the conglomerate away from the granitic basement on which the conglomerate was deposited. Pebbles and cobbles of andesite, andesite porphyry, and diorite increase in abundance upward in the conglomerate, as do fragments of epidote-rich sandstone and dark red siliceous shale. Lenses of interbedded red jasper and siliceous red shale up to as much as 15 m long and 4 m thick rest in sharp contact on the conglomerate, but grade upward into overlying laminated argillite. This progressive vertical change in the lithologic character of the conglomerate shows a change in the distributive province of the source

materials of the conglomerate as the sedimentary pile accumulated. When the upper parts of the conglomerate were formed, the granites were largely covered, and some sandstone and shale deposited in the lower parts of the conglomerate were reworked into the upper part of the conglomerate.

The conglomerate is sharply flexed along the granite as if the granite served as a buttress against which the sedimentary rocks were squeezed when they were folded. The conglomerate is unmetamorphosed although, as mentioned above, some epidote and quartz crystallized along joints.

The conglomerate is as much as 1,200 m thick. It is either discontinuous along the strike toward the northwest or is cut out there by a possible fault between the granite and the sedimentary rocks.

Abt Formation.-- The Abt Formation in the Wadi Mahraghah quadrangle consists of a great but unknown thickness of graywacke that overlies the Z'reiba Formation. Marble was not observed between the conglomerate of the Z'reiba Formation and the graywacke of the Abt Formation, nor was andesite found between the conglomerate and the graywacke. The two formations are here regarded as being stratigraphically equivalent to the Z'reiba and Abt Formations in the Bi'r al Badriyah quadrangle (Overstreet, Whitlow, and others, 1972), but the underlying sequence of massive andesite found in that area is absent in the Wadi Mahraghah quadrangle, except for the little bit in the southwest.

The Abt Formation consists of gray-green graywacke sandstone, laminated argillite, gray to black sand conglomerate, and sparse gray limestone. Ripple marks are present on bedding planes of the argillite, and scour-and-fill features are common in the sandstone. Much of the intraformational gray to black sandy conglomerate appears to occupy scour-and-fill channels in the sandstone. Most of the quartz in the conglomerate is stained black, and detrital epidote and fine-grained fragments of rhyolite are common. Numerous slump structures are present in the laminated argillite, which in part is tuffaceous, and thin intraformational breccia is associated with the slumped argillite. The Abt Formation here is interpreted to have been deposited under conditions of rapid sedimentation with frequent change in class of detritus.

The graywacke is essentially unmetamorphosed in its major exposures, but in the northeastern part of its outcrop area the rocks are metamorphosed and contain chlorite. An even higher grade is probably reached in the sand-covered area to the northeast near the Khuff Formation. The biotite isograd is inferred to project into that area. This rise in metamorphic grade is caused by the contact effect of a large body of granite intruded into the graywacke north of the quadrangle.

A few rhyolite dikes intrude the graywacke near the northern edge of the quadrangle, but the dikes have had no metamorphic effect on the graywacke.

Alkalic granite(?)

A small area of questionable alkalic granite is shown in the southwestern part of the quadrangle. This area is almost covered by pediment sand from the alkalic granite itself, and the sand has the pink color of the granite, but dikes and stringers of the alkalic granite are exposed where they intrude nearby andesite. A partial ring structure in the older red biotite granite is reflected by the distribution of outcrops. It is possible that a small circular stock of alkalic granite(?) occupies the central part of the ring.

Younger rhyolite

Red rhyolite dikes which tend to strike easterly and dip vertically, but which range in strike from N.70°E. to N.65°W. and in dip from 65°S. to vertical, intrude across the bedding of the Abt Formation in the Wadi Mahraghah quadrangle. Where the dikes are thin they are dark red and aphanitic, but where they exceed about 8 m in thickness they have pink aplitic cores of fine-grained hornblende and biotite set in equigranular feldspar and sparse quartz. Locally these dikes of red rhyolite intrude channel-filling conglomerate in the graywacke sequence. The dikes are younger than the channels and younger than the conglomerate, but pebbles and cobbles of pink to red rhyolite are in the conglomerate. From these relations it is inferred that rhyolite of at least two ages is present.

