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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian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

Three sequences of volcanic and sedimentary rocks are identified in the Precambrian rocks of the Bi'r Ghamrah quadrangle at the eastern edge of the Precambrian Shield in central Saudi Arabia. The oldest sequence is called the Bi'r Khountina Group. It consists of conglomerate, marble, andesite, and graywacke. Unconformably overlying this group is a sequence of graywacke with minor lava called the Murdama Group. In a small area in the southern part of the quadrangle, these rocks are unconformably overlain by rhyolitic tuff and rhyolite tentatively correlated with the Shammar Rhyolite.

The older of these sedimentary and volcanic rocks were intruded by diorite and gabbro and by a large pluton of alkalic granite. A contact metamorphic aureole was formed in the Bi'r Khountina and Murdama Groups adjacent to the granite, and feeder dikes of the Shammar Rhyolite(?) intrude the granite.

The Bi'r Khountina Group is folded into a south-plunging asymmetrical anticlinorium, the west limb of which is repeated across northwest-trending faults. The Murdama Group appears to have been folded along the same axes, but the contact aureole against the alkalic granite and the imprint of the west-northwest striking Najd fault zone cause the rocks of the Murdama Group to appear to trend westward.

Results of spectrographic and chemical analyses of wadi sand, heavy-mineral concentrates, and detrital magnetite show small anomalies. The ultramafic rocks intruded prior to the deposition of the Murdama Group are the source of anomalous chromium and lanthanum and of threshold nickel, scandium, and vanadium. The intrusive rocks younger than the Murdama Group are sources for anomalous lead and threshold silver, boron, barium, beryllium, zirconium, lanthanum, and tin.

One small ancient working, probably opened for gold, is present, and at least four places in the Precambrian part of the quadrangle are potentially favorable for gold, silver, and lead. Chromite is a potential resource in the northeastern part of the quadrangle.

INTRODUCTION

Location

The Bi'r Ghamrah quadrangle includes an area of 2,854 sq km in central Saudi Arabia (fig. 1) at the eastern edge of the Precambrian Arabian Shield. Along the eastern part of the quadrangle, Precambrian rocks are overlain by Permian and younger sedimentary rocks. Altitudes of the surficial deposits in the east-central part of the quadrangle are shown by Bramkamp and others (1956) to range from 673 m to 713 m. Altitudes are not known in the central and northwestern hills but probably reach 800 m to 850 m. Drainage is internal, toward the broad depression east of the unpaved road that crosses the quadrangle from north to south. A number of tracks passable by trucks and four-wheel-drive vehicles lead into the main wadis in the western part of the area. Permanent settlements are absent owing to the scarcity of fresh water.

Previous investigation

The area covered by this quadrangle occupies a small part of the western side of the geologic map of the Southern Tuwayq quadrangle (Bramkamp and others, 1956). No previous geologic investigations have been made of these Precambrian rocks.

Present work and acknowledgments

Reconnaissance of the Precambrian part of the Bi'r Ghamrah quadrangle was done May 20 to May 29, 1964. The principal effort was a search for ancient mines and areas of mineralization; delineation of the regional geology was secondary. Sedimentary rocks in the eastern part of the quadrangle were not examined.

This reconnaissance was made as partial fulfillment of the agreement reached in September 1963 by officials of the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the U. S. Geological Survey to explore the mineral potential of the Precambrian Shield of Saudi Arabia. The writers wish to express their appreciation to the Ministry and to officials of the Directorate General of Mineral Resources for support.

GEOLOGY

Many important relations shown on the geologic map (plate 1) have not been thoroughly tested. Inasmuch as the rocks of the different units have many similarities, the interpretation offered is more a statement of the probable geologic complexity of the area than a solution to the structure and stratigraphic succession in this part of the Arabian peninsula.

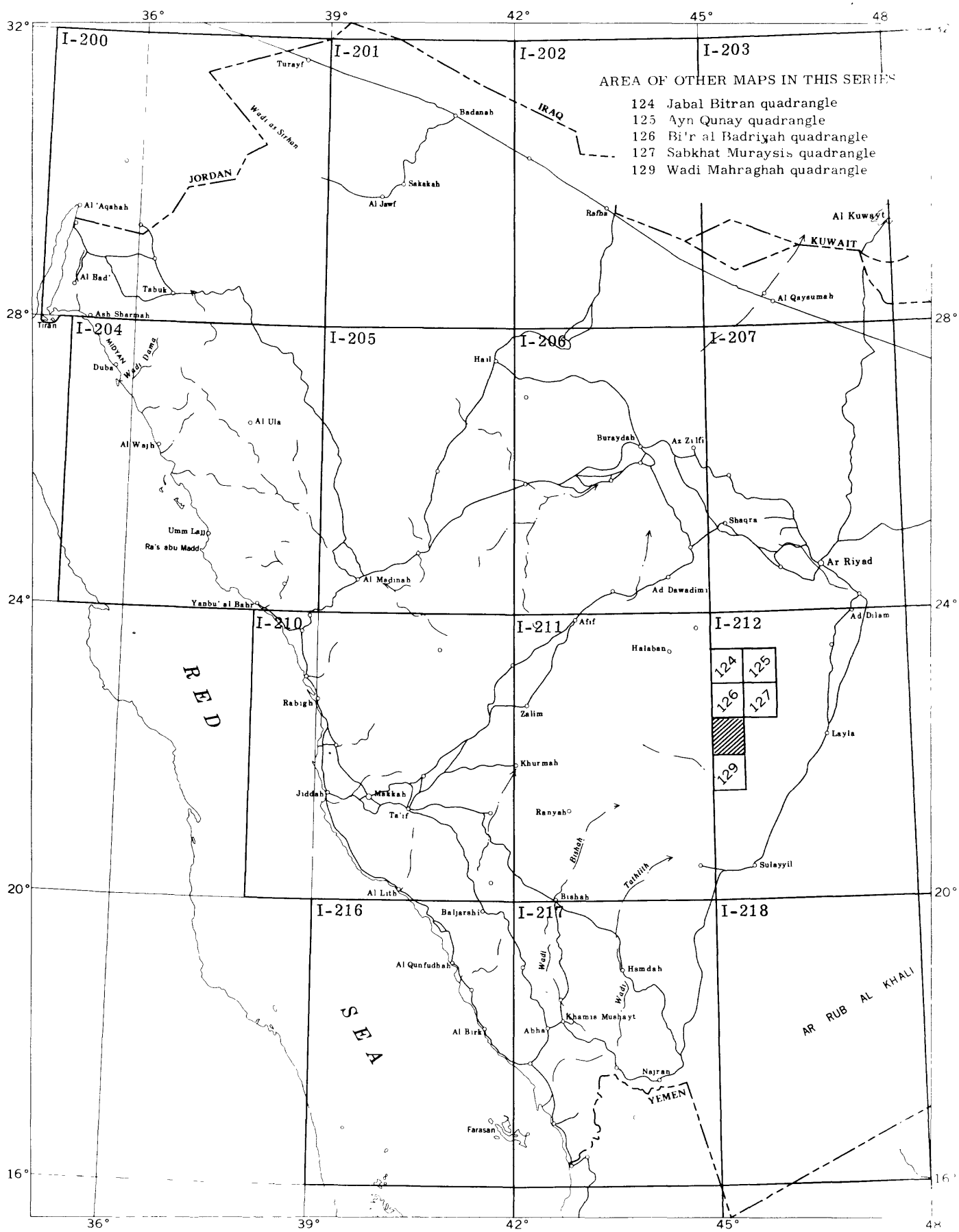

Figure 1.- Index map showing the location of the Bi'r Ghamrah quadrangle

Rock types and stratigraphic succession

The western and northern parts of the Bi'r Ghamrah quadrangle are underlain by Precambrian rocks, the eastern and southern parts by sedimentary rocks of Paleozoic age. The Precambrian rocks were formed over a long period during which successive piles of eugeosynclinal sedimentary and volcanic rocks were deposited on the eroded surfaces of earlier and similar materials. The oldest rocks in this succession in the quadrangle are conglomerate, marble, and thick sequences of graywacke and andesite to which the name Bi'r Khountina Group is here assigned from extensive exposures of the formations in the group in the ranges of hills west of Bi'r Khountina in this quadrangle. Unconformably overlying the Bi'r Khountina Group is a thick sequence of graywacke, argillite, and conglomerate to which the name Murdama Group was given in the quadrangle to the north (Overstreet, Whitlow, Kahr, and Ankary, 1972) from its resemblance to to rocks identified as Murdama Formation in the Southern Najd quadrangle (Jackson and others, 1963). Rhyolitic lithic tuff, rhyolite, and rhyolite porphyry occupy a small area in the southern part of the quadrangle. They are interpreted to lie unconformably on the other rocks and are tentatively correlated with the Shammar Rhyolite of Brown and others (1962).

These Precambrian sedimentary and volcanic rocks are intruded by gabbro, diorite, and granite of various ages. Large masses of alkalic granite are surrounded by contact-metamorphic aureoles up to 6 km in width.

A great unconformity separates the older rocks from the Permian limestone and younger sedimentary rocks.

