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 Also on open file in that office is a large amount of material, in the form of unpublished manuscripts, maps, field notes, drill logs, annotated aerial photographs, etc., that has resulted from other previous geologic work by Saudi Arabian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

The Jabal Bitrān quadrangle covers an area of 2833 sq km in the eastern part of the Precambrian Shield in Saudi Arabia. The rocks in the quadrangle are divided geographically along arcuate north-trending lines into an eastern area of granite intruded by a swarm of dikes of rhyolite and andesite, and a western area of dominantly pelitic chlorite-sericite schist, separated by the narrow central complex of the Idsas Range. This complex is composed of pyroclastic rocks, lava, conglomerate, marble, and plutonic mafic rocks that have been intricately modified by episodes of metamorphism, igneous intrusion, and faulting. The Idsas Range contains ancient gold and copper mines, and deposits of magnetite, copper, asbestos, and chromite.

The rocks in the Jabal Bitrān quadrangle are here interpreted to consist of three major sedimentary and volcanic groups, the lowermost of which was deposited unconformably on hornblende-biotite granite gneiss, and all of which are intruded by granite dikes and plutons. From oldest to youngest the layered rocks are called Halaban Group, Bi'r Khountina Group, and Murdama Group. A biotite-hornblende granite is older than uppermost Bi'r Khountina, and peralkalic granite is younger than Murdama.

The layered rocks of these groups are generally metamorphosed to the greenschist facies. The metamorphic grade rises abruptly at the Idsas Range to the albite-epidote-amphibolite facies and lower subfacies of the amphibolite facies in parts of the Halaban Group; some skarn east of the range may be in the upper part of the amphibolite facies. Characteristically, the Halaban Group has the highest grade and the greatest range in metamorphic grade, and the Murdama Group has the lowest but most uniformly developed metamorphic grade. The metamorphism of the rocks was caused by three successive pulses of regional dynamothermal metamorphism plus contact metamorphism around the younger bodies of plutonic igneous rocks.

Four major structural elements of the quadrangle are reflected in the geography and geologic units. These are a mantled gneiss dome on the east separated from a north-plunging synclinorium in rocks of

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the Murdama and Bi'r Khountina Groups on the west by a narrow dejective zone of the Halaban and lower Bi'r Khountina. The dejective zone is much modified by imbricate overthrusts and accompanying tear faults. These major faults have pushed elements of the Halaban and Bi'r Khountina westward over Bi'r Khountina and Murdama, with the result that very complex fault patterns have evolved.

Open geochemical reconnaissance of the area disclosed one positive anomaly for nickel and 40 threshold indications of several elements, principally nickel, chromium, copper, and tungsten. Heavy-mineral and radiometric reconnaissance showed 18 areas containing scheelite and/or powellite and four areas of anomalous radioactivity. Most of these features are in the dejective zone, as are five of the nine ancient workings, the massive and disseminated magnetite, most of the secondary copper minerals, and the traces of asbestos, magnesite, and chromite known in the quadrangle. The mantled gneiss dome and a complex of gabbro and amphibolite on its southwestern flank are the next most mineralized areas. Scant evidence of mineralization is present in the Murdama Group west of the dejective zone.

Magnetite deposits at Jabal Idsas have the greatest potential of the mineral deposits in the Jabal Bitrān quadrangle. Further study of gold at Fawara and Selib mines is recommended, as is investigation of a positive nickel anomaly that shows threshold cobalt and above background radioactivity. The garnetiferous skarn in the east-central part of the quadrangle should be examined for composition and abrasive character of the garnet and for the remote possibility of tungsten in scheelite and beryllium in helvite.

INTRODUCTION

Location and accessibility

The Jabal Bitrān quadrangle covers an area of 2833 sq km in the central part of the Kingdom of Saudi Arabia (fig. 1). The area of the quadrangle is nearly equally divided from north to south by the high ridge of the Idsas Range; Jabal Bitrān forms a conspicuous red peak near the north edge of the mapped area. The west side of the Idsas Range is a sharp escarpment which drops abruptly for several 100 meters to the wide valley of Wadi Isradeeyah. The east side of the range has a more gradual slope to the broad plains of Wadi al Jifr. Jabal Bitrān is about 500 m higher than the wadi floor to the east, which is about 700 m in altitude. To the south the main peaks of the Idsas Range decrease in height, so that near the southern edge of the mapped area the distinctive gabbroic peaks are about 300 m above the wadi floor.

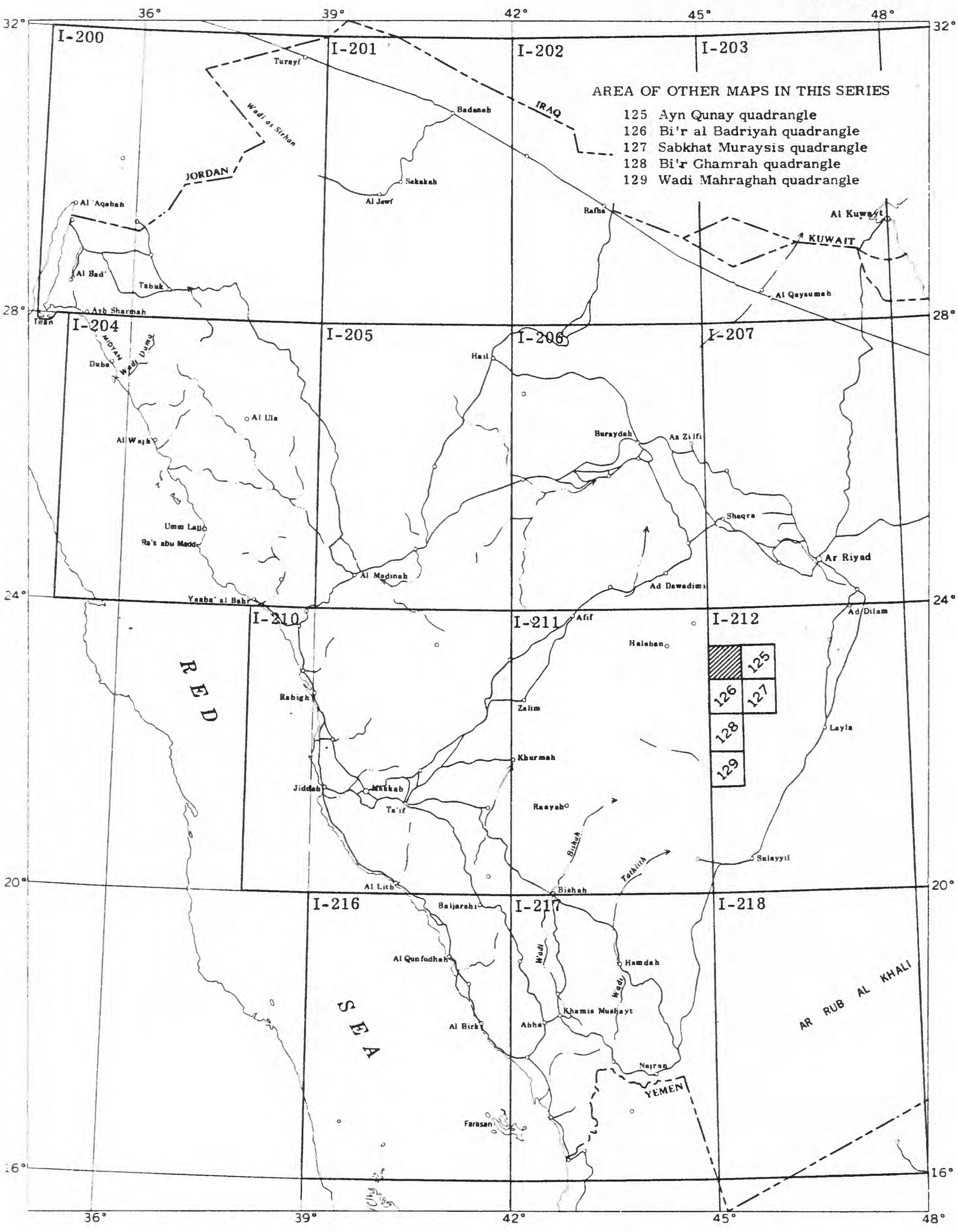

Figure 1. - Index map showing the location of the Jabal Bitran quadrangle

Major unpaved roads cross the area from east to west through passes in the Idsas Range in the vicinity of Jabal Idsas. On the west the roads join with one that extends northward across the quadrangle and leads to the settlements at Al Quway'iyah about 60 km north of Jabal Bitrān. The roads on the east side of the range reach northeastward about 40 km to Ar Rayn, northeast of the quadrangle. Both Al Quway'iyah and Ar Rayn are more plentifully supplied with water than the Jabal Bitrān area, where the wells are few and small. Access southeastward along the west side of Wadi al Jifr leads to Ayn al Minjūr, about 80 km from Jabal Bitrān, where water can also be had.

