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RECONNAISSANCE GEOLOGY OF THE PRECAMBRIAN ROCKS IN THE AYN QUNAY QUADRANGLE, KINGDOM OF SAUDI ARABIA

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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian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

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ABSTRACT

The Ayn Qunay quadrangle covers an area of 2833 sq km in central Saudi Arabia. Only the western edge of the quadrangle is underlain by Precambrian rocks, which were the subject of this investigation. Toward the east the Precambrian rocks are unconformably overlain by Permian and younger sedimentary rocks.

The Permian rocks at the west edge of the Ayn Qunay quadrangle consist mainly of a granitic intrusive complex of batholithic dimensions. Parts of the eastern edge of the granitic complex are exposed just west of the overlying Khuff Formation of Permian age, where biotite-hornblende granite of the complex intrudes chlorite-sericite schist of the Precambrian Bi'r Khountina Group. The biotite-hornblende granite of the comple also intrudes plutons of diorite, gabbro, and pyroxenite and is itself intruded by granite porphyry, thereby indicating some difference in age between the granitic rocks in the complex. A sequence of metamorphosed volcanic rocks composed mainly of andesite, rhyolite, and kindred rocks, and called the Halaban Group, is older than the Bi'r Khountina Group.

Relations between the Halaban and a gray hornblende-biotite granite gneiss are uncertain, but the gneiss may be older than the Halaban. The few observed contacts disclosed parallel foliation in the two units, but the foliation may have been imposed after the Halaban was deposited on the granite gneiss.

Two major left-lateral faults extend west-northwest across the Precambrian rocks but are not in the Permian rocks. These faults are parallel to the Najd fault zone found farther south. Seemingly they correlate in time with early movements on the Najd fault zone, but not with the latest.

Saprolitic material of variable thickness is present on the upper surface of the Precambrian rocks beneath the Khuff Formation at many places. Where the Khuff Formation has been removed by erosion, the saprolite is also stripped away. The weathering probably took place in pre-Khuff time.

No ancient mines or prospects were seen in the Precambrian rocks; however, a notable positive anomaly for tungsten in concentrates is associated with a small prominence of granite porphyry 35 km southwest of Ayn Qunay. Further investigation of the porphyry should be undertaken to learn the amount of scheelite at this locality.

INTRODUCTION

The investigation of the Precambrian rocks in the Ayn Qunay quadrangle reported here was part of a broader investigation undertaken through 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 in Saudi Arabia.

Location

The Ayn Qunay quadrangle covers an area of 2833 sq km in central Saudi Arabia (fig. 1) at the eastern edge of the Arabian Shield. Only the extreme western part of the quadrangle is occupied by the Precambrian rocks of the Shield. To the east the Precambrian rocks are overlain by Permian and younger sedimentary rocks. The western outcrop of the Permian limestone forms a conspicuous cliff that extends north-northwest the length of the quadrangle and reaches heights as great as 100 m above the mantle of sand on the Precambrian rocks.

A main road crosses the eastern part of the quadrangle from north to south, and in the western part of the area the sand covered granitic surfaces can be readily traversed by cars or trucks.

Previous investigations and present work

The area covered by the Ayn Qunay quadrangle was mapped geologically at 1:500,000 scale by Bramkamp and others (1956). The present investigation of the Precambrian rocks consisted of a brief reconnaissance on March 25 and on April 4, 1964. Subsequently, the Precambrian area in the Ayn Qunay quadrangle was included in a detailed survey of the Idsas-Wadi Jifr region by G. Eijkelboom (1966) of the Bureau de Recherches Geologiques et Minieres.