The younger rhyolite of the Wadi Mahraghah quadrangle may be equivalent to the dikes of Shammar Rhyolite(?) in the Bi'r Ghamrah

quadrangle (Overstreet and Whitlow, 1972). The stratigraphic position of the younger rhyolite accords with that shown by Bramkamp and others (1956) for rhyolite dikes in this area.

Post-Precambrian sedimentary rocks

Five units of post-Precambrian sedimentary rocks are shown on the map of the Wadi Mahraghah quadrangle. Four of them are adapted from the work of Bramkamp and others (1956) with little change in outline and description: the Khuff Formation of Permian age, two varieties of Quaternary gravel, and aeolian sand of Quarternary age. A fifth sedimentary unit of Quaternary age, as mapped in the present study, shows the distribution of alluvial sand, sheet wash sand, and non-dune-forming aeolian sand.

The Khuff Formation has little topographic expression in the Wadi Mahraghah quadrangle, and it is largely covered by thin sheets and dunes of aeolian sand. Outcrops of the Khuff Formation are sparse; features seen on aerial photographs have been interpreted to be subdued outcrops of the Khuff Formation and are so mapped. The inferred probably western edge of the Khuff Formation is modified from Bramkamp and others (1956) as a result of observations of the distribution of granitic sand, but little certainty attaches to the position marked for the contact.

Structure

The Z'reiba and Abt Formations are folded into a south-plunging syncline along the west edge of the mapped area. Hornblende-biotite

granite underlying these sedimentary rocks seems to have been folded with them, but not as intensely. Mainly the granite formed a buttress against which the Z'reiba and Abt Formations were squeezed. The axis of the syncline swings eastward where it approaches the west-northwest-trending fault south of Wadi Mahraghah, and was not observed south of the fault. Prominent wadis coincide in trend with the trace of joints parallel to the axis of the syncline, but the heads of these wadis and their southern tributaries tend to follow two other sets of joints. The northeast-trending set is the older and formed normal to major fold axes; the east-trending set is younger and is parallel to small fractures which are subsidiary to the Najd fault zone located about 25 km to the north (Overstreet and Whitlow, 1972). The asymmetry of the tributaries indicates that the folds are asymmetrical, and their northeast limbs dip more steeply than their southwest limbs.

The west-northwest-trending fault south of Wadi Mahraghah is parallel to the trace of the Najd fault zone. The east-trending fractures which are occupied by the long southern tributaries to the larger wadis in the Abt Formation are present in that formation as far north as the Najd fault zone. The east-trending fractures increase northward in frequency, and they are related to movement in the Najd fault zone.

Broad regional downwarping to the east preserves the Khuff Formation

GEOLOGIC RELATION OF SELECTED ELEMENTS

Twenty-two samples of wadi sand were collected in the part of the quadrangle underlain by Precambrian rocks, and the samples were analyzed in the Jiddah Laboratory of the Directorate General for Mineral Resources. The purpose of the sampling was to determine in reconnaissance fashion the abundances of selected elements in the sample media, relate these abundances to the geologic environments from which the samples came, and use data in interpreting direct field observations.

Procedure

Samples of sand weighing 10 kg were dug from the upper 30 cm of water-laid Holocene sediments in small wadis. Each sample was sieved on stainless steel screens, and 100 g of -30+80-mesh sand was split out. The residue from the sieving was panned to make a heavy-mineral concentrate, and magnetite was removed from the concentrate. Thus, from one locality three samples were prepared: -30+80-mesh raw sand, heavy-mineral concentrate, and detrital magnetite.

In the Jiddah Laboratory the raw sand was analyzed for 27 elements by a semiquantitative spectrographic technique modified from procedures of the U. S. Geological Survey (Theobald and Thompson, 1968). C. E. Thompson of the U. S. Geological Survey and Kamal Shahwan of the Directorate General for Mineral Resources performed the spectrographic analyses. Wet chemical analyses were made of the sand and magnetite

by L. Al Dugaither for copper, zinc, and molybdenum, and for these elements and tungsten in the concentrate.