Other investigations

The Jabal Bitrān quadrangle is a small part of the west edge of the area of the 1:500,000-scale geologic map of the southern Tuwayq are (Bramkamp and others, 1956). Several ancient mines in the Jabal Bitrar area were examined in the late 1950's by geologists of the Directorate General of Mineral Resources, and open-file reports of these investigations are in the Library of the Directorate in Jiddah (Schaffner, 1955; 1956a; MacLean, 1958a; Directorate General of Mineral Resources, 1959). The magnetite deposits at Jabal Idsas have been examined by several investigators (Schaffner, 1956b; Short, 1957; MacLean, 1958b; Agocs, 1961; Kahr, 1962; Herness and Kahr, 1963; and Keller, 1964). An airborne magnetometer-scintillometer surveys (Hunting Survey Corp., Ltd., 1962) of the Idsas Range was made in 1962, and low-altitude color aerial photographs (Aerocarto, 1964) were made of the Idsas magnetite deposits and of the Fawara and Selib ancient mines as part of the Directorate's exploration program.

Since 1961, several diamond drilling programs have been initiated by the Directorate at the Jabal Idsas magnetite deposits and continued intermittently until at least the time of the geophysical surveys by Davis, Allen, and Akhrass (1965).

Brief summaries of some of the minerals in the area of the Jabal Bitrān quadrangle were given in 1965 in the first bulletin to be published on the mineral resources of the Kingdom of Saudi Arabia (Saudi Arabia Ministry of Petroleum and Mineral Resources, 1965).

Subsequent to the completion of the field work described below, the area of the Jabal Bitrān quadrangle was included in a survey by geologists of the Bureau de Recherches Géologiques et Minières, and a thorough report on the mineral resources and geology was issued in 1966 (Eijkelboom, 1966).

A brief summary of geophysical activites by the United States Geological Survey at Jabal Idsas was made by Davis and Allen (1967).

Present work

This report is one of the products of a broad program of mineral exploration being conducted cooperatively by the Directorate General of Mineral Resources and the U.S. Geological Survey for the Ministry of Petroleum and Mineral Resources as part of an agreement made in September 1963 between the Government of Saudi Arabia and the United States Geological Survey. The text and map (plate 1) are the combined results of investigations of the Idsas Range made by V. P. Kahr during October-November 1959, August 1961, June-July 1963, and March-April 1964, and of geologic and geochemical reconnaissance by W. C. Overstreet, J. W. Whitlow, and A. O. Ankary in March-April 1964 (Overstreet, Whitlow, and Ankary, 1970). Kahr's interpretation of the geologic relations and mineral deposits of the Idsas Range were formulated in a report and maps in 1962 (Kahr, 1962). The present report and illustrations were prepared in October-November 1967 by W. C. Overstreet, based on the stratigraphic succession defined farther south (Overstreet and Whitlow, 1972a to 1972b; Overstreet, Whitlow, Kahr, and Ankary, 1972), and Kahr's detailed studies of the Idsas Range. This report differs somewhat from Kahr's interpretation of 1962, to which the reader is referred for fuller detail of specific geologic features.

Acknowledgements

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GEOLOGY

The entire area of the Jabal Bitrān quadrangle is underlain by rocks of Precambrian age, with the possible exception of the youngest granite. Isotopic data as yet incompletely evaluated suggest that some of the granite may have formed or been remobilized in early Paleozoic time.

Regionally the quadrangle is divided along arcuate north-trending lines into three general types of rocks. The easternmost rocks consist of granites cut by swarms of andesite, diabase, and rhyolite dikes. These are separated from pelitic sedimentary rocks and volcanic flows metamorphosed to the greenschist facies in the west, by a narrow central complex of pyroclastic material, lava flows, conglomerate, marble, and plutonic mafic rocks whose relationships are intricately modified by metamorphism, intrusion, and faulting. This central complex makes up the Idsas Range, named after the mountain, Jabal Idsas, which is near the center of the quadrangle. The important magnetite deposit and the largest ancient gold mines in the quadrangle are in or near the Idsas Range. Indications of copper, chromite, asbestos, and scheelite have also been found in the range, but no minable deposit is known. Several small ancient workings are near the range in the northwestern and southeastern parts of the quadrangle.

The complex geology of the Idsas Range has received the most study because of the associated ore deposits, of which the magnetite is among the more important mineral discoveries thus far made in Saudi Arabia. However, many of the geological relations are still poorly understood.

Rock types and stratigraphic succession

The stratigraphic succession of layered sedimentary and volcanic rocks in the Jabal Bitrān quadrangle seems to follow the sequences recognized farther south (Overstreet, Whitlow, and others, 1972 ; Overstreet and Whitlow, 1972a ; 1972b), and to consist of three main units of Precambrian age. From oldest to youngest these are the Halaban, the Bi'r Khountina, and the Murdama Groups. In the Jabal Bitrān quadrangle, the Halaban consists mainly of metamorphosed andesite; the Bi'r Khountina is principally greenschist-facies conglomerate, marble, albitized andesite, and serpentinite; and the Murdama is graywacke, calcareous graywacke, and sparse marble, and has been metamorphosed to the greenschist facies.

The major criteria used to distinguish these three formations are order of stratigraphic succession with reference to lithologic sequence and unconformable relations. These criteria can be recognized more or less continuously for 180 km south of Jabal Bitrān.

The metamorphic grade of these formations is generally in the greenschist facies. However, the grade rises abruptly eastward in the Idsas Range to the albite-epidote-amphibolite facies and the lower subfacies of the amphibolite facies in parts of the Halaban Group. Certain skarns exposed as inclusions in the granite gneiss in the eastern part of the quadrangle, and doubtfully correlated with the Halaban, reach at least the middle and possibly the upper subfacies of the amphibolite facies. Thus, the youngest Precambrian rocks in the quadrangle, those of the Murdama Group, are characterized by the lowest but most uniformly developed grade of metamorphism. Conversely, the Halaban Group, the oldest Precambrian layered rocks, displays both the highest grade of metamorphism and the greatest range in metamorphic grade of any stratigraphic unit in the quadrangle.

The rise in metamorphic grade of the layered rocks eastward toward the great batholiths of hornblende-biotite granite gneiss and biotite-hornblende granite is evident from examination of the geologic map (plate 1). However, it is far from certain that these granitic rocks are a major genetic factor in the origin and distribution of the metamorphic grades imposed on the stratigraphic units. A complex succession of events of regional scale operating over a long period of time appear to have been necessary to produce the metamorphic rocks in the Jabal Bitrān quadrangle.