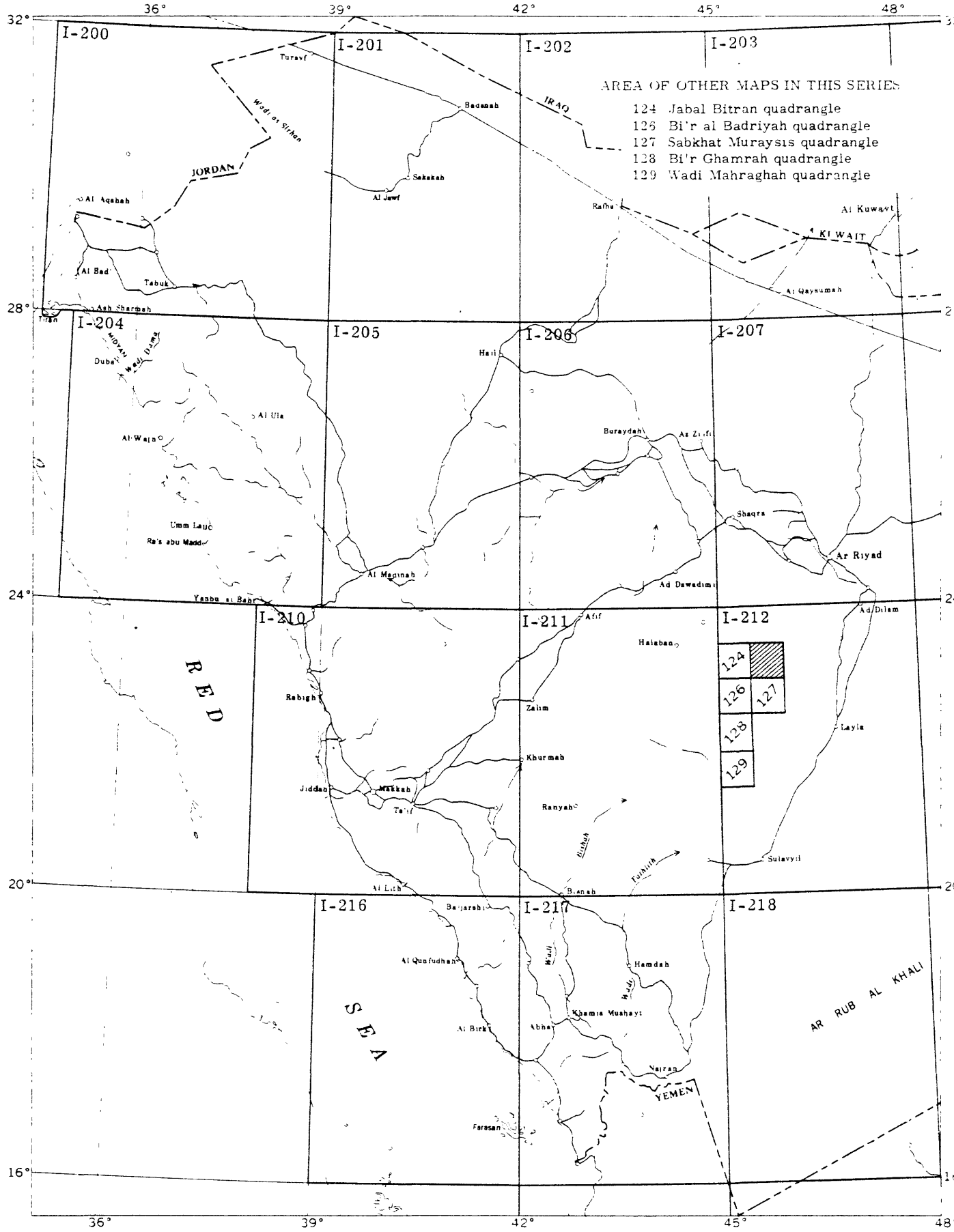

Figure 1. - Index map showing the location of the Ayn Qunay quadrangle

Acknowledgment

The writers wish to express their appreciation for the assistance received from officials of the Ministry of Petroleum and Mineral Resources and of the Directorate General of Mineral Resources, Kingdom of Saudi Arabia.

Artifacts

At the southeastern end of a series of low exposures of biotite-hornblende granite ribbed with west-northwest striking rhyolite dikes about 29 km west-southwest of Ayn Qunay (plate 1) a number of ancient artifacts made of rhyolite are scattered with flat rhyolite ventifacts (dreikanter). The ancient artifacts are typologically Paleolithic handaxes of the large heavy type assigned elsewhere to the Acheulean period. At first glance some of the artifacts can readily be mistaken for wind-sculpted rock fragments, because the exposed upper surfaces of the artifacts have been smoothed and polished by wind-borne sand. However, the under sides of these Acheulean-type hand-axes, when freed of a secondary coating of calcium carbonate and cemented grains of sand, show the conspicuous conchoidal depressions indicative of manufacture by man. These handaxes are of the same general size and shape as those found near the Khuff Formation in the Sabkhat Muraysis quadrangle (Overstreet and others, 1972). The site in the Ayn Qunay quadrangle is also associated with a series of exposures of rhyolite suitable for flaking and is situated near the cliffs of the Khuff Formation. Possibly more important evidence of ancient man is nearby.

GEOLOGY

Most of the details of the distribution of the Precambrian rocks shown on the geologic map (plate 1) are interpreted from aerial photographs. Relations of the post-Precambrian sedimentary rocks are adapted from Bramkamp and others (1956).

Rock types and stratigraphic succession

The west of the Ayn Qunay quadrangle is underlain dominantly by Precambrian granitic rocks which form an intrusive complex of batholithic dimensions in the adjoining quadrangle to the west (Kahr, 1962; Eijkelboom, 1966; Kahr and others, 1972), and that extends far to the north (Bramkamp and others, 1956). The oldest rock of the complex is hornblende-biotite granite gneiss, which is older than the Precambrian Halaban Group and Bi'r Khountina Group. These rocks are intruded by small masses of diorite, gabbro, and pyroxenite with sharp chilled contacts. Younger biotite-hornblende granite of the complex intrudes the mafic plutons; thus, it is probable that the components of the granitic complex were emplaced intermittently over a long period of time, or were emplaced independently and were widely separated in time.