Results

The results of these analyses are compiled as histograms (figs. 2 and 3), and selected data are shown on the geologic map (plate 1). No large amount of metal was found in any sample, and nine elements were below the limits of spectrographic detection. These elements, and their lower limits of detection are silver, 1 ppm; bismuth, 20 ppm; cadmium, 50 ppm; germanium, 20 ppm, niobium, 50 ppm; antimony, 200 ppm; tin, 10 ppm, tungsten, 50 ppm; and zinc, 100 ppm. The results of the analyses confirm visual observation that the small Precambrian area exposed in the Wadi Mahraghah quadrangle is devoid of readily detectable mineral deposits. A comparison of results of the analyses from this area with the results of analyses of 321 similar samples from the Precambrian rocks of the Southern Tuwayq quadrangle disclosed that threshold[1/] quantities of barium, beryllium, chromium, lanthanum, molybdenum, titanium, vanadium, and zirconium are present in a few samples and that one sample contains a slightly anomalous amount of beryllium:

[1/] Threshold is defined by Hawkes and Webb (1962, p. 31) as the analytical value exceeded by only 2½ percent of the observations.

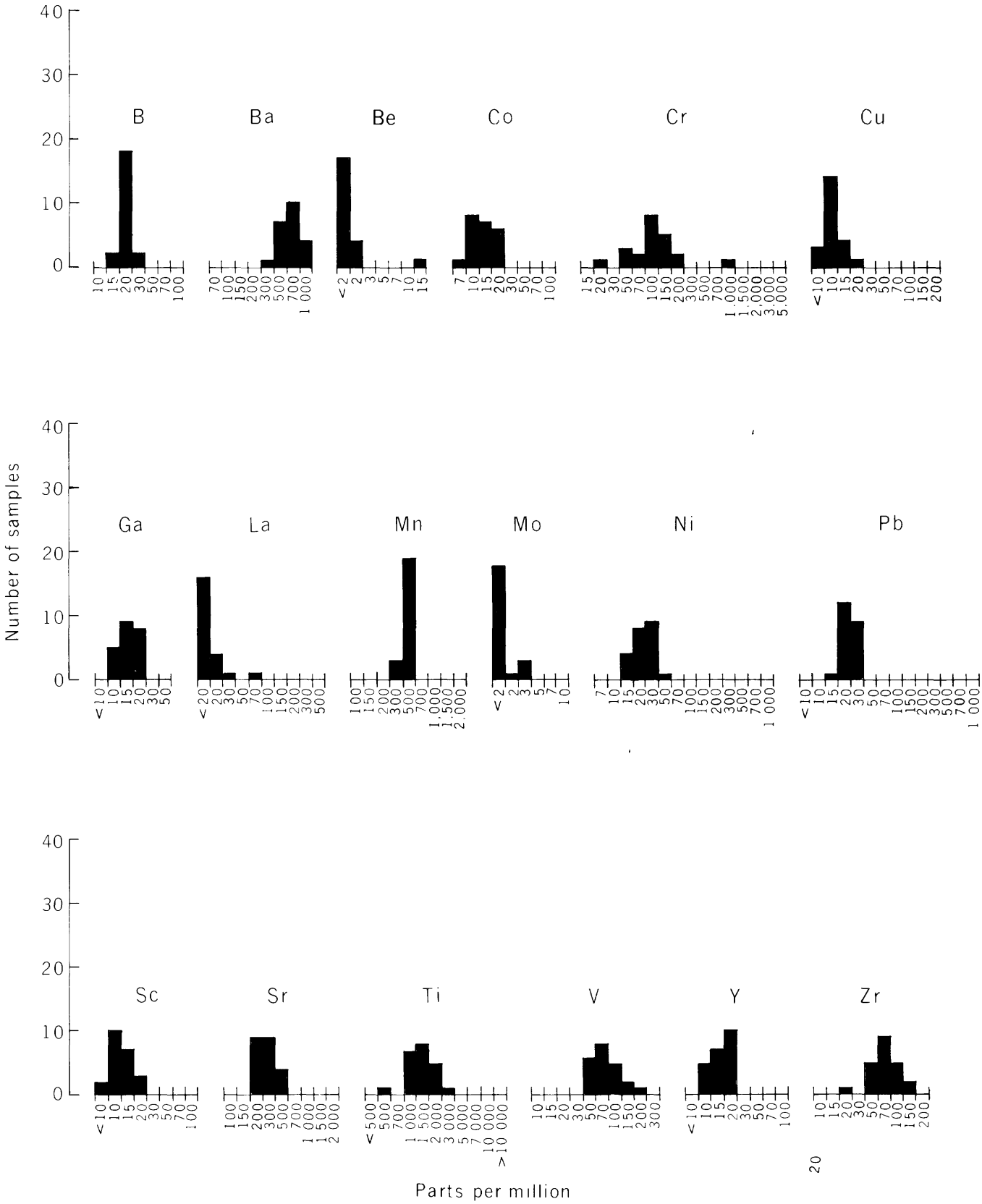

Figure 2. Histograms of 22 spectrographic analyses of wadi sand, Wadi Mahraghah quadrangle