Indeed, the hornblende-biotite granite gneiss itself is here interpreted to be widely metamorphosed and to have participated in metamorphic and structural episodes prior to the deposition of the Bi'r Khountina Group. A nearly complete representative suite of metamorphosed Halaban rocks and granite gneiss forms pebbles, cobbles, and boulders in the conglomerate at the base of the Bi'r Khountina Group in the Jabal Bitrān quadrangle. Thus, a pulse of metamorphism affected the area prior to the deposition of the Bi'r Khountina. The hornblende-biotite granite gneiss cannot have been a genetic factor in the metamorphism of either the Bi'r Khountina or the Murdama, because the gneiss and the Halaban were already in place before the Bi'r Khountina and Murdama were deposited.

The biotite-hornblende granite and the swarms of andesite and rhyolite dikes, though younger than the Halaban and lower Bi'r Khountina are clearly older than conglomerate at the base of the Murdama Group, which in the quadrangle to the south has copious detritus from the granite and the dikes (Overstreet, Whitlow, and others, 1972; Overstreet and Whitlow, 1972b). Thus, the biotite-hornblende granite cannot have been a genetic factor in the metamorphism of the Murdama, but it is known to have produced contact metamorphic aureoles in the Bi'r Khountina Group.

Only the small stocks of peralkalic granite are younger than the three principal stratigraphic units. These stocks have demonstratively metamorphosed their wallrocks in narrow aureoles (plate 1), but this late granite can have had little regional effect on the metamorphic grades of the three formations owing to its small total volume.

The common pelitic schists of the Murdama Group in the western part of the quadrangle occupy a northerly plunging synclinorium of regional scale. These schists appear to be normal products of regional dynamothermal metamorphism formed when the Murdama was squeezed and depressed to appropriate geothermal levels in the synclinorium. Inasmuch as the schist is the youngest of the Precambrian layered sequences in this area, it is thought here unlikely to have the great antiquity assigned to it on the Geologic Map of the Arabian Peninsula (U.S. Geological Survey and Arabian American Oil Company, 1963).

At least part of the metamorphism of the Bi'r Khountina and the Halaban Groups also occurred when the Murdama was deformed, but older cycles of both regional dynamothermal metamorphism and contact metamorphism have effected the Bi'r Khountina and the Halaban. Thus, they are polymetamorphic rocks. It is here thought that the Bi'r Khountina, Halaban, and hornblende-biotite granite gneiss were regionally metamorphosed at the time the biotite-hornblende granite was emplaced. Prior to that event, the Halaban is inferred (through the evidence of detritus in conglomerate of the Bi'r Khountina Group) to have undergone metamorphism. This is also thought to have been caused by folding, at which time the hornblende-biotite granite gneiss unit is interpreted to have been folded with the Halaban. The main contacts between the gneiss and the Halaban are conformable. This relation is interpreted to be the result of folding. The hornblende-biotite granite gneiss is inferred to be a basement rock on which the Halaban was deposited and through which the plutonic and hypabysal phases of the Halaban were intruded. Septa and inclusions of Halaban rocks in the gneiss are here interpreted to have been formed by a combination of infolding into the gneiss and inclusion in rheomorphic parts of the gneiss generated when the biotite-hornblende granite was emplaced.

Major faults have pushed elements of the Halaban and Bi'r Khountina westward over Bi'r Khountina and Murdama. Very complex fault patterns have evolved over a long period of time with the westward thrusts evolving rather late--perhaps later than the formation of the Murdama synclinorium. The eastern extensions of these faults do not seem to affect the Permian Khuff Formation to the east of the Jabal Bitrān quadrangle (Overstreet and others, 1972).

Hornblende-biotite granite gneiss

Light-gray to dark-gray, nonlayered, hornblende-biotite granite gneiss, biotite granite gneiss, granodiorite, and gneissic diorite are mapped as the hornblende-biotite granite gneiss unit on plate 1. It occupies part of the area shown by Bramkamp and others (1956) as granite gneiss; the remainder of the area is underlain by younger biotite-hornblende granite mapped as a separate unit on plate 1. The boundaries between the older hornblende-biotite granite gneiss and the younger biotite-hornblende granite are only approximately located; much more detailed work must be done to fix them with certainty.

The hornblende-biotite granite gneiss has a rather wide range in mineral composition, grain size, and texture. Hornblende may be absent, and where it is absent the biotite tends to be coarse grained and apparently pseudomorphic after hornblende. Ordinarily the rock is even grained, but locally it has augen of potassium feldspar, or, very rarely, of quartz. At most places both a gneissic structure and a lineation can be found. Where the gneissic structure is not strongly developed it tends to be obscured by exfoliation. The commonest linear features are streaks of oriented minerals, generally biotite, on the planes of gneissic foliation.

Inclusions of diverse size, composition, and origin are present in the hornblende-biotite granite gneiss. They pose formidable problems of correlation and age; some are evidently cognate, others are engulfed remnants of pre-Halaban rocks, and many, including some of the largest, are enclaves of infolded Halaban. Many of the inclusions are of mappable size; possibly the most spectacular are the hills of garnetiferous skarn in the east-central part of the quadrangle. The largest inclusions are great septa of amphibolite as much as 1.6 km across that are exposed in the northern part of the quadrangle. Inclusions of biotite schist, biotite-muscovite schist, and quartzite are also present.

Many of the smaller inclusions are complexly folded masses of schist or gneiss that have their principal planar structures athwart the principal planar structure of the granite gneiss, but which are intersected by a cleavage that also extends out into the gneiss. From these relations it is thought that some of the smaller inclusions are remnants of old schist and gneiss into which the hornblende-biotite granite gneiss was intruded. During later deformation of the gneiss, a cleavage was developed which passes through these old inclusions and is later than the foliation in the inclusions. These possibly old inclusions tend to have a higher metamorphic grade than the grade of the Halaban and Bi'r Khountina. None of the inclusions thought to be older than the period of initial emplacement of the granite gneiss is large enough to show on the map. It is possible, however, as is discussed in a following section, that some of the rocks mapped as Halaban are, in fact, part of a sequence older than the hornblende-biotite granite gneiss.

Pegmatite, felsite, and aplite intrude the hornblende-biotite granite gneiss as small, simple dikes, but it is not clear how many are interior dikes genetically related to the hornblende-biotite granite gneiss, and how many are exterior dikes genetically related to biotite-hornblende granite and to the younger peralkalic granite. The pegmatite is gray, pink, or white, and tends to grade into felsite, aplite, or quartz veins. Simple stringers of quartz and feldspar locally form ptygmatic folds. Dikes that cut the younger rocks are, of course, not genetically related to the granite gneiss.

Dike swarms of andesite and rhyolite in the hornblende-biotite granite gneiss form conspicuous ridges in the east-central part of the quadrangle.

The hornblende-biotite granite gneiss is thought to be the oldest mapped rock unit in the quadrangle. The Halaban and younger rocks are inferred to have been deposited unconformably on the granite gneiss or to intrude it. However, the foliation of the schistose rocks adjacent to the hornblende-biotite granite gneiss conforms to the gneissic structure in the granite gneiss, and no certain unconformity was observed between the granite gneiss and the Halaban Group. Linear features are partly conformable between the gneiss and the Halaban. Also, no basal conglomerate of Halaban was found that contains fragments of the granite gneiss. The oldest observed conglomerate having fragments of the granite gneiss is above the Halaban and at the base of the Bi'r Khountina Group. Thus, in the Jabal Bitrān quadrangle no direct evidence that the Halaban rests unconformably on the hornblende-biotite granite gneiss was found. However, considerable indirect evidence suggests that, in fact, the Halaban is younger than the granite gneiss, and that where the two units have concordant planar structures, the concordance has been brought about by deformation younger than both rocks.

At a few places, particularly in the northeastern part of the quadrangle, sills of schistose andesite are interlayered with inclusions of fine-grained biotite schist in the hornblende-biotite granite gneiss. The biotite schist is probably of pelitic origin and may be part of the old gneiss and schist seen only as inclusions in the hornblende-biotite granite gneiss. The schistose andesite extends out into the granite gneiss in dikelike masses.