Mylonitized biotite granite

Tectonic slices of mylonitized medium- to coarse-grained biotite granite are exposed in the Najd fault zone 4½ km northwest of Bi'r Ghamrah. These slices of granite are intruded by dikes of andesite porphyry which are also strongly sheared, and which end at the walls of the slices of granite. This granite is interpreted to be the biotite phase of a unit in the Wadi Mahraghah quadrangle called gray hornblende-biotite granite by Overstreet and Whitlow (1972). Its present position in the sequence of metasedimentary rocks is thought to result from movement on the Najd fault, because the gray hornblende-biotite granite is normally overlain unconformably by the metasedimentary rocks. The mylonitized biotite granite is the oldest rock in the quadrangle.

Bi'r Khountina Group

The main sequence of Precambrian layered rocks exposed in the quadrangle is here named the Bi'r Khountina Group for exposures in the northwest part of the quadrangle, west, northwest, and south of Bi'r Khountina (pl. 1). The group is comprised of three formations in the area of the Bi'r Ghamrah quadrangle, called, from oldest to youngest, the Idsas Formation, the Abu Sawarir Formation, and the Badriyah Formation. Where the lower units of the Bi'r Khountina Group are locally absent, either because of nondeposition or erosion, the Abu Sawarir or Badriyah Formations are deposited on older rocks.

Idsas Formation.-- The basal unit of the Bi'r Khountina Group was named the Idsas Formation for exposures near Jabal Idsas in the Jabal Bitrān quadrangle (Kahr and others, 1972). The base of the Idsas Formation in the Bi'r Ghamrah quadrangle consists locally of discontinuous remnants of greenstone and schistose agglomerate that rest on a unit of older diorite and gabbro, the age relations of which, discussed below, are uncertain. The greenstone and schistose agglomerate underlie either conglomerate or marble. At places where the conglomerate is absent, marble rests on the greenstone. Many fragments of greenstone are in the conglomerate, and some are in the marble.

The conglomerate which locally marks the base of the Idsas Formation in the Bi'r Ghamrah quadrangle is gray, green, or varicolored, and consists of well-rounded rock fragments up to 1 m in diameter. Pebbles, cobbles, and boulders of quartz, quartzite, greenstone, andesite, andesite agglomerate, red granite porphyry, brown rhyolite with quartz phenocrysts, conglomerate, and marble are set in a matrix consisting generally of fine grained graywacke, calcareous graywacke, or tuffaceous graywacke. Locally, the conglomerate is strongly sheared and the matrix consists of chlorite-sericite schist. Shear planes in the conglomerate pass through the coarse-grained components. Locally, two directions of closely spaced cleavage are present which produce a pencil structure in the conglomerate.

The conglomerate is overlain by brown and blue-gray marble, silicified marble, and dolomitic marble. Brown chert nodules are common in some layers of the blue-gray marble, but they are scarce in the brown marble. The blue-gray marble contains layers of calcareous conglomerate lacking noncalcareous components except locally where scattered pebbles and small cobbles of quartz, quartzite, and greenstone are present. Graded bedding in the conglomerate and marble is interpreted to show that the marble overlies the conglomerate.

The relations discussed above are interpreted here to show that the earliest rocks deposited in the Idsas Formation were andesitic lavas, possibly extruded under water, and converted by dueteric alteration to greenstone. The greenstone was partly eroded and the debris deposited in the conglomerate. Locally the greenstone was wholly eroded, or was not deposited, and the conglomerate rests on older rocks. The conglomerate was eroded and reworked, fragments of earlier-deposited conglomerate being incorporated in later beds of conglomerate. Some limestone was deposited intermittently with the conglomerate and was reworked into younger beds of conglomerate. At places in the Idsas depositional basin, but probably not uniformly over it, thick sequences of limestone, siliceous limestone, and dolomite accumulated as the deposition of coarse clastic debris slowed. Gradation from conglomerate to calcareous conglomerate shows this change. The presence of siliceous marble and tuffaceous conglomerate discloses that the volcanic phase with which the Idsas opened did not cease entirely, even during deposition of the limestone, which is thought to have taken place in water enriched in silica from solution of tuff. The main volcanic phases of the Bi'r Khountina Group followed deposition of the limestone and other sedimentary rocks represented by the lower formations of the Group.

Abu Sawarir Formation.-- The name Abu Sawarir Formation was introduced in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, Kahr, and Ankary, 1972) for the main clastic sequence in the Bi'r Khountina Group. In the Bi'r Ghamrah quadrangle this formation consists of graywacke, calcareous graywacke, conglomerate, and sparse lenticles of marble. Andesitic detritus is a major component in these sediments, and the conglomerate consists mostly of rounded fragments of andesite. Beds of graywacke appear to give way abruptly along strike to andesite. Some bodies of andesite interlayered with the graywacke are probably sills, because they have chilled borders. These sills may be related to the overlying andesite unit, because they are associated with andesite dikes of identical appearance, which appear to be feeders for the flows in the Badriyah Formation.

In the aureole of contact metamorphism around the intrusive mass of alkalic granite, the graywacke of the Abu Sawarir Formation is metamorphosed to argillite, chlorite-sericite-quartz phyllite, and biotite-muscovite-quartz schist. The matrix of the conglomerates is commonly metamorphosed to chlorite-sericite-quartz schist near the contacts of the alkalic granite, but the coarse-grained fragments in the conglomerate seemingly are unaffected.

Badriyah Formation.-- The term Badriyah Formation, introduced in the Bi'r al Badriyah quadrangle (Overstreet, Whitlow, Kahr, and Ankary, 1972), comprises the main sequence of volcanic rocks in the Bi'r Khountina Group. In the Bi'r Ghamrah quadrangle the Badriyah Formation consists of dark green, green, and black andesite, andesite porphyry, trachytic andesite, andesite tuff, and agglomerate. The sequence is probably many thousands of meters thick, and its actual thickness is not known because the lower part of the unit has been repeated at least twice by north-northwest-trending faults and the upper part is covered by sand. Massive andesite flows of great thickness with porphyritic phases having phenocrysts of feldspar and pyroxene are common. The upper(?) parts of some of these flows are trachytic and have long flat crystals of plagioclase that define flow bands. Elsewhere, thin tuffaceous beds, tuffaceous argillite, and layers of agglomerate are present. Interlayered with the volcanic and pyroclastic rocks of the Badriyah Formation are beds of graywacke, conglomerate, and marble, which resemble in appearance the sedimentary rocks of the Abu Sawarir Formation.

Low-rank metamorphism attributable to a variety of factors has affected the Badriyah Formation. At many places the andesitic rocks are altered to massive greenstone or are epidotized, probably through deuteric alteration, but some greenstone appears to have formed through contact effects of the mass of diorite and gabbro intruded near the center of the quadrangle. Fractured or brecciated andesite, schistose greenstone, and chlorite-sericite-quartz schist are common along the contacts of intrusive alkalic granite, and locally the contact-metamorphic effect was great enough to convert andesite to biotite-hornblende schist and hornblende schist. Dikes of andesite are common throughout the Badriyah Formation where they served as feeders for overlying andesitic flows. These dikes cut across the other units of the Bi'r Khountina Group.

Mafic intrusives

Older diorite and gabbro.-- In the west-central part of the Bi'r Ghamrah quadrangle an elongate pluton of dark-gray to black, massive to sheared diorite and gabbro with small inclusions of andesite is unconformably overlain by greenstone, conglomerate, and marble of the Idsas Formation. Thin dikes of pyroxenite and andesite are present but rare in this body, which is also intruded by alkalic granite. Because this western pluton of diorite and gabbro is unconformably overlain by conglomerate and marble of the Idsas Formation, and because the conglomerate contains detrital magnetite and olivine apparently derived from the gabbro, or from more mafic rocks associated with the gabbro but not

now exposed, the western pluton of diorite and gabbro is here interpreted to be older than the overlying sedimentary rocks and older than the eastern pluton of diorite and gabbro that intrudes the volcanic rocks of the Badriyah Formation. Further evidence that the western pluton is older than the eastern pluton is the presence of pyroxenite dikes, which reverse the intrusive order seen in the northeastern part of the quadrangle. The older diorite and gabbro may be part of a plutonic equivalent of the lower greenstone unit in the Idsas Formation, or it may be a plutonic equivalent of older andesites in the Halaban Formation exposed to the west (Jackson and others, 1963). Owing to lack of metamorphism and to close spatial relation to the younger diorite and gabbro, this pluton is here thought to be a deep-seated equivalent of the older greenstones of the Idsas Formation separated by some erosion.

Pyroxenite, peridotite, and serpentinite.-- In the northeastern part of the quadrangle, masses of pyroxenite, peridotite, dunite, and serpentinite rise as low hills and gentle protuberances above broad, sand-covered flats. The pyroxenite, peridotite, and dunite are locally chloritized and altered to serpentinite. Locally the pyroxenite and peridotite are sheared and converted to hornblende schist and chlorite schist. Where the rocks are altered to serpentinite, variable amounts of magnesite are also present. In places the serpentinite is associated with gray dolomitic marble, and brecciated masses of serpentinite are engulfed in recrystallized marble. The ultramafic rocks are intruded by later fine-grained metadiorite, diorite, and gabbro, and by dikes of dacite and pink rhyolite.