A pre-Permian weathering and erosion surface locally retaining saprolitic material marks a great unconformity. Permian and younger sedimentary rocks overlying the Precambrian rocks dip gently east above this erosion surface.

Hornblende-biotite granite gneiss

Gray, nonlayered, hornblende-biotite granite gneiss, biotite granite gneiss, and gneissic granodiorite of variable composition and texture make up the unit called hornblende-biotite granite gneiss, the oldest unit in the quadrangle.

The granite gneiss is in contact with amphibolite of the Halaban Group in the extreme southwestern part of the quadrangle, but the relations of the contact are uncertain. A strong foliation in the gneiss is parallel to foliation in the amphibolite, and both rocks are intruded by massive gabbro. It is not certain whether the Halaban rests unconformably on the gneiss or is intruded by it. The Halaban farther south rests unconformably on the gneiss.

The granite gneiss is intruded by diorite, gabbro, and pyroxenite bodies which have chilled margins. These mafic intrusives resemble rocks found to the southwest in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) where they intrude the Bi'r Khountina Group. Both the gneiss and the mafic plutons are intruded by massive to flow-banded biotite-hornblende granite which also intrudes metamorphosed sedimentary rocks of the Bi'r Khountina Group, but is itself intruded by rhyolite and andesite.

The contacts between the granite gneiss and the biotite-hornblende granite as shown on plate 1 are highly generalized. Detailed mapping is needed to accurately depict the outlines of these rocks.

Halaban Group

The Halaban Group is the oldest layered sequence of rocks in the Ayn Qunay quadrangle. The name of the group was given in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) to part of the stratigraphic unit called Halaban Formation by Jackson and associates (1963). The group is present only in the extreme southwestern part of the Ayn Qunay quadrangle, where it is represented by an amphibolite unit called the Umm Mushraha Formation and by a unit of schistose rhyolite porphyry and associated rocks called the Wadi al Jifr Formation.

Umm Mushraha Formation.-- The Umm Mushraha Formation, named in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) in the Ayn Qunay quadrangle consists of dark-green to nearly black, layered to massive amphibolite formed by the metamorphism of layered andesitic rocks and massive diorite, gabbro, and pyroxenite. The amphibolite is intruded by dikes of metarhyolite which are thought to be feeders for the Wadi al Jifr Formation that overlies the amphibolite.

Wadi al Jifr Formation.-- Wadi al Jifr Formation, named in the Sabkhat Muraysis quadrangle (Overstreet, Whitlow, and Ankary, 1972), consists of light-gray to brown and reddish-brown schistose rhyolite porphyry, sericite schist, fine-grained biotite-muscovite schist, and quartzite. These rocks were formed by the metamorphism of rhyolite flows, rhyolite porphyry, and interbedded pelitic sediment and sandstone

Relict blue quartz phenocrysts of the rhyolite porphyry are preserved as porphyroclasts in the schistose rhyolite porphyry and sericite schist.

Bi'r Khountina Group

The term Bi'r Khountina Group was introduced in the Bi'r Ghamrah quadrangle (Overstreet and Whitlow, 1972a) for a metamorphosed sequence of layered Precambrian rocks which are represented in the Ayn Qunay quadrangle by small areas of chlorite-sericite schist and chlorite schist called the Abu Sawarir Formation.

Abu Sawarir Formation.-- A small area of fine-grained chlorite-sericite schist and chlorite schist is exposed just west of the west edge of the Khuff Formation in the west central part of the quadrangle. The schist is foliated and cleaved with a locally strong north-striking and north-plunging lineation consisting of crenulations and the intersections of foliation and cleavage. These schists are thought to have formed by the metamorphism of interlayered shale, andesite, tuffaceous shale, and calcareous shale of the Bi'r Khountina Group where these rocks are intruded by biotite-hornblende granite. These schists are intruded by unmetamorphosed dikes of diabase which strike N. 40° E., dikes of andesite porphyry which strike ENE., and dikes of red rhyolite which strike N 35° -45° E and intersect the andesite porphyry. The chlorite-sericite schist in the Ayn Qunay quadrangle resembles that in the Jabal Bitrān quadrangle (Kahr and others, 1972) to which the name Abu Sawarir Formation was given. The name is here extended to these schists in the Ayn Qunay quadrangle.

Diorite, gabbro, pyroxenite, and amphibolite

Circular to kidney-shaped small intrusive complexes of diorite, gabbro, and pyroxenite have been mapped in the Ayn Qunay quadrangle (plate 1). Generally the complexes are grossly layered; and irregular outer layer of fine-grained diorite grades inward to gabbro of variable but generally medium to coarse grain. Locally the outer layers may be gneissic, but generally the gneissic habit is osbcured by exfoliation. At most places the gneissic layering is probably a crude primary flow banding, but in the gabbro and pyroxenite in the extreme southwestern part of the quadrangle the gneissic layering at the outer parts of the bodies may result from shearing. The pyroxenitic parts of the mafic plutons tend to be quite coarse grained.