Isotopic age data from the hornblende-biotite granite gneiss east of Jabal Idsas has been stated by G. F. Brown (Kahr, 1962, p. 7; Brown, G. F., written commun., 1970) to reflect two thermal events in the history of the rock. Whole-rock rubidium/strontium ratios of a dioritic phase of the hornblende-biotite granite gneiss gave 1010 m.y. in analyses by Thomas Aldrich, Carnegie Institution, Washington, D.C. Potassium/argon ratios of hornblende gave an apparent age of 900 m.y. and potassum/argon ratios of the biotite gave an apparent age of the biotite of 650 m.y. in analyses by Isotopes Incorported. Biotite from hornblende-biotite granite gneiss(?) in the extreme southeastern corner of the quadrangle is reported to have a potassium/argon age of 581 m.y. It is not certain if this younger apparent age correlates with the formation of the biotite-hornblende granite, the intrusion of the later peralkalic granite, or the episode of thrusting. Further work is needed to resolve these problems.

Halaban Group

The oldest layered sequence shown on the Jabal Bitrān quadrangle is called the Halaban Group, a usage modified from the term Halaban Formation of Jackson and others (1963), and following the terminology introduced in the Bi'r al Badriyah quadrangle (Overstreet, Whitlow, and others, 1972).

The Halaban Group in the Jabal Bitrān quadrangle consists of an unknown thickness of metamorphosed andesitic volcanic rocks and sparse associated graywacke and marble to which the name Umm Mushraha Formation was given in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972). Hypabyssal to plutonic mafic and ultramafic rocks, associated with the lava and sedimentary rocks of the Halaban Group, are also variably affected by dynamic and contact metamorphism.

The Halaban Group is thought to be unconformable on the hornblende-biotite granite gneiss, but unconformable contacts and basal conglomerate at the bottom of the Halaban were not discovered. Schistose andesite thought to be possible feeder dikes for the Halaban are present but scarce in the hornblende-biotite granite gneiss in the northeastern part of the quadrangle. Near the southern edge of the mapped area, the intrusive contact of a large mass of gabbro and pyroxenite, thought to be the plutonic equivalent of mafic flows in the Halaban Group, is parallel to the foliation of the granite gneiss. The gabbro and pyroxenite are also foliated harmoniously with the contact. The foliation in the mafic rocks is less well developed than the foliation in the granite gneiss, and lineation in the gneiss is absent from the gabbro and pyroxenite. The gneiss also has an earlier cleavage which is absent from the mafic rocks. Sheared mafic dikes, possibly originally andesite, in the gneiss are cut by the unit of gabbro and pyroxenite. These dikes are foliated, like the granite gneiss, in two directions. The dikes are thought to be feeders for early Halaban lava flows which preceded the intrusion of the gabbro and pyroxenite. This indirect evidence is also thought to support the inference that the hornblende-biotite granite gneiss is older than the Halaban Group.

The Halaban Group together with the hornblende-biotite granite gneiss are inferred to have undergone a period of folding prior to the deposition of the Bi'r Khountina Group, because cobbles and boulders of these rocks are in the conglomerate at the base of the Bi'r Khountina.

The degree of metamorphism of the rocks in the Halaban Group is variable, but in general the Halaban is more highly metamorphosed than the younger Bi'r Khountina and Murdama Groups. Dynamic and thermal metamorphism have both affected the Halaban, and some of the units in the group are polymetamorphic.

The possibility exists that the unit called amphibolite includes some pre-Halaban rocks older than the granite gneiss in the northeastern part of the quadrangle, and that the unit called skarn may in its entirety be older than the hornblende-biotite granite gneiss.

Umm Mushraha Formation

Amphibolite.--Gray, purple, green, and dark green, fine- to coarse-grained amphibolite, greenschist, and meta-andesite formed from dominantly andesitic lava by either dynamic metamorphism or thermal metamorphism or both is mapped as amphibolite of the Umm Mushraha Formation on plate 1. The terminology has been projected northward from the Bi'r al Badriyah quadrangle (Overstreet, Whitlow, and others, 1972). Also included in the amphibolite unit are layers of quartz schist, medium-grained biotite gneiss, dense hornfels, and, locally, essentially unmetamorphosed andesite. Generally the unit is schistose andesite to fine-grained hornblende schist, but it is variable and complex. Massive andesite grades through shear and becomes hornblende schist and amphibolite. Small areas of the amphibolite are fine grained and resemble microdiorite. Gradations from andesite porphyry to amphibolite, microdiorite, and hornblende diorite exist in the area of one outcrop. Generally in these areas of nebulous contacts and gradation from andesite to amphibolite, small calcite veins are common. Locally, as along the southeast side of Jabal Bitrān, the amphibolite unit is coarse grained and has large hornblende crystals. These areas give the appearance of higher metamorphic grade than the bulk of the amphibolite, possibly owing to polymetamorphic contact effect.

The amphibolite unit of plate 1 is the andesite and amphibolite of Kahr (1962) and the amphibolite schist with mafic undifferentiated intrusive and extrusive rocks of Bramkamp and others (1956).

The amphibolite unit is overlain unconformably by the basal conglomerate of the Bi'r Khountina Group, and fragments of the amphibolite, consisting of both meta-andesite and nearly unmetamorphosed andesite, are in this conglomerate. Inasmuch as the hornblende schist and schistose andesite of the amphibolite fragments are of higher metamorphic grade than the matrix of the conglomerate, it is here inferred that some metamorphism of the amphibolite unit of the Umm Mushraha Formation took place before deposition of the conglomerate in the Bi'r Khountina Group.

The amphibolite as exposed in the Jabal Bitrān quadrangle appears to be only a small part of a thick volcanic sequence. Inasmuch as no basal conglomerate, basal agglomerate, unconformity, or other evidence for the base of the formation was seen in the quadrangle, it is not possible to estimate the stratigraphic thickness of the amphibolite unit. The felsic lavas (Overstreet and others, 1972) that characterize the upper part of the Halaban Group to the southeast of the Jabal Bitrān quadrangle are absent here; thus, it is probable that the upper part of the Halaban Group was eroded away in this area before the Bi'r Khountina Group was deposited.

On the west side of Jabal Idsas andesitic and meta-andesitic parts of the amphibolite unit, together with adjacent diorite, are the hosts of variable, even copious, amounts of magnetite. Commonly the magnetite-rich andesite and diorite are closely jointed, fractured, and more or less strongly sheared. Veinlets of and aggregates of epidote, and brown calcite veins are common with the magnetite, and in some places the magnetitie-rich andesite is amphibolitized (Kahr, 1962, p. 10). The magnetite forms elongate, lenticular masses which are harmoniously folded, the fold axes being parallel to the axes of small folds in the andesite. Less commonly the magnetite makes up small stringers and veinlets. The larger masses of magnetite are fractured and jointed like the host rock, and the fractures are slickensided (Kahr, 1962, p. 16). A considerable part of the total amount of magnetite is scattered in disseminated grains and interstitial fillings in the host, and really large bodies of magnetite are not exposed. Details of the magnetite and its possible mode of origin are taken up in the section on mineral deposits.

Hornfels.--Hornfels, fine-grained amphibolite, and strongly epidotized andesite are developed in the Umm Mushraha Formation at the contact of the peralkalic granite along the east and south sides of Jabal Bitrān near the northern edge of the quadrangle. Metamorphism of the rocks is variable and complex. The hornfels and other rocks of the unit are strongly fractured, and the fine-grained amphibolite is weakly foliated parallel to the intrusive contact of the peralkalic granite. Several periods of epidotization are represented by various cross-cutting relations of epidote veins and granitic contacts, the principal feature of which is that some epidote veinlets are clearly older than the peralkalic granite, because they are cut by the granite. Early epidotization of the andesite in the Umm Mushrah Formation is at least as old as the biotite-hornblende granite on the west and north of Jabal Bitrān. Epidotization of the andesite again took place with the formation of hornfels at the time of emplacement of the peralkalic granite. This was followed by another period of epidotization, or the epidotization process continued, after the peralkalic granite was solidified and fractured.