Younger diorite and gabbro.-- Dark-gray to dark-green and nearly black, fine- to medium-grained diorite and gabbro form a composite, elliptical pluton in the east-central part of the quadrangle. These rocks intrude andesite, laminated andesite tuff, and greenstone of the Badriyah Formation as well as pyroxenite, peridotite, and serpentinite. The younger diorite and gabbro unit is intruded by sparse dikes of andesite and rhyolite, and common dikes of gray to pink alkalic granite, pegmatite, and grayish-white quartz veins. Along the eastern edge and northern end of the mafic pluton, at its contact with the alkalic granite, the diorite and gabbro are locally sheared in north-trending zones as much as 5 m thick. These shear zones are stained reddish brown, possibly from pyrite or hematite, but no other mineralization was seen. At the northern end, eastern side, and southwestern end of the mafic pluton, where the diorite and gabbro have been metamorphosed by alkalic granite, original pyroxene and hornblende in the mafic rocks are chloritized, and the rocks are converted to metadiorite and metagabbro. Unmetamorphosed diorite and gabbro are most common along the western side of the pluton.

Well-displayed intrusive contacts between the composite pluton and andesite of the Badriyah Formation along the western and southeastern flanks of the pluton, indicate that the diorite and gabbro are younger than at least part of the andesite. However, dikes of andesite in the diorite and gabbro show that the diorite and gabbro probably intruded the base of the andesite sequence before extrusion of andesite had ceased altogether. Dikes of gray and pink alkalic granite in the diorite and gabbro are evidence that the composite pluton is older than the granite.

Murdama Group

A sequence of unmetamorphosed and metamorphosed Precambrian sedimentary rocks unconformably overlies the Bi'r Khountina Group in the Bi'r Ghamrah quadrangle. The sequence consists of graywacke sandstone, laminated argillite, gray to black sandy conglomerate, and some interbedded volcanic flows and tuff. These rocks are metamorphosed to sericite-chlorite schist, biotite-hornblende schist, and hornblende schist in the metamorphic aureole of the intrusive alkalic granite.

This sequence was originally mapped at 1:500,000-scale on the Southern Tuwayq quadrangle (Bramkamp and others, 1956) as sericite and chlorite schist (their unit s), which was considered to be the second oldest rock in the area. Immediately to the west in the 1:500,000-scale Southern Najd quadrangle (Jackson and others, 1963), extensions of the graywacke and sericite-chlorite schist from the Bi'r Ghamrah quadrangle were called andesite and graywacke of the Halaban Formation (their units hc and ha). Extensions of the biotite-hornblende schist in the Bi'r Ghamrah quadrangle into the area of the Southern Najd quadrangle were mapped by Jackson and associates (1963) as Murdama Formation (their unit mu). The term Murdama Formation was used by Jackson and associates for a dominantly sedimentary sequence of Precambrian conglomerate, phyllite, siliceous slate, graywacke, and local interbedded tuffaceous rocks, generally unmetamorphosed, but including units metamorphosed to chloritic and biotitic schists.

The term Murdama Formation as described by Jackson and others (1963) fits the lithologic succession and stratigraphic position of these graywackes and schists in the Bi'r Ghamrah quadrangle and Wadi Mahraghah quadrangle (Overstreet and Whitlow, 1972) better than the term Halaban Formation of Jackson and others (1963). The rank of the sequence, however, is greater than that of a formation. Hence, this Precambrian sequence is here named the Murdama Group by correlating the sequence in the Bi'r Ghamrah quadrangle to the Murdama Formation of Jackson and others (1963) in the Southern Najd quadrangle and elevating the term formation to group. The name Murdama Group is here

adopted for this entire sequence of graywacke, conglomerate, interbedded volcanic rocks, and their metamorphic equivalents.

In the Bi'r Ghamrah quadrangle, and in the Wadi Mahraghah quadrangle to the south (Overstreet and Whitlow, 1972), the basal formation of the Murdama Group was not identified, but in the Bi'r al Badriyah (Overstreet and others, 1972) and Jabal Bitran (Kahr and others, 1972) quadrangles, a conglomerate called the Z'reiba Formation was mapped at the base of the Group. The main part of the Murdama Group is the Abt Formation, which overlies the Z'reiba. It is the only formation of the Murdama Group in the Bi'r Ghamrah quadrangle.

Abt Formation.-- The Abt Formation, named in the Jabal Bitran quadrangle (Kahr and others, 1972), is exposed in the southwestern part of the Bi'r Ghamrah quadrangle, and consists dominantly of graywacke, sericite-chlorite schist, and biotite-hornblende schist. These rocks are part of a sequence that extends southward into the northwestern corner of the Wadi Mahraghah quadrangle (Overstreet and Whitlow, 1972), where the sequence rests unconformably on gray hornblende-biotite granite. The metamorphic rocks of the Abt Formation in the Bi'r Ghamrah quadrangles are interpreted to be the part of the formation that was affected by intrusion of the large body of alkalic granite lying to the north of the Najd fault zone. The Najd fault zone cuts across the Abt Formation and probably affects the stratigraphic succession in the more northerly part of the exposures in the Bi'r Ghamrah quadrangle, but the metamorphism of the graywacke and other rocks was caused by heat and stress accompanying intrusion of the granite, not by movement on the fault. Thus, three main lithologic units are shown for the Abt Formation in this quadrangle: (1) graywacke, sandy conglomerate, and interbedded volcanic rocks, (2) sericite-chlorite schist, and (3) biotite-hornblende schist.

The graywacke unit consists of unmetamorphosed to slightly metamorphosed gray-green graywacke sandstone, thick- to thin-bedded, fine-grained graywacke and argillite, and conglomerate. Conglomeratic phases have a sandy matrix in which are set pebbles, cobbles, and boulders of greenstone, epidotized andesite, gneissic granite, shale, and andesitic tuff. Locally in the graywacke the matrix is partly recrystallized to fine-grained sericite and chlorite, but the rock remains flaggy; it is not schistose. Andesite flows(?) are interlayered locally with the graywacke. Seemingly, the amount of interlayered andesite increases toward the northeast.

The unit mapped as sericite-chlorite schist is thought to be the metamorphic equivalent of the graywacke unit, but the schist consists of rocks in the chlorite zone of contact metamorphism. The boundary between the metamorphosed and unmetamorphosed parts of the sequence

is only approximately located in the Bi'r Ghamrah quadrangle. The boundary is probably more irregular than shown on plate 1. At least in places the foliation in the schist is an axial-plane cleavage; elsewhere it seems to follow bedding. Conglomeratic layers in the sericite-chlorite schist, particularly layers close to the Najd fault zone, contain stretched pebbles and cobbles which tend to form a horizontal lineation. Recrystallization of the pebbles and cobbles has been so extreme that the long axes of the deformed pebbles are at least 10 times the intermediate dimension of the pebble. In the same places veins and stringers of pink granite and pink pegmatite show striking boudins. Possibly these effects were caused by early and deep-seated movement on the Najd fault zone, or in folds associated with the fault zone, but the characteristic deformation along the Najd fault zone is mylonitization, not recrystallization. However, at a few places near the southwestern edge of the Najd fault zone, sericite-chlorite-quartz schist was seen on the south side of the fault and quartz-sericite-chlorite-actinolite schist was seen on the north side of the fault. The rock on the north side of the fault is retrogressively metamorphosed, with chlorite and actinolite replacing hornblende, and sericite replacing feldspar and quartz. Thus, locally, recrystallization accompanied movement on the fault.

A metamorphic isograd for biotite is approximately located along the southern side of the Najd fault zone. Biotite-hornblende schists on the northern side of the isograd are at the highest metamorphic grade reached in the contact zone south of the granite. These schists consist of fine-grained hornblende schist, black magnetite-bearing hornblende schist, and fine-grained interlayered biotite-hornblende-quartz schist, biotite schist, biotite-muscovite-quartz schist, and feldspathic biotite schist. They are here interpreted to have been formed from interlayered graywacke and andesite through contact metamorphism caused by the alkalic granite. Excepting the actinolite schist mentioned above, the biotite-hornblende schist is not retrogressively metamorphosed in the Najd fault zone. The biotite-hornblende schist is commonly seen to have undergone more or less cataclastic deformation, and the schist is locally mylonitized without subsequent recrystallization. Felsite and rhyolite dikes in the schist are commonly mylonitized.

Alkalic granite

Dominantly gray, locally pink to red, fine- to medium-grained, equigranular to porphyritic, massive biotite granite is strongly fractured and sheared along a N. 20° W.- trending fault zone and along west-northwest-trending fault zones. Mylonitized parts of granite in the west-northwest-trending fault zones have well-developed

cataclastic lineation consisting of oriented porphyroclasts of quartz and potassium feldspar and clots of biotite; however, no recrystallization was observed in the fault zones.

The granite is intrusive into graywacke and conglomerate of the Murdama Group, into andesite of the Bi'r Khountina Group and into the mafic intrusive rocks. At its contact with the Murdama Group, the alkalic granite has produced a metamorphic aureole as much as 6 km wide in which the graywacke near the granite has been converted to biotite-hornblende schist, and graywacke farther from the granite has been changed to sericite-chlorite schist. Along the contact of the granite with andesite of the Bi'r Khountina Group, the andesite is converted to greenstone, and tuffaceous layers in the extreme northwestern part of the quadrangle are changed to chlorite-sericite-quartz phyllite. The granite in its southern part is widely intruded by dikes of rhyolite and rhyolite porphyry, fine-grained, gray, biotite granite, and pegmatite and quartz. Black rhyolitic lithic tuff is inferred unconformably to overlie the alkalic granite.

On the map of the Southern Tuwayq quadrangle (Bramkamp and others, 1956) this rock is identified as the youngest granite in the area; however, small exposures of a younger granite are present in the Bi'r Ghamrah quadrangle.