Serpentine and jasper are present in some of the masses of gabbro and pyroxenite, but dunite, chromite, and asbestos were not seen, nor was any unusual abundance of chromium found in spectrographic analyses of sand from the vicinity of the mafic rocks. No large masses of magnetite were seen in these rocks, but the northern part of the large gabbro body in the northwestern quarter of the quadrangle, in the vicinity of a scheelite-bearing sample, has from 2 to 3 percent of disseminated magnetite. In this area serpentinized pyroxenite and sheared gabbro and diorite adjacent to the pyroxenite, contain irregular zones that have been altered to dark-red jasper and are locally stained dull green. Ghosts of pyroxene crystals up to several

centimeters across are preserved in the jasper. Only background quantities of copper and nickel are associated with the green-stained material. Possibly the jasper formed during pre-Khuff weathering of the upper part of the mafic rocks.

The fine-grained diorite and coarse-grained gabbro of the gabbro and pyroxenite unit are intruded by unmetamorphosed dikes of reddish-brown rhyolite.

Biotite-hornblende granite and granite porphyry

Gray, pink, and red, fine- to coarse-grained, massive to weakly flow banded biotite-hornblende granite underlies a larger area than any of the Precambrian rocks in the Ayn Qunay quadrangle. Locally the rock is pink felsite, and much of it in the central part of the quadrangle is granodioritic. It forms part of the unit called granite gneiss by Bramkamp and others (1956), but is here separated from that unit; on the basis of texture, color, composition, primary flow banding, associated dikes, and intrusive relations it is correlated with the biotite-hornblende granite of the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972). Boundaries between the biotite-hornblende granite and the older granite gneiss shown on the geologic map (plate 1) are only approximate. The actual contacts are thought to be complex.

Locally the biotite-hornblende granite is mylonitized and displays a strong lineation marked by spindle-shaped aggregates of quartz drawn down-dip in the plane of cataclastic foliation. These

mylonite zones strike about N. 45° E. and dip about 60° NW. This strike is parallel to systems of closely spaced fractures in the Khuff Formation. Thus, either movement on the mylonite zones was renewed in post-Khuff time, or the mylonite in the granite actually is post-Permian in age.

A single small prominence of pink granite porphyry is mapped in the southwestern part of the Ayn Qunay quadrangle, where the porphyry is associated with a prominent tungsten anomaly. The granite porphyry intrudes the biotite-hornblende granite, and thus is younger than the granite. Whether it is a late phase of the biotite-hornblende granite or is related to even younger granitic rocks designated "granite" in the Southern Tuwayq quadrangle (Bramkamp and others, 1956) and "peralkalic granite" farther west (Jackson and others, 1963) is uncertain. It is here correlated with the unit of granite porphyry mapped in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972), but it may possibly be related to the peralkalic granite of Jackson and others (1963).

The granite porphyry is fractured, and the fractures are filled with veins of pyritiferous milky quartz, veins and masses of white to gray quartz with clusters and rosettes of black tourmaline, and masses of calcite. Many limonite pseudomorphs after pyrite are in the fan detritus around the prominence, as is scheelite. Traces of malachite are present.

Andesite and rhyolite dikes

Swarms of westerly striking dikes of unmetamorphosed andesite and unmetamorphosed rhyolite intrude the hornblende-biotite granite gneiss and biotite-hornblende granite in the southwestern, west-central, and northwestern parts of the quadrangle. In all megascopic characteristics these dikes resemble swarms in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) and the Wadi Mahraghah quadrangle (Overstreet and Whitlow, 1972) where this rhyolite and andesite was also found as detrital boulders in the conglomerate at the base of the Murdama Group which unconformably overlies the Bi'r Khountina Group. The Murdama is absent in the Ayn Qunay quadrangle. It is inferred that the unmetamorphosed andesite and rhyolite dikes intrusive into the granites are equivalent in age to the very similar dikes exposed to the southwest, and that these dikes in the Ayn Qunay quadrangle are late Bi'r Khountina in age.

The andesite dikes include andesite, andesite porphyry, microdiorite, diabase, and possible lamprophyre. Andesite porphyry and microdiorite seem to be the most common types. Fine-grained, chilled margins are typical. Thin dikes tend to be fine grained throughout, but dikes more than 5 or 6 m thick generally have coarser-grained cores. A few have diabasic texture.

Possibly the andesite dikes commenced to form a little earlier than the rhyolite dikes, because more andesite dikes are intruded

by rhyolite than the reverse. Some overlap in the time of emplacement took place, because andesite dikes also intrude rhyolite dikes. Many rhyolite dikes are not intersected by andesite dikes, thus, the last stages of intrusion may have been essentially silicic.