Small areas of hornfels are probably more common along the various intrusive contacts than is shown on the map.

Hornblende gneiss and hornblende schist.--The hornblende gneiss and hornblende schist unit of the Umm Mushraha Formation comprises both layered and schistose mafic rocks in the south-central and central parts of the quadrangle (plate 1). The southernmost of the exposures are both sedimentary paragneiss and paraschist, and cataclastic gneiss and schist produced along a fault zone in gabbro, pyroxenite, diorite, andesite, and rhyolite.

The cataclastic deformation which formed the gneissic and schistose rocks in this area is much younger than the Umm Mushraha Formation, because schistose andesite and rhyolite at the extreme northern end of this exposure are part of the swarm of andesite and rhyolite dikes of the Bi'r Khountina Group outcropping immediately to the northeast. Four to 18 km farther north, the layered and schistose mafic rocks mapped as the hornblende gneiss and hornblende schist unit of the Umm Mushara Formation are amphibolite and hornblende schist formed from gabbro, pyroxenite, and diorite. Probably some of the layering is primary flow banding in a mafic plutonic complex. The unit of hornblende gneiss and hornblende schist is included with the other layered rocks of the Umm Mushraha Formation because of its layering. However, some of its source rocks were massive plutonic gabbro, pyroxenite, and diorite; thus, the unit contains both para- and orthogneiss. Where the plutonic mafic rocks are gneissic, it was not possible to separate them from the paragneiss and paraschist of the Umm Mushraha Formation. Where the plutonic mafic rocks are massive, they are mapped as younger rocks than the Umm Mushraha, because they can be distinguished.

Marble.--Thin layers of gray and brown marble and silicified marble are present in paragneissic parts of the hornblende gneiss and hornblende schist of the Umm Mushraha Formation in the south-central part of the quadrangle.

Skarn.--Calc-silicate lenticles, mapped as the skarn unit of the Umm Mushraha Formation, are interlayered with amphibolite, hornblende schist, and layered gneiss which occupy complex synforms in the older hornblende-biotite granite gneiss in the east-central part of the quadrangle. The skarn is resistant to erosion, thus it supports conspicuous sharp ridges that rise as much as 40-50 m above the surrounding plain of hornblende-biotite granite gneiss. These ridges are a somber dark brown, jagged, and irregular.

The skarn forms layers as much as 4 or 5 m thick and several hundred meters long in the layered gneiss and amphibolite. Many layers of skarn are present, but most are less than 2 m thick. These layers of skarn are tough intergrowths of randomly oriented, colorless to white tremolite and diopside with calcite and with aggregates of gray, pale brown, very dark weathering, generally euhedral but flattened garnets. The garnet tends to occupy layers which may define relict bedding. It is thought from color and mode of occurrence to be the calcium-iron garnet andradite, but analyses have not been made. Wind erosion has spectacularly exposed the andradite crystals which stand out in clusters on the surfaces of massive blocks of skarn.

Intimate cross-cutting relations within the synforms between the hornblende-biotite granite gneiss and the skarn were not seen, but the skarn is intruded by younger gray to pale pink biotite granite, stringers of pegmatite, and diabase dikes. The pegmatitic stringers in the skarn contain coarse-grained black and brown crystals of garnet, and possibly a little beryl. The biotite granite is part of the unit called biotite-hornblende granite on plate 1.

Layering and foliation in the synforms of skarn, amphibolite, and layered gneiss in the hornblende-biotite granite gneiss at many places appear to be athwart the general trend of the body of granite gneiss. However, faint gneissic structure in the granite gneiss tends to conform to the general outlines of the synforms, thus the principal planar features of the skarn and granite gneiss are not everywhere conformable. The relations noted might be explained as having developed during plastic deformation of both rock units after the granite gneiss was consolidated, but it seems more probable that the skarn was included in the granite gneiss at the time the gneiss was a magma. Detailed petrographic and petrofabric analysis of the rocks would resolve this problem. If the skarn is shown to be an inclusion in the granite gneiss, then the skarn is part of a sequence of metasedimentary rocks older than the granite gneiss and older than the Halaban Group.

The grade of metamorphism of the tremolite-diopside-andradite skarn seems to be somewhat higher than the typical metamorphic grades of the Halaban amphibolites. This may be caused by the skarn being an inclusion in the original magma of the granite gneiss. Tight infolding in the gneiss doesn't seem likely to have produced the unoriented texture of the tremolite and diopside. Probably the skarn originated by the contact metamorphism of marl or shaly limestone.

<u>Gneissic granodiorite</u>

The gneissic granodiorite consists of light-colored to dark-green and gray gneissic granodiorite, diorite, and associated epidotized, chloritized, and feldspathized mafic volcanic rocks. At most places in the Jabal Bitrān quadrangle the gneissic granodiorite is coarse grained to very coarse grained and strongly fractured. It has rather poorly developed gneissic structure on which is imposed a younger, weak foliation. At places it is possible that the granodiorite is part of the older hornblende-biotite granite gneiss unit. At many places the gneissic granodiorite is closely intruded by schistose to massive andesite dikes. Commonly, gradation exists between the gneissic granodiorite and metamorphosed andesite with porphyroblasts of feldspar, and both rocks grade into epidiorite.

The gneissic granodiorite is a composite of several rocks of several ages. At some places granodiorite is intruded by dikes of meta-andesite. Elsewhere the granodiorite grades into meta-andesite. Either the andesite or the granodiorite must be of different ages. These relations were not resolved by this work.

The gneissic granodiorite is associated with feldspathized andesite and epidiorite. The feldspathization of the andesite may be related to metamorphic events that took place later than in Halaban time. The feldspathization may have taken place when the biotite-hornblende granite was emplaced in Bi'r Khountina time.

The gneissic granodiorite is separated from the overlying conglomerate of the Bi'r Khountina Group on the west by both an unconformity and faults. Inasmuch as cobbles of the gneissic granodiorite are in the conglomerate, the unconformable relation seems to have more stratigraphic significance than the faults. The gneissic granodiorite is a plutonic rock; therefore, considerable erosion must have preceded its exposure in early Bi'r Khountina time. This suggests that an important interval of time exists between the close of Halaban sedimentation and metamorphism and the onset of Bi'r Khountina sedimentation.

Diorite, gabbro, pyroxenite, and serpentinite

A group of rocks described as diorite, gabbro, pyroxenite, and other ultramafic rocks and serpentinite intrude andesite, meta-andesite, and amphibolite of the Halaban Group in the southeastern quarter of the quadrangle. They also intrude the gneissic granodiorite unit of the Halaban and the hornblende-biotite granite gneiss, but they are intruded by the biotite-hornblende granite. Numerous fragments of all varieties of these plutonic mafic rocks are in the conglomerate at the base of the Bi'r Khountina Group. These mafic rocks are here thought to be plutonic igneous phases of the Halaban mafic extrusives. However, it has been difficult in some places to separate the bodies of mafic rock attributed to Halaban plutonic episodes from bodies of mafic rock attributed to later episodes of plutonism in Bi'r Khountina time. Where massive and relatively unmetamorphosed, the mafic plutonic rocks are not defined with certainty as plutonic phases of the Halaban extrusives; hence, they are questionably attributed to a Bi'r Khountina age. Both ages of mafic plutonic rocks are present in the southeastern quarter of the quadrangle.