Isotopic age determinations reported in the Bi'r al Badriyah (Overstreet and others, 1972), Jabal Bitran (Kahr and others, 1972), and Ayn Qunay (Overstreet, Whitlow and Ankary, 1972) quadrangles are interpreted to show that the alkalic granite and the somewhat younger peralkalic granite(?) mentioned below are Upper Precambrian to Lower Paleozoic(?).

Peralkalic granite(?)

Fine-grained, quartz-poor, gray to pink, biotite granite forms a small stock intrusive into andesite of the Badriyah Formation in the northwestern quarter of the quadrangle. The granite resembles similar stocks of peralkalic granite exposed 11 to 14 km to the north in the Bi'r al Badriyah quadrangle (Overstreet and others, 1972), and this granite is tentatively correlated with them. Openings of an ancient mine are in this stock, and ancient workings are also associated with one of the stocks to the north.

Shammar Rhyolite(?)

Possible Shammar Rhyolite of Brown and others (1962) is exposed in the southwestern part of the quadrangle. Both extrusive and

intrusive phases are mapped.

Rhyolite, rhyolite porphyry, and rhyolitic lithic tuff.-- Massive red to gray rhyolite and red to gray rhyolite porphyry form dikes and intrusive masses in the southwestern part of the quadrangle about 9 km northeast of Bi'r Ghamrah and a few kilometers west and northwest of Bi'r Ireyeyah. Pyrite is a minor mineral in some dikes. In the porphyry, phenocrysts of feldspar reach 2 mm in diameter, phenocrysts of quartz are as much as 4 mm in size, and biotite phenocrysts may be present. Locally in areas of intense fracturing the rhyolite is bleached to buff or cream color and the fractures are filled with oxides of iron and manganese. Where the bleaching is most intense, the rhyolite is altered to kaolinite. These features can be seen around the northwest-trending faults near the eastern end of the largest exposure.

Dikes of rhyolite porphyry are particularly common in the gray alkalic granite. Similar dikes of rhyolite porphyry and rhyolite intrude the Murdama and Bi'r Khountina Groups. The large body of rhyolite 9 km northeast of Bi'r Ghamrah consists of a swarm of red rhyolite porphyry dikes cutting earlier but probably genetically related, dense, black rhyolitic lithic tuff. Locally, the rhyolitic lithic tuff is bleached to a pale brown or buff color. Within 0.3 km of the Najd fault zone the rhyolite is converted from dense, massive black or red rocks without planar structure into mylonitized red rhyolite with cataclastic structure that strikes west-northwest nearly parallel to the trace of the fault. Porphyroclasts of quartz in the mylonitized rhyolite define a lineation that plunges 15° S. in the plane of cataclastic foliation. At many places in the biotite-hornblende schist unit of the Abt Formation, dikes of red rhyolite porphyry are present. These dikes are sheared and mylonitized parallel to the plane of the Najd fault zone, but the rhyolite mylonite is not recrystallized.

The rhyolite, rhyolite porphyry, and rhyolitic lithic tuff are here interpreted to be younger than the alkalic granite. The lithic tuff is an extrusive phase of the rhyolite, and probably unconformably overlies the alkalic granite and rocks intruded by the granite. Owing to the great fault along the southwestern side of the rhyolite and to sand along the northeastern side of the rhyolite, actual unconformable contacts have not been seen. The trend of the rhyolite unit is across the trends of the other units, thereby further supporting the probability that the lithic tuff rests unconformably on older rocks. The rhyolitic lithic tuff is unmetamorphosed, but it overlies graywacke metamorphosed to biotite-muscovite-quartz schist. From these relations the possibility exists that the rhyolite is equivalent to the Shammar Rhyolite described by Brown and others (1962), but the small area and obscure relations makes the correlation uncertain.

Granite dikes, pegmatite, quartz, and red granite porphyry.--Dikes of fine-grained gray biotite granite intrude the dark-gray rhyolite dikes previously described that contain phenocrysts of quartz, orthoclase, and biotite. The intrusive relations are well exposed at the central part of the west edge of the quadrangle, where both types of dikes occupy fractures in the alkalic granite. The dikes of fine-grained gray biotite granite are inferred to be the holocrystalline equivalent of the rhyolite dikes. These later holocrystalline dikes of fine-grained granite are interpreted to have been feeders for the upper parts of a sequence of rhyolite extrusives now largely removed by erosion.

The fine-grained gray biotite granite dikes appear to grade into red aplite and pink, quartz-rich pegmatite dikes, and massive, milky white quartz veins. Epidote is present as a minor accessory mineral in the pegmatite. Locally the pegmatite dikes are large, and their quartz cores stand as white knobs and low hills. Doubtless there are several ages of similar simple eutectic pegmatites and masses of white quartz, but those observed here cut the rhyolite dikes.

Closely associated red granite porphyry and rhyolite porphyry are intrusive into the older diorite and gabbro, and form a northerly elongated group of dark red hills 17 km north-northeast of Bi'r Ghamrah. The red granite porphyry is intensely brecciated at its southern end where it is crossed by a fault zone, and the breccia is cemented by milky white quartz which in places is also brecciated and is healed with brown quartz. Because of its close spatial association with rhyolite porphyry and lavas of the Shammar Rhyolite(?), this body of red granite porphyry is interpreted to be one of the holocrystalline shallow intrusives of that sequence. Similar rocks are present in the rhyolite unit on the northeast side of the Najd fault 9-½ km east-northeast of Bi'r Ghamrah.

Peridotite and serpentinite

Nearly black, very fine-grained peridotite lacking cataclastic structure is present along the trace of the Najd fault zone in the southwestern corner of the quadrangle. The peridotite is more or less altered to serpentinite. Veins of brown calcite, also undeformed, are in the serpentinite and adjacent rocks. On the southwest side of the peridotite are tectonic slices of mylonitized biotite granite, and on the northeast side of the peridotite cataclastically deformed hornblende schist of the biotite-hornblende schist unit of the Abt Formation is exposed. Absence of cataclastic structures in the peridotite is interpreted to mean that the peridotite was intruded along a fracture of the Najd fault zone after major movement on the fault had ceased. Inasmuch as the fault cuts all Precambrian rocks

in the area, but is not known to cut the Khuff Formation of Permian age, the age of the peridotite is inferred to be pre-Permian.

Post-Precambrian sedimentary rocks

Four post-Precambrian sedimentary units are shown on plate 1.

Permian(?) sandstone and conglomerate.-- A small area of sandstone and conglomerate, possibly equivalent to the Permian Wajid Sandstone which crops out farther southwest (Jackson and others, 1963), is mapped in the east-central part of the quadrangle. It consists of brown sandstone, calcareous sandstone, and brown quartz-pebble conglomerate. Striated pebbles were not seen, but some of the pebbles contain single groovelike cracks along one side which may be the trace of small fractures or of soluble mineral grains in the quartz from which the pebbles formed. The unit of sandstone and conglomerate is here correlated with the Permian Wajid Sandstone (Jackson and others, 1963) which rests unconformably on Precambrian rocks and lies disconformably below the Khuff Formation. The stratigraphic relation of the sandstone and conglomerate at this locality to the Precambrian and Permian rocks is unknown. Contacts are covered, and the unit was not traced. The marked disconformity, reported by Helal (1964, p. 198) as a distinguishing feature at the base of the Khuff Formation was not seen, nor was evidence observed that the conglomerate is tillite, as Helal infers for other exposures of the Wajid. Sorting, shapes of pebbles, and uniform quartzose composition indicate that the rock is possibly alluvial in origin. It may be Tertiary in age.

Khuff Formation.-- The Khuff Formation of Permian age has little topographic relief in the Bi'r Ghamrah quadrangle. Areas of Khuff shown here as outcrop have been interpreted from aerial photographs or adapted from Bramkamp and others (1956) with little change in outline. The rock was not examined.

Alluvial and aeolian sand.-- Quaternary alluvial sand has been mapped to show the distribution of wadi sediments and of non-dune forming aeolian sand, and to define outcrops of Precambrian rocks. The aeolian sand unit is adapted from Bramkamp and others (1956).

Structure

The main structural element of the Precambrian rocks in the Bi'r Ghamrah quadrangle is a south-plunging, asymmetrical anticlinorium of andesitic rocks of the Bi'r Khountina Group. The west flank and core of the anticlinorium are intruded by alkalic granite, and the western limb of the anticlinorium is repeated by north-northwest-striking faults of uncertain age. The east limb is covered by sand.

The andesitic rocks in the southwest quarter of the quadrangle appear to have been overlain unconformably by a thick sequence of graywacke of the Murdama Group, folded possibly along axes parallel to those in the Bi'r Khountina Group (Overstreet and Whitlow, 1972), and also altered by the contact effect of the alkalic granite. However, actual contacts between these groups are lacking owing to the intrusion of alkalic granite between them. Overlying these rock units is the Shammar Rhyolite(?).

Relations among these rocks are obscured by the great Najd fault zone. This zone, which is 1 to 2½ km wide and strikes west-northwesterly, is younger than the Shammar Rhyolite(?) but older than the Permian Khuff Formation. The zone is marked by cataclasis and exotic tectonic slices of mylonitized granite, but the amount of movement is not known. Rocks on the northeast side of the main fault planes moved relatively toward the northwest, and rocks on the north side of short, east-trending subsidiary faults in the zone moved toward the west. A parallel fault about 15 km north of the Najd fault zone, possibly of older relative age because it is intruded by undeformed rhyolite dikes, has a similar apparent relative movement of northern block toward the west. The presence of large numbers of fractures parallel to the Najd fault zone and occupied by rhyolite dikes of the Shammar Rhyolite(?) is interpreted to mean that deformation occurred several times along this trend. Early openings were filled by rhyolite dikes of the Shammar Rhyolite(?). The dikes were mylonitized by later Najd movement.