The rhyolite dike swarms consist of red to very dark red and brown rhyolite, rhyolite porphyry, felsite, granite porphyry, and microgranite. Most of the dikes have fine-grained, chilled margins. Among the thicker dikes the grain size coarsens toward the center, and quite a variety of textures and rock types result. Some of the rhyolite dikes have red, fine-grained walls and gray, fine-grained granitic cores. Phenocrysts of quartz, feldspar, biotite, and brown garnet are variably present. Dikes carrying phenocrysts of garnet are likely to be very fine grained. Finely disseminated pyrite is present in both the rhyolitic and andesitic dikes.

Isotopic ages of selected rocks

Potassium 40/argon isotopic ages have been determined recently for two specimens of granitic rock (Glen F. Brown, written commun., March 18, 1970), one from the southwestern part of the Ayn Qunay quadrangle and the other from the southeastern part of the Jabal Bitran quadrangle. An isotopic age of 610± 12 m.y. was found for biotite and 621±12 m.y. for hornblende from granite gneiss (specimen 420) collected by Brown just south of Wadi Minjur in the southwestern corner of the Ayn Qunay quadrangle (plate 1). An isotopic age of 581±12 m.y. was found for biotite from white granite (specimen 419) collected by Brown

in the southeastern corner of the Jabal Bitran quadrangle (Kahr and others, 1972, plate 1). Ages were determined by Isotopics, Inc., U.S.A. The white granite, certainly, and the granite gneiss, possibly, may be phases of the unit shown on the geologic maps of the Ayn Qunay and Jabal Bitran quadrangles as late Precambrian biotite-hornblende granite, but crop out in areas too small to be mapped as such.

Post-Precambrian sedimentary rocks

Six units of post-Precambrian sedimentary rocks are shown on the geologic map (see map explanation, plate 1).

Structure

Little can be seen of the structure of the Precambrian rocks. The older Precambrian formations appear to have been folded along northerly axes prior to the intrusion of the biotite-hornblende granite which cuts across the earlier structures despite a regional tendency to occupy the old northern folds.

Following the emplacement of the andesite and rhyolite dikes in the biotite-hornblende granite, and prior to the deposition of the Permian Khuff Formation, the Precambrian rocks were broken by at least two prominent west-northwest striking, left-lateral faults. Western extensions of the more southerly of these faults intersect rocks of the Murdama Group in the Jabal Bītran quadrangle (Kahr and others, 1972); thus, the faults are younger than the Precambrian Murdama Group and older than Permian. To the southwest in the Bi'r Ghamrah quadrangle (Overstreet and Whitlow, 1972) the Najd fault zone, parallel to the

strike of faults, causes cataclastic deformation in the Murdama Group and the Shammar Rhyolite(?) of early Paleozoic(?) age. Some rhyolite of the Shammar(?) actually emerged through these west-northwest striking faults in the Najd zone and was brecciated by later movement on the Najd fault. Beryllium is commonly present in minor amounts in that part of the Najd fault zone associated with Shammar Rhyolite(?). Neither traces of beryllium nor flows of Shammar Rhyolite(?) are associated with the west-northwest striking faults in the Ayn Qunay quadrangle. It is here inferred that the west-northwest faults in the Ayn Qunay are part of the same system as the Najd fault zone, but that movement on the faults ceased in the north before the onset of Shammar(?) volcanism. Thus, in the Ayn Qunay area the faults are younger than Murdama and older than Shammar(?). They probably were formed at the time movement began along the Najd fault zone, but they did not remain active as long as more southerly faults of the zone.

The Precambrian rocks are warped downward to the east and are unconformably overlain by the Permian Khuff limestone. Minor, northeast-striking mylonite zones in the Precambrian rocks are reflected as systems of close-spaced joints in the limestone. Possibly renewed movement along this direction in post-Permian time accounts for the fractures in the limestone, because the fractured limestone is less intensely deformed than the mylonitized granite.

Weathering

The Precambrian rocks beneath the Khuff Formation display relict weathering surfaces, but in most areas where the Khuff is eroded from the Precambrian the relict surface has also been eroded. Rhyolite porphyry locally is weathered to purple saprolite at least 4 m thick. Similar weathering of the rhyolite was seen as far north as Al Quway'-iyah in the Northern Tuwayq quadrangle (Bramkamp and Ramirez, 1958). Jasper in the weathered parts of gabbro and pyroxenite probably formed as a product of weathering prior to the deposition of the Khuff. Sheared diorite has a dark-red weathered zone under the Khuff Formation.

These weathered zones rarely extend more than 6 to 8 m into the Precambrian rocks. The weathering is thought by us to have taken place under subaerial conditions prior to the deposition of the Khuff.

GEOLOGIC RELATIONS OF SELECTED ELEMENTS

Ten samples of wadi sand were taken from the area of Precambrian rocks in the Ayn Qunay quadrangle. Analyses of the samples were made in the Jiddah Laboratory of the Directorate General of Mineral Resources to determine in reconnaissance fashion the abundances of selected elements.