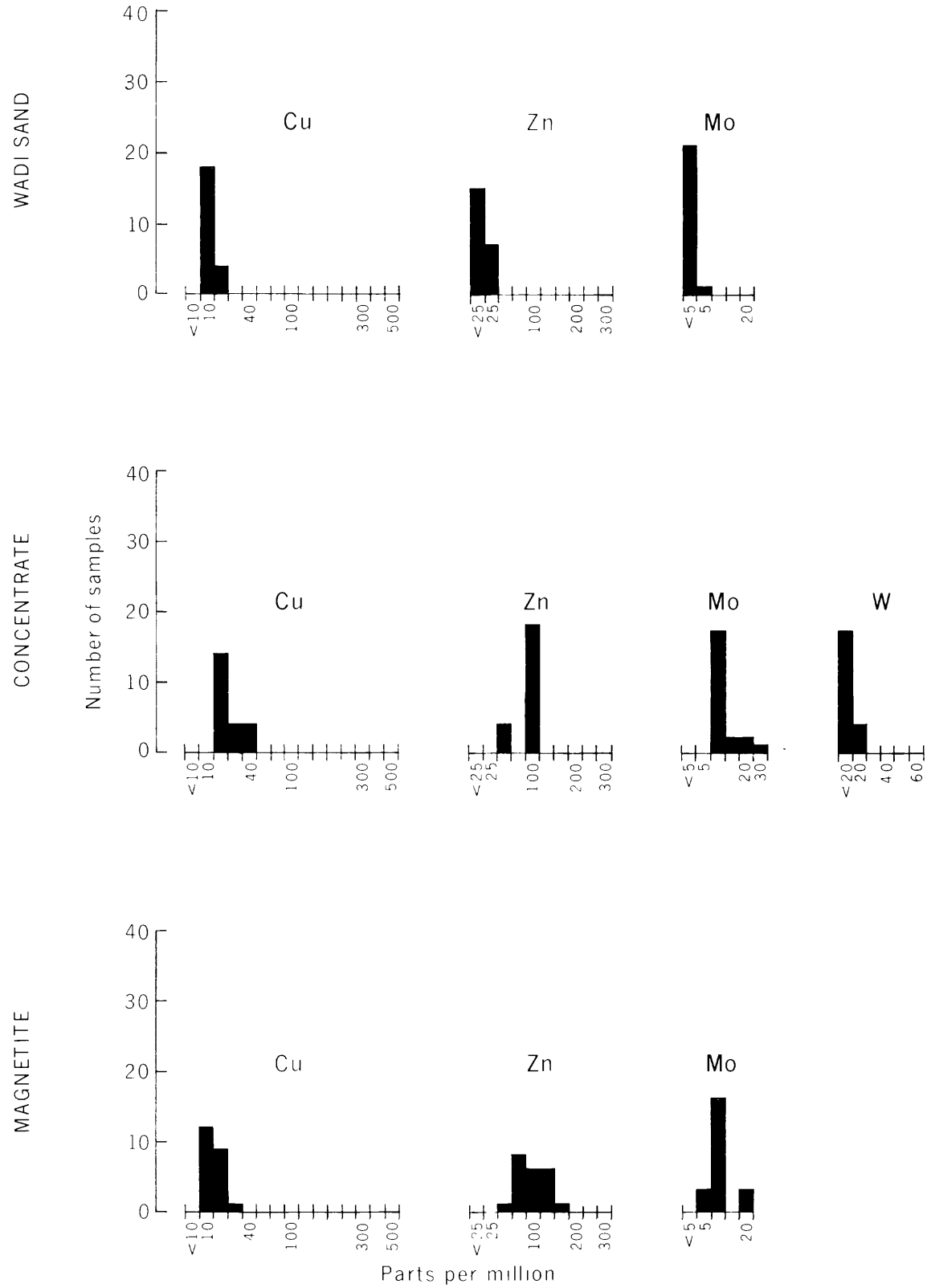

Figure 3. Histograms of 22 wet chemical analyses of magnetite, concentrate, and wadi sand, Wadi Mahraghah quadrangle

Element	Threshold value in 1:500,000-scale, Southern Tuwayq quadrangle, ppm	Number of samples from Wadi Mahraghah quadrangle at or above threshold
Barium	1,000	4
Beryllium	2	5 (a)
Chromium	1,000	1
Lanthanum	20	6
Molybdenum	3	3
Titanium	3,000	1
Vanadium	150	3
Zirconium	150	2

(a) Includes one anomalous sample with 15 ppm Be.

The distribution of threshold values in the samples of sand is generally related to source rocks, although in some samples the threshold value may be caused by laboratory variation (Theobald and Thompson, 1968). Beryllium, chromium, titanium, and zirconium reach threshold values only in samples from areas underlain by the sedimentary rocks of the Murdama Group. Barium and lanthanum are in threshold abundances only in sand from areas underlain by granitic rocks, and in these areas barium and lanthanum are more common in the red biotite granite than in the gray hornblende-biotite granite. Molybdenum and vanadium in threshold amounts were found locally in both terranes.

The distinctive difference in the distribution of beryllium between the granitic rocks and the sedimentary rocks might be related to the presence in the sediments of detritus from rocks not now exposed in the granitic area; but the common rise in the amount of beryllium in the sedimentary rocks is thought to be related to the presence in the sediments of detritus from rocks not now exposed in the granitic area; but the common rise in the amount of beryllium in the sedimentary rocks is thought to be related to the west-northwest- and east-trending faults, probably part of the Najd fault zone, and to the presence of dikes of younger rhyolite in the Z'reiba and Abt Formations.