GEOLOGIC RELATIONS OF SELECTED ELEMENTS

Samples of wadi sand, concentrates, and detrital magnetite were collected at 55 localities in the part of the quadrangle underlain by Precambrian rocks, and the samples were analyzed for selected elements. The principal results of this geochemical reconnaissance are plotted on the geologic map (plate 1).

Procedure

Samples weighing about 10 kg were dug from the upper 30 cm of dominantly water-lain wadi sand and sieved on stainless steel screens to obtain 100 g of -30 to + 80-mesh material. Tailings from the sieves were panned to recover concentrates, which were examined under ultraviolet light for scheelite and powellite. Magnetite was separated from the concentrate. The sieved wadi sand concentrate and magnetite were analyzed in the Jiddah Laboratory of the Directorate General of Mineral Resources. The wadi sand was analyzed spectrographically by C. E. Thompson, U. S. Geological Survey, and Kamal Shahwan, Directorate General of Mineral Resources, for 27 elements, and chemically by Thompson

for copper, zinc, and molybdenum. The heavy-mineral concentrate was analyzed chemically for copper, zinc, molybdenum, and tungsten by L. Al Dugaither, who also analyzed the magnetite chemically for copper, zinc, and molybdenum. The semiquantitative spectrographic analyses were performed according to modified techniques used by the U. S. Geological Survey (Theobald and Thompson, 1968, p. 2), and the wet chemical analyses followed normal trace-elements procedures.

Results

Results of the analyses are given in histograms (figs. 2 and 3). The 20 histograms in figure 2 show elements present in spectrographically detectable amounts in wadi sand. Seven elements were below the limits of detection: antimony, 200 ppm (parts per million); bismuth, 20 ppm; cadmium, 50 ppm; germanium, 20 ppm; niobium, 50 ppm; tungsten, 50 ppm; and zinc, 100 ppm. The abundances of the 20 elements were compared with the results of analyses of 321 similar samples of wadi sand collected from the Precambrian area in the Southern Tuwayq quadrangle. Fourteen elements reached threshold 1/ amounts in some samples, and small positive anomalies were identified for chromium, lanthanum, and lead (table 1). The wet chemical analyses of wadi sand (fig. 3) confirm the spectrographic determinations for copper, zinc, and molybdenum, and show that zinc is 50 ppm or less.

1/ Threshold amount as here used is a quantity that is exceeded by about 2½ percent of the total observations (Hawkes and Webb, 1962, p. 31).

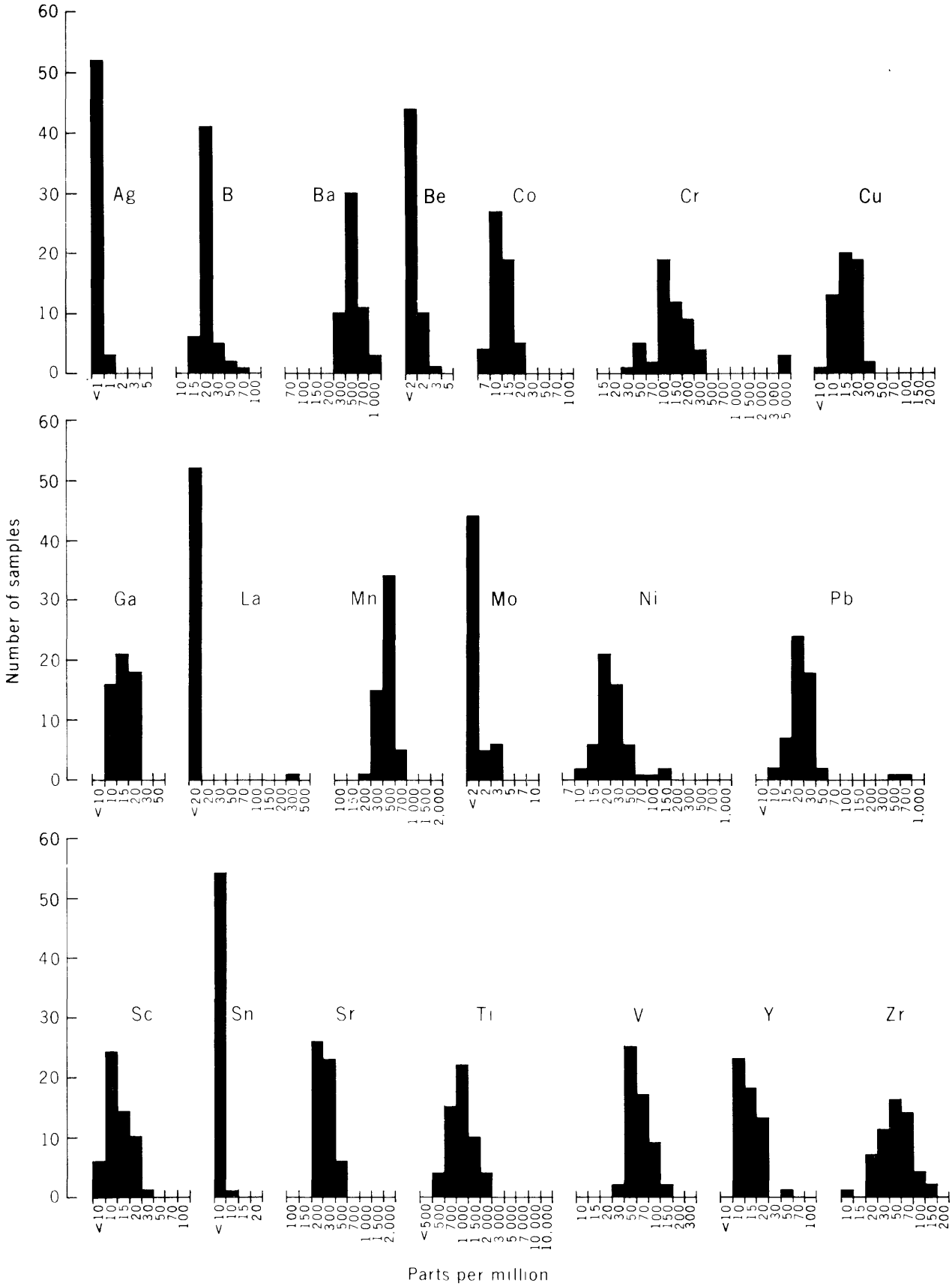

Figure 2. Histograms of 55 spectrographic analyses of wadi sand, Bi'r Ghamrah quadrangle

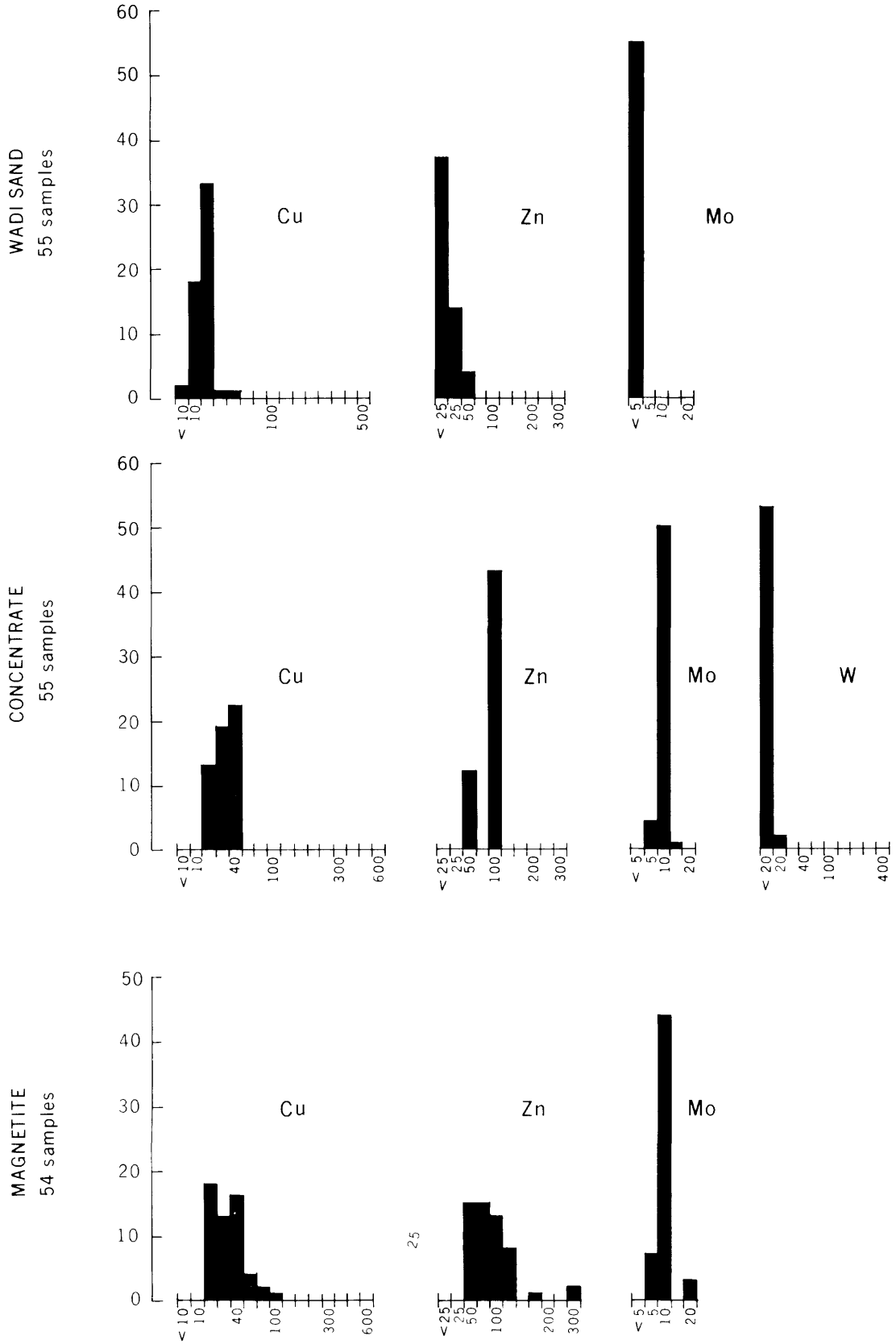

Figure 3. Histograms of wet chemical analyses of magnetite, concentrate, and wadi sand, Bi'r Ghamrah quadrangle