Procedure

Samples of wadi 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 taken. The residue from sieving was panned to recover a concentrate

of heavy minerals, and magnetite was removed from the concentrate. At each locality, therefore, three samples were obtained: -30+80-mesh wadi sand; concentrate; and detrital magnetite.

Wet chemical analyses were made by C. E. Thompson of the U.S. Geological Survey and L. Al Dugaither for copper, zinc, and molybdenum in the sand and magnetite, and for these elements plus tungsten in the concentrate. The sand was also analyzed by C. E. Thompson and Kamal Shahwan by semiquantitative procedures; 27 elements were determined by using a modified U.S. Geological Survey procedure (Theobald and Thompson, 1968).

Results

Histograms (fig. 2 and 3) give the results of these analyses, and selected data are shown on the geologic map (plate 1). A comparison of the results of these analyses with the results of analyses of 321 similar triplets of samples from the Precambrian area of the southern Tuwayq quadrangle disclosed only background amounts of copper, zinc, and molybdenum in wadi sand and magnetite. Chemical analysis of the concentrates gave a strong positive anomaly for tungsten and one threshold 1/ amount for zinc, By spectrographic procedure no large amount of metal was found in any of the samples of wadi sand, and no sample had threshold or anomalous values for two or more elements.

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

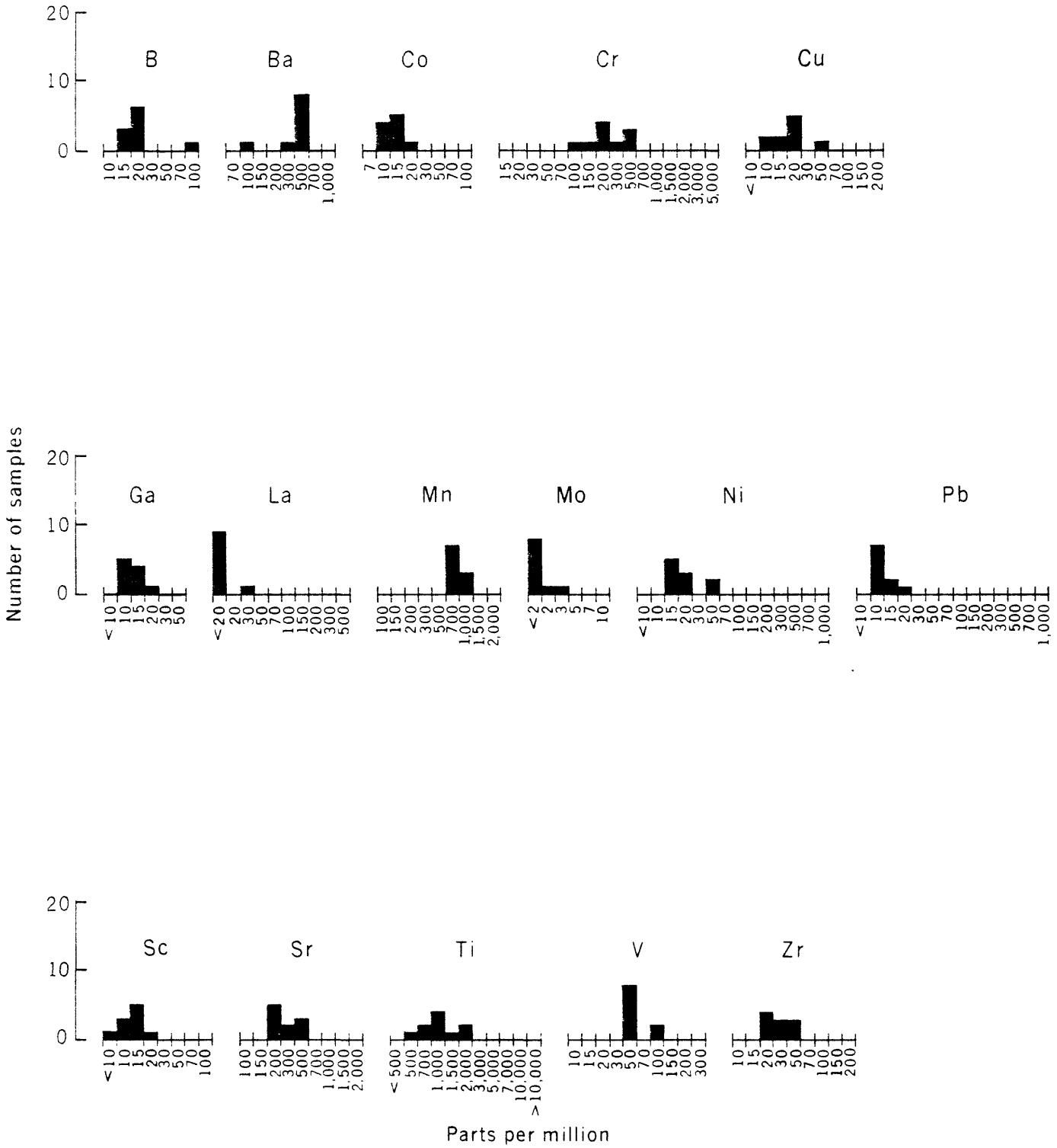

Figure 2. Histograms of 10 spectrographic analyses of wadi sand, Ayn Qunay quadrangle