Where the west-northwest-trending fault south of Wadi Mahraghah enters the granite, samples are lacking; thus, a possible increase in beryllium in the granite because of possible hydrothermal activity along the fault cannot be shown. Dikes of the younger rhyolite were not found in the granite.

Metals by multiple analyses

The abundances of copper, zinc, and molybdenum were determined by spectrographic and chemical methods in the samples of wadi sand, and the same elements were also determined chemically in detrital magnetite and heavy-mineral concentrates (fig. 3).

Copper.-- The amount of copper in the wadi sand was found by both methods of analysis to be 20 ppm or less throughout the quadrangle (plate 1). Copper was also found to be 20 ppm or less in all samples of detrital magnetite except one, which had only 30 ppm copper.

Concentrates contained 40 ppm or less copper. These are about the mean background values for copper in these media in the area of the Southern Tuwayq quadrangle.

Zinc.-- By spectrographic methods zinc was found to be below the limit of detection (100 ppm), and by chemical methods it was 25 ppm or less, in all samples of wadi sand. Magnetite contained less than 125 ppm zinc except one sample from the scheelite-bearing locality in red biotite granite near the western edge of the mapped area and about 4 km south of the southern margin of the swarm of andesite dikes. Here a bleached, fine-grained aplitic zone 1.4 m wide with an exposed length of 6 m strikes N.70°W. and dips 75°S. through the granite. It is possible that this altered zone is part of a fault, but exposures are too poor for the relations to be determined. Molybdenum, tungsten, and lanthanum in threshold amounts in different kinds of sample media are also present at this locality.

Concentrates from all sampled localities contain 100 ppm or less zinc, which is well below the regional threshold of 150 ppm for zinc in concentrates from the Precambrian area of the Southern Tuwayq quadrangle.