Table 1. Threshold values of selected elements in wadi sand, Bi'r Ghamrah quadrangle, Kingdom of Saudi Arabia (analyses by C. E. Thompson and Kamal Shahwan)

Element	Regional threshold in Southern Tuwayq quadrangle, ppm	Number of samples in Bi'r Ghamrah quadrangle at or above regional threshold value
Ag	1	3
B	50	2
Ba	1000	3
Be	2	11
Cr	1000	3 1/
La	20	3 2/
Mo	3	6
Ni	70	4
Pb	50	4 3/
Sc	30	1
Sn	10	1
V	150	2
Y	30	1
Zr	150	2

1/ The three samples have the anomalous amount of 5000 ppm Cr.

2/ One sample has the anomalous amount of 300 ppm La

3/ Two samples have the anomalous amounts of 500 ppm and 700 ppm Pb respectively.

Metals by multiple analyses

The abundances of copper, zinc, and molybdenum were determined in the three samples media by wet chemical methods, and in wadi sand by spectrographic means, and the results of the spectrographic analyses are shown on the map (plate 1). Copper and zinc in wadi sand are present in background quantities only, but six of the determinations for molybdenum are at the threshold value. None of these metals forms a positive geochemical anomaly.

Copper.-- All samples of wadi sand contain 20 ppm or less copper, with the exception of two that contain 30 ppm. The first exception is a sample from the ancient working in the extreme northwestern part of the area, and anomalous leads with threshold molybdenum and silver were also detected in material from this old mine. The other exception

is from a locality 8 km southeast of the old mine and about a kilometer east of the north-northwest-trending fault that passes just east of the mine. No anomalous or threshold metals were found in this sample.

Slightly greater amounts of copper were found in concentrates and in magnetite (fig. 3) than in the wadi sand; one concentrate has the anomalous amount of 600 ppm copper, and is from the old mine. The most copper in magnetite, 100 ppm, is from a scheelite-bearing sample in the center of the pluton of diorite and gabbro 31½ km northeast of Bi'r Ghamrah.

Zinc.-- Zinc in wadi sand is below the limit of detection by spectrographic methods (100 ppm). By wet chemical analysis four samples of wadi sand were found to have 50 ppm zinc, but the remainder contain 25 ppm or less. Two samples with 50 ppm zinc came from the ancient mine in the northwestern part of the quadrangle. A third sample having 50 ppm zinc came from the locality east of the fault and 8 km southeast of the mine. The fourth sample having 50 ppm zinc is molybdenum- and scheelite-bearing sand from an area underlain by the alkalic granite intruded by rhyolite dikes just north of a northwest-trending fault and near the west edge of the map 28 km north-northwest of Bi'r Ghamrah.

The bimodal distribution of zinc in the concentrate (fig. 3) results from lack of reported values at the 75 ppm interval. This represents a laboratory procedure and is not a real geologic difference.

Three samples of magnetite are moderately high in zinc. Two of these samples have 400 ppm and one has 200 ppm zinc. The two samples containing 400 ppm zinc are not exceeded by zinc in magnetite at any other sampled locality in the area of the Southern Tuwayq quadrangle. They come from the two easternmost chromium-rich sample localities in the mass of pyroxenite, peridotite, and serpentinite in the northeastern part of the quadrangle, but zinc minerals were not observed in the pyroxenite unit. This zinc in magnetite is in the lower part of the range cited by Theobald and Thompson (1962, p. C73) for potential association with zinc mineralization. A sample of magnetite containing 200 ppm zinc, is from fractured red rhyolite porphyry of the Shammar Rhyolite(?) on the northwest-trending fault zone at a point 11½ km east-northeast of Bi'r Ghamrah. Wadi sand from the same locality also has threshold amounts of beryllium, boron, and zirconium, but no mineralization was seen, and the rhyolite is not bleached.

Molybdenum and tungsten.-- Eleven samples of wadi sand are molybdenum bearing in the range 2 to 3 ppm, of which six samples attain the threshold value of 3 ppm. The molybdenum-bearing sand is

typically associated with younger intrusive and extrusive rocks: one sample is from pre-Premian peridotite and serpentinite in the Najd fault zone, two samples are from red granite porphyry, one from rhyolite porphyry, one from the old mine in peralkalic granite(?), and two from alkalic granite intruded by dikes of gray granite and rhyolite. These samples are commonly beryllium bearing. Where molybdenum was found in samples of sand from the volcanic and sedimentary rocks, the sources are adjacent to intrusive contacts similar to the locality 4 km west of the mine and the scheelite-bearing locality in marble of the Bi'r Khountina Group 24 km north-northeast of Bi'r Ghamrah.

The source of the molybdenum in the wadi sand is not certainly known. Of the 10 scheelite-bearing concentrates, 3 were from sands that contain molybdenum. Of the two powellite-bearing concentrates, one was from sand that has molybdenum. Inasmuch as most of the concentrates contained only one or two grains of powellite or scheelite, it is unlikely that molybdenum attributable to this small amount of powellite or scheelite would be detected in the sample used for analysis. Several samples lacking powellite or scheelite were found to have molybdenum.

Concentration of the sand effected a large increase in the amount of molybdenum detected (fig. 3). By wet chemical analysis the raw sand had less than 5 ppm molybdenum, but 50 concentrates contained 10 ppm molybdenum and one had 15 ppm. Thus, the molybdenum appears to be present in some mineral of high specific gravity. Both powellite and scheelite have high specific gravity but they seem unlikely to be sources, for the reasons given above. The water-soluble secondary molybdenum mineral ilsemannite, often found in rhyolitic terrain, is also eliminated as a possible source for the molybdenum because it would have dissolved in panning. The lead molydate, wulfenite, also seems to be excluded as a possible source, because the most molybdenum-rich concentrate, from the locality 1.5 km north-northwest of Jabal Ash El Khountina, is derived from sand having only background quantities of lead. The most likely possibility is that the molybdenum-bearing mineral in the sands and concentrates is molybdenite. However, molybdenite was not seen.

The similarity between the amounts of molybdenum in detrital magnetite and in magnetite-free concentrates (fig. 3) is remarkable. No reason for the similarity is known. Three samples of magnetite contain 20 ppm molybdenum, and are the most molybdenum-rich magnetites found in the quadrangle. They are from three localities along the northern edge of the large mass of Shammar Rhyolite(?) in the southern part of the quadrangle. Sands from these localities are characterized

by threshold amounts of beryllium and may contain threshold amounts of silver, lead, boron, and zirconium.

Two scheelite-bearing concentrates were found to have 20 ppm tungsten (fig. 3). One came from sand derived from andesite, trachytic andesite, and andesitic lithic-tuff of the Badriyah Formation exposed 11 km east-northeast of the ancient mine. The other came from biotite-muscovite-quartz schist of the Abu Sawarir Formation on the northwest-trending fault 14 km northeast of Bi'r Ghamrah. Neither the amount of scheelite nor the quantity of tungsten is large.

Anomalous elements

Anomalously large amounts of chromium, lanthanum, and lead were detected spectrographically in some samples of sand. The chromium and lanthanum are associated with pyroxenite, peridotite, and serpentinite in the northeastern quarter of the area 14 km east of Bi'r Khountina, and the anomalous lead is in sand from the ancient working.

Chromium.-- Three samples of sand from small wadis draining serpentinite and other ultramafic rocks poorly exposed near the eastern edge of the Precambrian Shield contain 5,000 ppm chromium each. At the westernmost chromium-rich locality, exposures reveal serpentinite derived from dunite, and partly serpentinized relicts of dunite as much as 3 m thick and 20 m long. Dustlike particles of chromite are present in the dunite where they are associated with magnetite, and the two minerals together make up several percent of the dunite. No large masses of chromite were seen. At the two other chromium-rich localities, relict dunite was not found. There the chromium is probably derived from serpentinite.

The amount of chromium detected in the wadi sand represents a strong positive anomaly for chromium, but only normally expectable amounts of chromite were found in the ultramafic rocks. Inasmuch as chromite was not previously known in the area, and the exposures are poor, more work should be done to determine the amount of chromite actually present.

Lack of norite in the suite of rocks and lack of cobalt in the analyses are inferred here to indicate that the probability for plantinum is poor, but the presence of anomalous chromium and threshold nickel means that the possibility of platinum must be entertained in further investigations of the area.