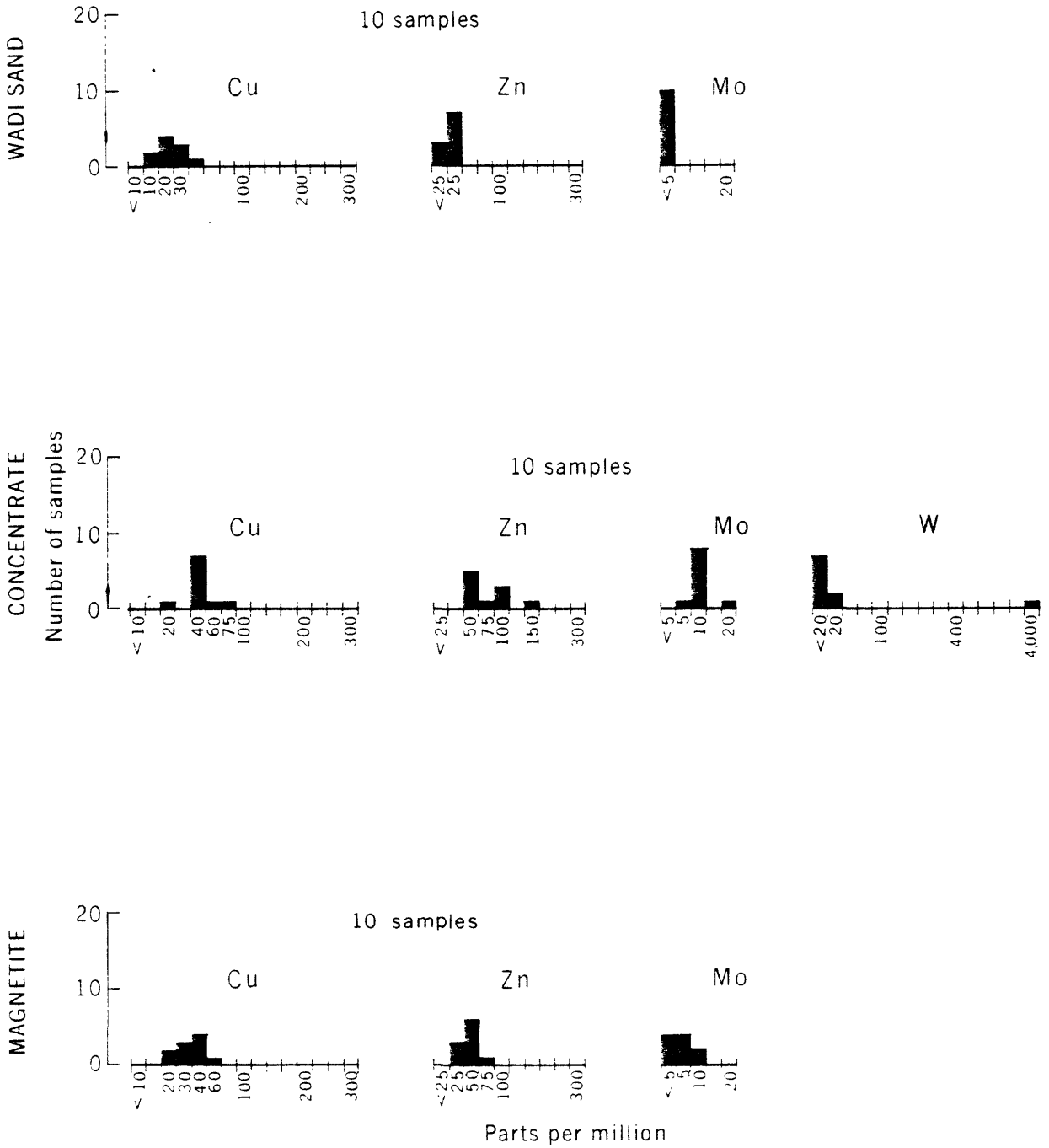

Figure 3. Histograms of wet chemical analyses of magnetite, concentrate, and wadi sand, Ayn Qunay quadrangle

Nine of the 27 elements looked for were below the limit of detection in all samples. These elements, and their limits of detection are: silver, 1 ppm; beryllium, 2 ppm; bismith, 20 ppm; cadmium, 50 ppm; niobium, 50 ppm; antimony, 200 ppm; tin, 10 ppm; tungsten, 50 ppm; and zinc, 100 ppm. By spectrographic procedures three samples of wadi sand had low, single-element threshold values for, respectively, boron, lanthanum, and molybdenum:

Element	Threshold value in southern Tuwayq quadrangle, ppm	Number of samples from Ayn Qunay quadrangle at or above threshold
Boron	50	1 (a)
Lanthanum	20	1 (a)
Molybdenum	3	1 (b)

(a) Above threshold

(b) At threshold.