Diorite

The unit called diorite consists of gneissic to massive diorite and biotite diorite. Commonly the borders of the diorite are gneissic and the core massive. The diorite tends by decrease in grain size to grade into microdiorite and andesite porphyry and by increase in grain size locally to grade into thin selvages and veins of pyroxenite, or more commonly, into gabbro. The diorite contains abundant disseminated magnetite in the Jabal Idsas area, although elsewhere in the quadrangle magnetite is not unusually abundant in the diorite.

Gabbro and pyroxenite

The gabbro and pyroxenite tend to occur in intrusive complexes composed of both rocks plus diorite. In these complexes the gabbro is most abundant. Core parts of the complexes tend to be massive and the margins are gneissic. Much of the original pyroxene in these rocks is altered to hornblende, and locally to biotite.

Ultramafic rocks

A large and complex mass of ultramafic rocks is exposed in the mountains north of the magnetite deposit at Jabal Idsas. Peridotite, pyroxenite, and serpentinite are present and they form a core partly surrounded by gabbro and diorite. Amphibolite, schistose andesite, and quartzite of the Umm Mushraha Formation form a large septum on the northwest side of the ultramafic rocks. Prominent black knobs of steeply southwest-dipping pyroxenite separate the ultramafic mass from the diorite to the southwest, and the pyroxenite grades into serpentinite. White, oligoclase-rich differentiates of the ultramafic rocks are associated with the pyroxenite and serpentinite as dikes and irregular masses. According to Felix Ronner (written commun., 1965) the differentiates have the composition of oligoclasite. They occupy a stratigraphic position similar to that described for a sill of white hornblende syenite in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972). Upon closer study that syenite may also prove to be an oligoclasite.

Bi'r Khountina Group

The term Bi'r Khountina Group is extended from the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) for a thick sequence of weakly metamorphosed to locally unmetamorphosed Precambrian sedimentary and volcanic rocks that overlies the Halaban Group with marked unconformity. In the area of the Southern Tuwayq quadrangle (Bramkamp and others, 1956) represented here on plate 1, the rocks of the Bi'r Khountina Group were called sericite and chlorite schist and amphibole schist. The term Abt Schist was later applied (U.S. Geol. Survey and Arabian American Oil Co., 1963) to the parts of the Bi'r Khountina Group and Murdama Group that have been metamorphosed to chlorite-sericite schist in the area of the Jabal Bitrān quadrangle. The term Abt Schist as there used is here thought to apply to a single metamorphic facies reached by similar rocks in the two groups. The term as there used does not uniquely define one formation. In the Jabal Bitrān quadrangle the term Abt Schist is restricted to rocks in the Murdama Group. Usage followed here for the Bi'r Khountina Group was introduced in the Bi'r Ghamrah quadrangle (Overstreet and Whitlow, 1972a).

The Bi'r Khountina Group in the Jabal Bitrān quadrangle consists of a basal conglomerate and/or agglomerate overlain by marble which in turn is overlain by an immense but unknown thickness of graywacke and volcanic rocks. These are divided into four formations called, from oldest to youngest, the Idsas Formation, the Fawara Formation, the Abu Sawarir Formation, and the Badrīyah Formation. The names for the two older formations are introduced in this quadrangle.

The conglomerate at the base of the Bi'r Khountina Group rests unconformably on the Halaban Group and contains detrital fragments of all major units in the Halaban, including masses of magnetite. Cobbles of the old hornblende-biotite granite gneiss, possibly older than the Halaban, are also in the basal conglomerate.

The Bi'r Khountina Group is unconformably overlain by the Murdama Group.

The lower part of the Bi'r Khountina Group, comprising the Idsas, Fawara, and Abu Sawarir Formations, tends to be clastic. These sedimentary rocks are succeeded upward by the main volcanic rocks of the group in the Badrīyah Formation. Because the Bi'r Khountina Group appears to occupy a large north-northwest plunging synclinorium in which it is overlain by the Murdama, the chief exposures of the volcanic rocks of the Bi'r Khountina are in the southern and southwestern parts of the Jabal Bitrān quadrangle. Although most of the volcanic rock in the Bi'r Khountina Group exposed in the Bi'r al Badrīyah and Bi'r Ghamrah quadrangles to the south seem to be andesite, much of the volcanic rock along the eastern rim of the exposures of the Bi'r Khountina in the Jabal Bitrān quadrangle is albitized. Kahr (1962, p. 9-10) has recognized pillow lava, probable spilite, and probable quartz karatophyre among the volcanic rocks associated with silicified marble and ultramafic rocks of the Bi'r Khountina.

This assemblage grossly resembles an ophiolite sequence, but several important exceptions suggest that the ophiolite sequence of under-water intrusion and differentiation actually did not take place here. The age relations of the rocks are inconsistent with the theory of formation of ophiolite. In the Jabal Bitrān quadrangle silicified marble is older than the spilite, keratophyre, and pillow lava, not younger, as is demanded by the theory of formation of ophiolite. The ultramafic rocks associated with the marble are intrusive into both the albitized lavas and the marble. Thus, if the ultramafic rocks had formed by differentiation from the lavas, as demanded by the ophiolite theory, then the ultramafic differentiates would have had to intrude stratigraphically downward to reach their present actual position. Downward intrusion normally might be regarded as unavailable because of increase of pressure in that direction.

It is here thought that the ultramafic rocks of the Bi'r Khountina Group are localized along the conglomerate and marble and near the base of the group because these rocks are less competent than the thick overlying sequence of lava in the Badrīyah Formation and the massive underlying Umm Mushraha Formation of the Halaban Group and granite gneiss, and because the least competent rocks are the loci of regional faults. Peridotite magma reached by these faults ascended them long after the spilite, pillow lava, and keratophyre had solidified. Partial to complete conversion of the peridotite to serpentinite probably took place after the ultramafic rocks were formed, but how long after is not known. Possibly some of the silicified marble was altered at that time also, but it seems highly probable that several episodes of silicification are represented by this marble, and some marble may have been silicified when it was laid down.

Following deposition of the Bi'r Khountina Group, but prior to the deposition of the Murdama Group, large bodies of biotite-hornblende granite were emplaced in the Bi'r Khountina rocks, and a swarm of andesite and rhyolite dikes was intruded. Cobbles and boulders of the Bi'r Khountina rocks, granite, andesite, and rhyolite are common in the conglomerate at the base of Murdama Group in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972).

Idsas Formation

The name Idsas Formation is here given to metamorphosed graywacke conglomerate and meta-agglomerate exposed intermittently along the west flank of the Idsas Range where it unconformably overlies meta-andesite of the Umm Mushraha Formation and gneissic granodiorite. The formation name is taken from Jabal Idsas, situated 3 km northeast of exposures of the conglomerate. The metaconglomerate is quite variable in thickness, size of fragments, and composition of the matrix; no estimate is available of its thickness. The base of the unit is generally conglomeratic, but locally, as at a point 3.4 km east-southeast of Fawara mine, the base of the unit consists of andesite flows and interbedded lenticles of gray marble. These rocks also appear as detrital fragments in the conglomerate where they are mixed with fragments of meta-andesite of the Halaban Group and gneissic granodiorite The unit as shown on plate 1 in some places is largely a succession of thin pebble beds intertonguing with graywacke sandstone and quartzite; elsewhere it is a thick boulder metaconglomerate, the boulders as much as a cubic meter in size. The boulder metaconglomerate grades upward into fine-grained graywacke sandstone, pelitic material, calcareous graywacke, and lenticles of marble. Elsewhere, particularly near the southernmost exposures of marble in the quadrangle, the metaconglomerate grades upward from noncalcareous to calcareous boulder metaconglomerate composed mainly of round fragments of blue to black marble, round fragments of graywacke, quartz, rhyolite, andesite porphyry, and fine-grained conglomerate.