Lanthanum.-- Sand from the westernmost of the three chromium-rich localities has the anomalous amount of 300 ppm lanthanum. No other sample in the Precambrian area of the Southern Tuwayq quadrangle has

this much lanthanum. The source-mineral for the lanthanum was not identified. Possibly the lanthanum is in allanite, a mineral known as an accessory in mafic rocks, or possibly it is present in carbonate veins as the mineral bastnaesite. Inasmuch as niobium is below the limit of detection (50 ppm), the niobates and the tantalates are not possible sources for the lanthanum. The amount of titanium reported in the sample, 1,000 ppm, is the mean background for this element in this quadrangle (fig. 2), and is not unusual for an area of mafic rocks. If the lanthanum is in titanite, an anomalous amount of titanium should be present in the sand. Because zirconium is also enriched in this sample (150 ppm equal to the regional threshold for zirconium), the source of the lanthanum possibly is a complex accessory silicate mineral.

Enrichment in lanthanum and zirconium has been reported for rocks in mafic volcanic pipes, as has enrichment of zinc in magnetite (Theobald and Thompson, 1962, p. C73). Magnetite from this body of mafic rocks 14 km east of Bi'r Khountina contains the most zinc found in magnetites from the Precambrian area of the 1:500,000-scale Southern Tuwayq quadrangle. The possibility therefore exists that part of this body of serpentinized mafic rock may be an ancient volcanic pipe. Such a structure could be associated with rare earth and thorium minerals, zinc and fluorite, or diamond. Of these, this reconnaissance has disclosed traces of the rare earths and zinc, but no evidence was found of the titanium-rich accessory minerals and pyrope generally associated with diamond.

Lead.-- Anomalous lead was reported in two samples of wadi sand from the small ancient working. One sample contained 500 ppm and the other 700 ppm lead. Both samples have threshold quantities of silver (1 ppm), an element detected at only one other locality in the quadrangle. The mine is in an area where adjacent samples contain scheelite and also have threshold amounts of beryllium, tin, and yttrium.

Threshold elements

Spectrographic analyses of wadi sand disclosed threshold quantities of silver, boron, barium, beryllium, lanthanum, molybdenum, nickel, lead, scandium, tin, vanadium, yttrium, and zirconium. The threshold quantities of molybdenum have already been discussed, as has the presence of threshold zirconium in peridotite, pyroxenite, and serpentinite, and of silver in two samples from the old mine.

Close spatial correlation exists between the distribution of many of the samples that have threshold quantities of silver, boron, barium, beryllium, lead, molybdenum, and zirconium, and the distribution

of rhyolite and red granite porphyry of the Shammar Rhyolite(?). Nickel, scandium, and vanadium in threshold amounts tend to be associated with the diorite and gabbro. Lanthanum, yttrium, and tin reach threshold abundances near the contacts of alkalic granite. Thus, the thresholds of selected elements in wadi sand are mainly attained in or near the younger intrusive rocks, and several elements with strong geochemical affinity for the mafic rocks reach their thresholds in samples from areas underlain by such rocks.

The contacts of the alkalic granite, peralkalic granite(?), and areas of closely spaced rhyolite dikes seem to be the most favorable for potential lead, silver, and gold. Mafic rocks have a potential for nickel, chromium, and zinc. Fractures subparallel to but older than the Najd fault zone appear to have partly controlled the extrusion of the Shammar Rhyolite(?). To that extent they exert control on potential ore deposits. Fractures parallel to the northwest-trending faults are filled by the only mined quartz veins in the quadrangle. The peralkalic granite(?) in which the veins occur is young; only the rhyolite and porphyry of the Shammar Rhyolite(?) are younger. Thus, the only mined mineral deposit in the Bi'r Ghamrah quadrangle was formed probably no earlier than late Precambrian time, and may have been formed in early Paleozoic time.

Silver, boron, barium, beryllium, lead, and zirconium.--Silver (1 ppm) was detected in wadi sand from the central sample of the line of three along the north side of the mass of Shammar Rhyolite(?) in the southern part of the area. The only other samples having threshold amounts of silver are at the ancient working in the northwestern part of the map.

The largest quantity of boron (70 ppm) is in the easternmost of the three samples in rhyolite 13 km northeast of Bi'r Ghamrah. An isolated sample of sand from andesite and agglomerate intruded by andesite dikes, located 6 km south-southeast of Jabal Ash El Khountina, contained 50 ppm boron. No evidence was found of skarn in the boron-bearing localities.

Two samples of sand containing 1,000 ppm barium came from alkalic granite intruded by swarms of rhyolite dikes and fine-grained granite dikes at the west-central part of the area about 24 km south of the ancient working and 22 km north of Bi'r Ghamrah. Another came from an area of fractured and epidotized andesite porphyry having large feldspar phenocrysts exposed 8.5 km east-southeast of Bi'r Umm Muslehm. These threshold appearances of barium probably relate to the presence of barium in feldspar.

Beryllium was detected in the three samples of sand from the large mass of rhyolite 11 km northeast of Bi'r Ghamrah. The only sample in the quadrangle to have 3 ppm beryllium is the westernmost of these three. Other beryllium-bearing samples in which the beryllium can be attributed to rocks of the Shammar Rhyolite(?) are two from red granite porphyry 18 km north-northeast of Bi'r Ghamrah, one from a scheelite-bearing locality in alkalic granite intrudedby a swarm of rhyolite dikes 13½ km west-northwest of Bi'r Ghamrah, and one from a scheelite-bearing area in andesite intruded by rhyolite porphyry 2½ km east of the ancient mine. Threshold beryllium is associated with tin and yttrium in sand from sericite-chlorite-quartz phyllite in the contact zone of alkalic granite at a locality 4½ km west of the old mine. Andesitic agglomerate and graywacke conglomerate with sparse, chlorite-bearing stringers of white quartz was the source of a sample with threshold beryllium and background molybdenum at Jabal Ash El Khountina. Sandstone and well-foliated sericite-chlorite-quartz schist of the Abt Formation close to Bi'r Ghamrah were the sources of two samples of sand having threshold amounts of beryllium but which lack any other indication of mineralization.

The two samples of sand having threshold amounts of lead (50 ppm) came from areas underlain by rocks of the Shammar Rhyolite(?). One is the westernmost beryllium-bearing locality in the mass of rhyolite 11 km northeast of Bi'r Ghamrah. The other is the eastern beryllium-bearing locality in red granite porphyry 18 km north-northeast of Bi'r Ghamrah.

Zirconium is in threshold amount (150 ppm) in beryllium- and boron-bearing sand from the easternmost locality in the large mass of rhyolite 11 km northeast of Bi'r Ghamrah.

Nickel, scandium, and vanadium.--Three specimens of wadi sand from the mass of pyroxenite, peridotite, and serpentinite 14 km east of Bi'r Khountina contain threshold amounts of nickel. A sample of sand from an area 7½ km west-northwest of Bi'r Ghamrah, where graywacke and andesite are intruded by buff to pink felsite dikes, has 100 ppm nickel. The westernmost nickel-bearing sample in the pyroxenite has the least nickel (70 ppm); the two samples farther east have 150 ppm each. This rise above regional background (20 ppm nickel) is expectable in an area of ultramafic rocks; however, the cause of the local rise in nickel in the graywacke is unknown. No evidence of mineralization was seen.

Layered, fine-grained hornblende schist of the Abt Formation, probably the metamorphic equivalent of mafic lava, was the source of the only sample of sand having a threshold amount of scandium (30 ppm). Inasmuch as concentrates from the same locality have less than 20 ppm

tungsten, the scandium is not associated with wolframite. It is probably a dispersed element in hornblende.

Threshold quantities (150 ppm) of vanadium were detected in two samples of sand. One was derived from the younger diorite and gabbro in the south-central part of the composite pluton in the center of the quadrangle. The other is from biotite-muscovite-quartz schist containing local carbonate layers about 7½ km west-northwest of Bi'r Ireyeyah. Scheelite occurs in the sand from schist, and the concentrate contains 20 ppm tungsten, but the schist appears to be unmineralized. Vanadium is appropriate in sand from the diorite and gabbro and the question can be asked why it was not detected in samples from the pyroxenite, but no reason was found for its rise above background (70 ppm) in sand from the schist. Presumably its reported presence in the schist is a result of normal variation in analysis (Theobald and Thompson, 1968, p. 3).

Lanthanum, yttrium, and tin.-- Threshold quantities (20 ppm) of lanthanum were found in a sample of sand from an area underlain by mylonitized alkalic granite intruded by schistose dikes of rhyolite in the northwest-trending fault zone 22 km north of Bi'r Ghamrah, and from an area of sericite-chlorite phyllite 13 km southwest of Jabal Ash El Khountina. The sample from granite also has a threshold amount of barium. Although a little pyrite is present in the mylonitized granite, and fractures in the rocks at both localities are filled with milky quartz, no mineralization was seen. The sources of the small amounts of lanthanum are probably normal accessory minerals.

Threshold yttrium (50 ppm) is associated with threshold tin (10 ppm), molybdenum, and beryllium in chlorite-sericite-quartz phyllite in the contact zone of alkalic granite 4½ km west of the ancient working. The tin and yttrium are thought to have been introduced by the granite.