Molybdenum and tungsten.-- Threshold amounts of molybdenum (3 ppm) were detected spectrographically in three samples of wadi sand, the northernmost of which also was found by chemical methods to have threshold molybdenum. The northernmost sample is free from the axis of the syncline in the Abt Formation near the northwestern corner of

the mapped area. This sample is anomalously rich in beryllium, contains threshold quantities of titanium, vanadium, and zirconium, and has threshold molybdenum (20 ppm) in magnetite. Very small amounts of pyrite are scattered in graywacke of the Abt Formation, and sparse epidote and quartz coat joints in the rock, but no other evidence of mineralization was seen. Threshold quantities of molybdenum are present in samples of sand from red biotite granite near andesite of the Badrīyah Formation in the southwestern part of the quadrangle. The southernmost of these localities was also the source of sand with threshold barium and lanthanum, and of a concentrate with threshold molybdenum (20 ppm).

Threshold molybdenum (20 ppm) occurs in detrital magnetite from three localities, one of which was described above. One of the other localities is in the Abt Formation at the head of Wadi El Hewara and the other is from red biotite granite exposed 7 km west-southwest of the mouth of Wadi Mahraghah. Threshold beryllium and chromium are in the wadi sand where the magnetite was taken in Wadi El Hewara, and threshold barium is present in the sand from the red granite. No alteration was seen at either locality.

Four samples of heavy-mineral concentrates contained threshold molybdenum (15 ppm and 20 ppm) and another sample had the anomalous quantity of 30 ppm. All are from the granitic areas in the southwestern part of the quadrangle. The anomalous sample is the most southerly. Barium and lanthanum, singly or together, are present in

threshold amounts in the sand from which the molybdenum-bearing concentrates were prepared.

The concentrates were examined under ultra-violet light for scheelite and powellite, and two concentrates were found to have one grain each of both minerals. The northern scheelite- and powellite-bearing concentrate contained 60 ppm tungsten, a regional threshold quantity for this element in concentrates. The other concentrate had 20 ppm or less tungsten.

Anomalous beryllium

The single positive anomaly, 15 ppm beryllium in wadi sand from the syncline in the Abt Formation near the northwest corner of the area, was described under the section on molybdenum.

Threshold elements

The elements in threshold abundances in wadi sand are listed above. All four localities of threshold barium are in areas underlain by red biotite granite. Three are in the southwestern quarter of the quadrangle and one is at the northern end of the red biotite granite just south of the Z'reiba Formation. Possibly the barium is from feldspar. The four samples with threshold beryllium in the Z'reiba and Abt Formations have already been discussed.

The single sample with threshold chromium (1,000 ppm) also is in the Abt Formation. However, fragments of olivine basalt of unknown provenance are in the Holocene alluvium at this locality near the north edge of the mapped area. Doubtless the rise in chromium in wadi

sand at this locality is related to the presence of this ultramafic rock.

All the samples with threshold lanthanum are from the granitic areas in the southwestern part of the quadrangle. The sample highest in lanthanum, 70 ppm, is from the southern of the two scheelite localities.

The single sample containing a threshold amount of titanium is also the sample with anomalous beryllium and threshold zirconium and vanadium from the syncline in the Abt Formation near the northwestern corner of the area.

The three samples with 150 ppm to 200 ppm vanadium are scattered geographically and geologically. The richest is from the locality with anomalous beryllium; one of the others is near the eastern end of the exposures of conglomerate, and the third is from an area of gray hornblende-biotite granite intruded by a swarm of andesite dikes. The first two vanadium localities are also the sites of the two threshold values for zirconium.

CONCLUSIONS

No ancient mine was discovered in the Wadi Mahraghah quadrangle, nor were mineralized areas seen, thus the Precambrian part of the quadrangle is devoid of readily detectable mineral deposits. However, two places deserve further study for possible ore deposits: the axial part of the syncline in the Abt Formation together with the fault

crossing the syncline, and the northern of the two scheelite-bearing localities. Both places should be examined for possible gold, and the scheelite locality should be studied for a possible northwest-trending shear zone that might extend into and be mineralized in the quadrangle to the west.

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