Where the calcareous component is dominant, the metaconglomerate is interpreted to be part of the marble of the Fawara Formation and is so shown on the map. At some places, particularly in the northern and central parts of the quadrangle, volcanic ash, banded tuffaceous rocks, and andesite flows are mixed with the metaconglomerate. With increased admixture of ash and flow rocks the metaconglomerate grades into meta-agglomerate. In the northern part of the quadrangle, a dark-green, massive meta-agglomeratic facies dominates, and it contains fragments of rocks of the Halaban Group and granite gneiss.

Metaconglomerate of the Idsas Formation west of Jabal Idsas is notable for its fragments of detrital magnetite. The pieces are subangular to subrounded and are of pebble and cobble size. Doubtless even larger fragments of magnetite can be found in the metaconglomerate because the pebbles and cobbles are associated with boulders of magnetite-bearing meta-andesite and andesite of the Halaban. The detrital magnetite is restricted to the basal part of the metaconglomerate (Kahr, 1962, p. 15). Lack of magnetite in the upper part of the metaconglomerate is interpreted here to mean that the magnetite-bearing part of the Halaban Group was bared to erosion only during the early part of Bi'r Khountina time. Thereafter, it was covered.

The metaconglomerate and meta-agglomerate locally are unmetamorphosed, and the sedimentary bedding planes are well developed and dip very steeply (Kahr, 1962, p. 13).

The metaconglomerate is strongly sheared locally, and a continuous shear zone dipping toward the northeast follows the base of the Idsas Range. Vertical shears are common in the metaconglomerate. The shearing has been thoroughly penetrative, and shear planes are developed in cobbles and boulders as well as the matrix, resulting in immensely elongated and drawn-out pebbles. Fractures in the elongated pebbles are parallel to the cleavage in the matrix. Where ash and andesitic lava are a major component in the matrix, epidote veinlets and segregations have formed, and the outlines of the coarse clastic fragments are obscured and difficult to define. The metamorphic grade of the metaconglomerate and meta-agglomerate is in the greenschist facies. Chlorite is the most common new mineral to have formed in the matrix.

Very slightly metamorphosed to unmetamorphosed exposures of agglomerate in the northern part of the quadrangle contain fragments of meta-andesite and amphibolite that have the aspect of rocks of the Halaban Group exposed nearby. The metamorphic grade of these fragments is not duplicated by the grade of the matrix of the meta-agglomerate. These relations are interpreted to show that the Halaban Group was already metamorphosed at the time the basal unit of the Bi'r Khountina Group was laid down.

Dikes of andesite intrude the metaconglomerate. At one locality 9 km south-southwest of the Selib mine, where the metaconglomerate is composed mainly of boulders of marble, pieces of natural slag are present locally along the walls of an andesite dike. Probably the slag formed because the calcite of the marble lowered the fusion point of the silicate minerals and silica-bearing rock fragments in the matrix of the metaconglomerate. An estimate of the lowest probable temperature of the andesite dike at the time the slag was formed could be made by remelting the slag and determining its melting point.

Fawara Formation

The term Farawa Formation is here introduced for marble, dolomitic marble, silicified marble, schistose marble, and dolomite that forms white, reddish-brown, brown, pink, gray, dark-blue, and nearly black discontinuous ridges commonly near serpentinite and other ultramafic rocks west of the metaconglomerate. The name is taken from the excellent exposures of these rocks near the Fawara mine.

The Fawara Formation as mapped on plate 1 is thought to represent a zone of lenticles of marble in conglomerate, pelitic material, volcanic ash, and flows. The lenticles are of variable thickness and length. The unit thus mapped is not a single bed of marble, it is a zone in which marble is more common than elsewhere in the quadrangle.

The reddish-brown and brown dolomitic marble is closely associated with the ultramafic rocks. This dolomitic marble is fine to medium grained, crystalline, and iron-carbonate-bearing. It is partly to almost wholly silicified and is cut by many white quartz masses ranging in size from thin stringers to massive, thick veins (Kahr, 1962, p. 10-11 Several of the most prominent ancient gold mines in the quadrangle have open stopes in these quartz veins. The white, pink, gray, and nearly black marble is less commonly silicified than the brown marble, and it is less dolomitic. These marbles and schistose marbles are intensely folded and contorted, and their structural relations are complicated by faulting and rock flowage.

The brown silicified marble has very complex stratigraphic relations which cannot be explained by attributing the silicified marble to a singl stratigraphic horizon. At several places extensive movement of calcium carbonate and silica after deposition of the marble is indicated. In the area 5 to 6 km south-southwest of the Selib mine, the brown silicified marble has been observed to occur as: (1) clearly defined beds to 1 m thick in sheared mafic pyroclastic rocks; (2) as veins crossing massive andesite; (3) as partial replacement of boulders and cobbles of blue marble in conglomerate and breccia; and (4) as spectacular north-trending ridges possibly oriented along shear planes in metaconglomerate composed of blue marble. These relations are interpreted to indicate the possibility of at least two modes of origin for the silicified marble. In some layers, such as those interbedded with pyroclastic rocks, silicification of the marble may have taken place essentially at the time of deposition of the original limestone. This relation assumes that the limestone was deposited in water containing silica from partial solution of volcanic ash, and that reaction between the calcium carbonate and silica caused the original limestone to be silicified. There is evidence that the silicified marble also formed by hydrothermal replacement of marble by silica along preferred carbonate layers of diverse but narrow stratigraphic range. Possibly the replacement by silica was localized by shears.

The blue and black marble grades stratigraphically downward by increments of clastic debris into calcareous metaconglomerate and breccia and grades stratigraphically upward by increasing increments of pelitic sediments and ash into the main facies of the Bi'r Khountina Group. The calcareous metaconglomerate at the base of the Fawara Formation is interpreted originally to have been an intraformation conglomerate formed from earlier-deposited parts of the marble. In part the calcareous breccia at the base of the Fawara Formation may have formed originally from a subaerial weathering of the lower part of the original limestone without transport and rounding of the detritus. This angular debris was then incorporated in succeeding calcareous sedimentation. A not dissimilar surface is presently exposed at the top of the Permian limestone of the Khuff Formation to the east (Bramkamp and others, 1956). Other parts of the calcareous breccia grade into schistose phases of the marble, and are interpreted to be tectonic breccias formed along shear zones in the marble.

The little exposure of dolomitic marble about 2 km south of the Mashaliya mine now seems to be a dolomite rim on the serpentinite immediately to the east. Both the dolomite and serpentinite are strongly athwart the prominent planar features and quartz stringers in the chlorite-sericite schist of the Abt Formation to the west, and quartz stringers in the schist do not enter the dolomitic marble. From these relations it is inferred that the fault separating the Fawara and Abt Formations at this locality is younger than the regional metamorphism of the Abt. A small exposure of dolomitic marble 9 km north-northeast of the Mashaliya mine is heavily brecciated and sheared, but it grades into the chlorite-sericite schist of the Abu Sawarir Formation.

Gray marble exposed about 1 km north of the Fawara mine is schistose and occurs as lenticles in the plane of schistosity of associated sericite schist, quartzite, and schistose andesite.

Enlongate ridges of gray marble form conspicuous outcrops 6 to 7 km west-northwest of Selib mine. They are marked by the symbol m on plate 1 to show that they are not assigned to the Fawara Formation. Tan dolomite is associated with the gray marble. Physically this marble resembles that near Selib mine, but they are thought not to be stratigraphically correlative. Similar marble, also labelled m, extends intermittently southwestward for 14 km, and it appears farther southwest in the northwestern part of the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972).

The ultramafic rock intimately associated with the Fawara Formation in the central and northern part of the quadrangle is described in a later section.