MINERAL DEPOSITS

The only exploited mineral deposit in the Bi'r Ghamrah quadrangle is the small ancient working, probably opened for gold, in the northwestern corner of the area. Other similar but as yet unlocated mines may be nearby. Potential resources are indicated for gold, silver, lead, chromium, and other materials.

Gold, silver, and lead related to younger intrusive rocks

Ancient working

A small ancient working on the north side of a little group of low hills in the northwestern part of the quadrangle is in milky quartz veins in a mass of quartz-poor peralkalic granite intrusive into andesite. This old mine consists of three trenches, here called the south, north, and west openings, of which the south is the largest.

The south trench is 2 to 3 m wide, up to 2 m deep, and 15 m long on a quartz vein that strikes N. 20° W., and dips 40° E. A trace of pyrite was seen in the vein. Sand derived from the dump contains 700 ppm lead, 1 ppm silver, 30 ppm copper, and 3 ppm molybdenum. Magnetite and concentrates from this locality respectively carry 40 ppm and 600 ppm copper, 100 ppm zinc each, and 10 ppm molybdenum each. Less than 10 ppm tungsten was found in the concentrate, but the amount of copper present exceeds any found in concentrates taken elsewhere in the Precambrian area of the Southern Tuwayq quadrangle.

The north opening, now filled with wind-blown sand, is about 100 m N. 20° W. along the ridge from the south opening. It is a prospect pit about 2 m long and a meter wide that explored milky quartz resembling that at the south trench. The quartz may be a small podlike mass instead of a vein. Near the north opening is another little prospect pit a meter long, 20 cm wide, and about 10 cm deep which follows a quartz vein oriented N. 35° E.

The west opening, 47 m distant at S. 50° W. from the south opening, is a trench alined N. 45° W. in fractured granite along an inclusion of andesite. The trench is about 2 m deep, 2 to 3 wide, and 8 m long. It follows a narrow lode of vertical thin quartz stringers and veins striking N. 45° to 70° W. in andesite. The veins are milky to gray and contain cavities from which pyrite was leached and into which euhedral prisms of quartz project. Veins and andesite were mined together in the proportion of about 10 parts andesite to 1 part quartz. A sample of sand taken from the trench, adulterated by wind-blown material, contained 500 ppm lead, 1 ppm silver, and 15 ppm copper, but lacked molybdenum. Magnetite and concentrates contained, respectively, 40 ppm copper and 100 ppm zinc. The magnetite had 5 ppm molybdenum and the concentrates contained 10 ppm molybdenum but less than 20 ppm tungsten.

Very little wall-rock alteration was seen at any opening. Chloritized fragments of andesite are present in the veins at the west opening, and red stains from pyrite partly films quartz and granite at the north opening, but copper stains are absent.

Probably less than 150 cubic meters of quartz was processed, and no extension of the small veins is visible. However, the grinding operation, situated north of the south and west trenches and west of the north pit, appears to have processed more ore than came from the trenches. Possibly ore was brought in from other as yet undiscovered mines in the neighborhood. Among the six or eight grindstones at the working, one small piece of slag was found, but no slag pile is present. It would appear that the mine recovered free gold from the upper part of small and discontinuous veins, and that the recovery was too low to encourage deeper mining.

The fractures are in one of the youngest granitic rocks in the area and they are parallel to the relatively young northwest-trending fault just to the east of the mine. This fault, in its southerly extension, fractures rhyolite younger than the granite. From these relations it is inferred that repeated fracturing took place along this fault direction, and that late in the consolidation of the peralkalic granite, or during the period of emplacement of the Shammar Rhyolite(?), small auriferous quartz veins carrying minor amounts of silver and lead filled fractures in the granite. The ancient working itself is too small to justify further exploration, but it is the most positive evidence that gold is present in the area of the Bi'r Ghamrah quadrangle. The area near the old mine and extending northward to nearby mines in the Bi'r al Badriyah quadrangle (Overstreet and others, 1972) and Jabal al Hawshah quadrangle (Whitlow, 1969) should be examined in detail for gold and silver.

Potential areas

Four areas in the Bi'r Ghamrah quadrangle possess a potential for deposits of gold, silver, and lead. Present data identifies them as the area covered by the northwestern corner of the quadrangle, the area around Jabal Ash El Khountina, the small body of red granite porphyry 18 km north-northeast of Bi'r Ghamrah, and the mass of rhyolite 10 km northeast of Bi'r Ghamrah. All localities should be assigned a low order of priority in the national program of mineral exploration.

Northwestern corner.-- The northwestern corner of the quadrangle, including the ancient working, seems to be the southeastern extension, or a southeastern outlier, of the ancient mining district on Wadi Umm Mushraha in the Bi'r al Badriyah quadrangle (Overstreet and others, 1972) and at Jabal Zain and Umm Amal in the Jabal al Hawshah quadrangle (Whitlow, 1969; Saudi Arabia Min. Pet. Mineral Res., 1965, p. 24). Presence of threshold amounts of tin, beryllium, and yttrium in the contact zone of the alkalic granite a few kilometers west of the ancient mine and of threshold beryllium east of the mine, and of a group of barren samples from andesite north and east of the old mine

further indicate that possible mineralization extends northwestward from the area of the mine. No present evidence shows anomalous silver or lead in this area, but the association of threshold metal suggests the need for a more detailed examination. Gold seems to have been the principal product of the mines in the south, but silver may have been more important in the north. Although the ancient mine explored quartz veins too small to be worth developing now, the area around the mine, comprising about 100 sq. km, should be searched for lead, silver, and gold deposits.

Jabal Ash El Khountina.-- Threshold amounts of molybdenum and beryllium in sand from andesite, agglomerate, graywacke, conglomerate, and marble in the complexly folded and faulted area at and north of Jabal Ash El Khountina, and slight enrichment of molybdenum in a concentrate from there, suggest the possible presence of mineralization westward from the jabal to the north-trending fault.

Red granite porphyry.-- A little body of red granite porphyry is intrusive into diorite and gabbro about 18 km north-northeast of Bi'r Ghamrah, and the rocks are fractured along northwest-trending faults. The porphyry is intensely brecciated at its southern end, and the fractures are healed by milky white quartz which in places is also broken and is healed with brown quartz. No sulfide minerals were seen in the quartz, but samples of sand from the area contain threshold amounts of beryllium, molybdenum, and lead. The porphyry, its contacts with the diorite and gabbro, and the fractured zone in both rocks should be examined for possible gold, silver, lead and molybdenum.

Rhyolite porphyry.-- The west-northwesterly elongated hills of red rhyolite, rhyolite porphyry, and rhyolitic tuff 10-14 km northeast of Bi'r Ghamrah were the source of three samples of sand having threshold amounts of silver, lead, beryllium, boron, and zirconium. Magnetite from these localities was enriched in molybdenum and zinc. The sample from the fracture zone near the eastern edge of the rhyolite contained more threshold elements than the two samples from localities farther west. No mineralization was seen in the fractured part of the rhyolite, nor elsewhere in the unit, but these outcrops should be examined for alteration zones and the possible presence of gold, silver, and lead.

Potential resources related to older intrusive rocks

The older intrusive rocks comprising pyroxenite, peridotite, serpentinite, and dunite crop out in the northeastern part of the Bi'r Ghamrah quadrangle. A smaller mass of similar rocks is exposed about 7 km farther north in the Bi'r al Badriyah quadrangle (Overstreet and

others, 1972). Strongly anomalous chromium and anomalous lanthanum were found, high threshold zirconium was observed, and magnetite has low anomalous zinc. The ultramafic rocks are extensively altered to serpentinite. Magnesite forms veins in the serpentinite and dunite, but it makes up less than 3 percent of the volume of the rock, and commonly constitutes less than 1 percent. No asbestos was seen. These rocks are a potential source for chromium and dunite. Observed magnesite bodies are too small to mine, but in the southern part of the mass and under a cover of aeolian sand, larger percentages and larger individual bodies of magnesite are probably present. It is possible that in sand-covered parts of the mass some chrysotile asbestos may be found. The remarkable association of lanthanum and zirconium in wadi sand and zinc in magnetite may indicate that these serpentinized rocks are part of an ancient volcanic pipe. Should this be so, then the possibilities are opened for rare earths, thorium, or, quite remotely, diamond. The absence of noritic rocks, only background quantities of cobalt, and threshold amounts of nickel are interpreted to indicate that platinum is probably not enriched in these rocks. However, this mass of ultramafic rocks has sufficient potential for possible mineral resources that it should be examined in detail before other work is undertaken in the quadrangle.

RECOMMENDATIONS

Early examination of the unit of pyroxenite, peridotite, and serpentinite in the northern part of the quadrangle should be undertaken. An airborne magnetometer survey of the body and of adjoining sand-covered areas should be made to determine its shape and to define any volcanic pipes that might be associated with it. The same survey should include radiometric traverses to determine whether radioactive elements (mainly thorium) are associated with the lanthanum and zirconium. Surface examination and geologic maps of the outcrops should be made for megascopic chromium, asbestos, dunite, and magnesite. A detailed geochemical survey using rock chips as sample media should be done if the airborne work and bedrock geology give favorable results. Drilling through the sand to geophysical anomalies might be required. If it is, then the water for drilling will become a problem, because Bi'r Ghamrah in the south and Bi'r al Badriyah in the north probably could not supply it.

At a much lower priority, surface geological and geochemical work could be done on possible gold, silver, lead, and/or molybdenum at four localities in the quadrangle as part of the exploration of the Umm Amal district in the Jabal al Hawshah quadrangle (Whitlow, 1969).

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