The strong positive anomaly for tungsten, 4000 ppm, is in a concentrate from wadi sand taken at the base on the east side of the small prominence of granite porphyry about 35 km southwest of Ayn Qunay (plate 1). In the whole area of Precambrian rocks in the southern Tuwayq quadrangle (Bramkamp and others, 1956) the threshold value for tungsten in concentrates is 60 ppm, and of the more than 300 concentrates taken by us in that area the next closest value for

tungsten is 400 ppm in a concentrate from the Jabal Bitrān quadrangle (Kahr and others, 1972). The quantity of tungsten detected chemically is confirmed by the presence of abundant scheelite in the concentrate, as shown under ultraviolet light. However, the ordinary sand from the area has less than the limit of detection of tungsten by spectrographic means. Although tourmaline is present in quartz veins in the porphyry, boron was not detected in the sand. All three sample media from this locality contain only background quantities of copper, lead, and zinc, confirming the observed absence of base metal sulfides. However, sparse malachite stains are present in the granite porphyry.

The threshold value of 150 ppm zinc in concentrates was found in material derived from outcrops of strongly crenulated chlorite schist of the Abu Sawarir Formation intruded by a diabase dike that strikes N. 40° E. The outcrops are just west of the Khuff Formation at a point 13 km northeast of the tungsten-bearing prominence of granite porphyry. No evidence of zinc mineralization was seen at this locality in either the Precambrian rocks or the Khuff Formation.

A threshold value of 3 ppm molybdenum was found by spectrographic analysis of wadi sand derived from biotite-hornblende granite closely intruded by rhyolite dikes at the locality where ancient stone artifacts were made about 6 km northeast of the scheelite-bearing prominence of granite porphyry. No megascopic evidence of mineralization was found.

Sand with the threshold value of 100 ppm boron, but lacking other threshold values, was taken from a small wadi draining weathered diorite, gabbro, and pyroxenite exposed just west of the Khuff Formation at a point 29 km N. 65° W. from Ayn Qunay. Just to the west another sample of sand from gabbro and pyroxenite had the low threshold value of 30 ppm lanthanum.

It is thought that the threshold values for boron, lanthanum, and molybdenum in the three samples of sand and the threshold value for zinc in concentrate probably represent normal laboratory variation in analysis (Theobald and Thompson, 1968).

MINERAL DEPOSITS

Direct evidence of mineral deposits, such as ancient mines, prospects, or mineralized zones, was not found in the area of Precambrian rocks in the Ayn Qunay quadrangle. Several large barren quartz veins were observed, and scheelite and magnetite were found, but only the scheelite appears to deserve further investigation.

Quartz veins

Five large milky quartz veins form conspicuous white hills in the extreme southwestern corner of the Ayn Qunay quadrangle, and small stringers of quartz with black tourmaline are associated with the scheelite in the small isolated body of granite porphyry. Tourmaline and scheelite are absent from the five large masses of white quartz, but a trace of magnetite is present in these veins. They appear to be

devoid of base and precious metals. Their position in the geologic column in the Ayn Qunay quadrangle is uncertain, but they may be late Precambrian in age.

Scheelite

The most important mineralization seen in the Ayn Qunay quadrangle is the scheelite associated with the prominence of granite porphyry in the southwestern part of the quadrangle (plate 1). Scheelite is present in both the porphyry and the tourmaline-bearing quartz veins, but most of it is in fractured parts of the porphyry. Inasmuch as the tungsten anomaly around this prominence is associated with the concentrates but not also with the ordinary sand derived from the prophyry, the tenor in scheelite may be low.

Scheelite is also more than ordinarily abundant in concentrates from the northern part of the mass of gabbro and pyroxenite in the northwestern quarter of the quadrangle, but the amount of tungsten in the samples was only 20 ppm or less. Probably no enrichment in tungsten is present at that locality.

In the extreme southwestern corner of the Ayn Qunay quadrangle the locality on the east side of the mass of diorite, gabbro, and pyroxenite was the source of a concentrate with a trace of powellite, but it lacked scheelite. The other scheelite-bearing concentrates shown on plate 1 did not contain powellite.

Magnetite

Two to three percent of disseminated magnetite is present in gabbro and pyroxenite about 0.6 km northeast of the scheelite-bearing locality described above. The magnetite is a normal accessory mineral in these mafic rocks. No large masses of magnetite, like those exposed at Jabal Idsas in the quadrangle to the west (Kahr and others, 1972), crop out at this locality. The disseminated magnetite in the Ayn Qunay quadrangle is in rocks of the Bi'r Khountina Group; that at Jabal Idsas is associated with the older rocks of the Halaban Group.

RECOMMENDATIONS

A detailed survey of the small prominence of granite porphyry in the southwestern quarter of the quadrangle should be made for tungsten, molybdenum, and copper.

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