Abu Sawarir Formation

Gray to dark gray, fine- to medium-grained chlorite-sericite schist of the Abu Sawarir Formation generally overlies marble of the Fawarara Formation. This schist is interpreted in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) to have formed by dynamothermal metamorphism of graywacke, tuffaceous graywacke, nearly black siltstone, and other pelitic materials in the lower and middle part of the Bi'r Khountina Group. Carbonate layers are locally present, as are beds of calcareous quartzite and hematitic quartzite. Thin flows of meta-andesite are also interlayered in the dominately pelitic schists. Most of the rocks are at the greenschist facies of regional metamorphism. At some places, however, they are scarcely touched by metamorphism, and the original composition of the rocks can be ascertained.

In the center of the quadrangle, west and south of the magnetite-bearing meta-andesite of the Umm Mushraha Formation and conglomerate of the Idsas Formation is a body of schist which is assigned to the Abu Sawarir Formation. The outcrops are described by Kahr (1962, p. 11-12) as consisting of black schist and shale, quartzite, and cavernous leached rocks. The schist and shale are dark gray to black, dark green to gray, and locally purplish-gray, fine-grained, blocky, shaly, sheared, and schistose rocks which seem to have been originally iron-rich sedimentary and tuffaceous rocks with intermixed andesite flows. Parts of the dark schist have been converted within narrow zones to white sericite schist. In some places the schists are speckled dark gray and white (fleckenschiefer) or are locally knotty (knotenschiefer) on the foliation planes. Epidote is rather common, and where it is most abundant the rock is also enriched in specularite.

The quartzites at this locality are white, gray, and red, contain finely dispersed specularite and hematite, and have a strong planar structure. The greater the iron content, the darker the color of the quartzite. At several places the quartzite is converted to mylonite along tectonic zones, and the mylonitic parts have been thoroughly leache

Adjacent dark shales and flow rocks intersected by the same tectonic zones are also leached, but not as conspicuously as the quartzite, which becomes cellular. The cavities are as much as 1 or 2 cm across, and they contain specularite, commonly in euhedral crystals, and crystalline chlorite and sericite. Where the quartzite is not leached to a cellular mass, it is leached to a sandy or pulverulent, white to gray relict of mylonite. The leached rocks form conspicuous small trenches.

Badrīyah Formation

Unaltered, albitized, or epidotized massive andesite flows, porphyritic andesite, pillow lava, and agglomerate of the Badriyah Formation are exposed west of the Fawara Formation in the central and southern parts of the Jabal Bitran quadrangle. Spilite, keratophyre, and quartz keratophyre were identified by Kahr (1962, p. 9-10), and were interpreted to indicate the underwater extrusion of some of the flows. Dolomitic and silicified marble is locally interbedded with the lava, as is some pelitic material. Dikes and sills of andesite and diabase commonly cut the flows. Toward the southwestern edge of the area of exposure the andesite is widely epidotized and chloritized. It is there mapped as greenstone of the Badrīyah Formation. The andesite and greenstone units of the Badrīyah are unconformably overlain by the Abt Formation.

Sheared and silicified andesite is commonly associated with the silicified marble. At the Selib mine strong vertical fractures in the andesite are filled with jasper, and some of the andesite is silicified.

Dynamothermal metamorphism of the Badrīyah Formation has locally converted it into chlorite schist and chlorite-sericite schist.

Diorite, gabbro, pyroxenite, amphibolite, hornblendite and ultramafic rocks

Dark gray and dark green to nearly black intrusive complexes and composite plutons of diorite, gabbro, and pyroxenite and amphibolite consisting mainly of hornblendite formed from gabbro and pyroxenite, are common in the northeastern and southeastern quarters of the quadrangle.

Composite plutons of diorite and gabbro

In the northeastern part of the quadrangle a north-trending composite pluton of diorite and gabbro intrudes the hornblende-biotite granite gneiss with sharp contact. The walls of the pluton tend to be diorite. They have clearly defined chilled margins. Both the diorite and gabbro were intruded by dikes of pink granite and dikes of pink quartz porphyry which are apophyses of the small stock of peralkalic granite intruded around the northern end of the composite pluton of diorite and gabbro. The margins of the granitic dikes are chilled against the diorite and gabbro, and near the contacts the dikes have many inclusions of chlorite. Six kilometers northeast of this composite pluton several small masses of gabbro intrusive into hornblende-biotite granite gneiss are also intruded by peralkalic granite.

Near the southeastern edge of the quadrangle a number of relicts of diorite and gabbro are included in biotite-hornblende granite. Many of the mafic inclusions are large enough to show on the map. They are threaded with dikes of biotite-hornblende granite, and the edges of the inclusions are amphibolitized. Some inclusions are altered to amphibolite.

Farther south, masses of gabbro and pyroxenite are intrusive into the hornblende-biotite granite gneiss, but are themselves intruded by the biotite-hornblende granite.

Relations of pyroxenite and hornblendite

Pyroxenite dikes intrude gabbro, the most common rock at most exposures, and dikes of gabbro cut the pyroxenite; thus, complex spatial relations exist among these plutonites. Small masses of hornblende-rich gabbro pegmatite tend to grade into hornblendite. The largest mass of hornblendite in the quadrangle is 2 km east of Mashaliya mine where dark green hornblendite is associated with gabbro. Weathered pebbles of this hornblendite have a black, metallic appearance. The relation of this gabbro and hornblendite to the ultramafic rocks closely associated with marble is uncertain. Possibly it is part of the ultramafic sequence and not part of the diorite-gabbro sequence exposed near the northeastern edge of the quadrangle.

Relations of ultramafic rocks

A belt of ultramafic rocks associated with marble makes an arcuate discontinuous outcrop as much as 1.4 km wide and about 20 km long in the central part of the quadrangle. Two northward-converging belts of the same rocks crop out in the northwestern part of the quadrangle. The regional structural relations thought to control the distribution of the outcrops is discussed in the section on structure, and the general relations of these ultramafic rocks to the marble were treated in the introductory comments on the Bi'r Khountina Group; however, the relations of these rocks and their probable age are major stratigraphic and structural problems.

Because the ultramafic rocks are associated with ancient gold mines, because sparse copper stain, asbestos, magnesite, and chromite are known to be associated with them, and because they are conspicuous, they have been discussed extensively in the earlier investigations of this area (Schaffner, 1955; 1956b; MacLean, 1958a, b; Directorate General of Mineral Resources, 1959; Kahr, 1962; Herness and Kahr, 1963). These reports show the ultramafic rocks to consist of peridotite, pyroxenite, serpentinite, and serpentine schist. Wherever exposed, the serpentinite is extremely deformed, and within the serpentinite are small to large felsitic lenticular masses that have been moved and rotated as the serpentinite flowed.

The ultramafic rocks are here interpreted to have been intruded into the Bi'r Khountina Group along a major fault zone that follows the least competent rocks--marble--of the Fawara Formation and metaconglomerate of the Idsas Formation. In many places the ultramafic rocks intimately intruded the marble, and where peridotite was later changed to serpentinite, thick bands of dolomitic marble have formed along the old intrusive contact between the peridotite and marble. The dolomite is thought to have formed by magnesian metasomatism of the marble at these contacts. Serpentinization of the peridotite is incomplet At many places relicts of peridotite are in the serpentinite.

The intrusion of the ultramafic rocks took place after the deposition of the conglomerate, marble, andesite, spilite, pillow-lava, and keratophyre of the Bi'r Khountina Group. How much later is not known. As interpreted here, these ultramafic rocks are considered to be older than the biotite-hornblende granite, because the granite is not known to be intruded by peridotite and serpentinite. The ultramafic rocks of the Jabal Bitrān quadrangle are also thought to be older than the Murdama Group, because peridotite was not observed to intrude the Murdama.

This assumed age of the ultramafic rocks west of the Idsas Range is challenged by two observations: (1) peridotite in the Murdama Group in the Bi'r Ghamrah quadrangle, and (2) small masses of basalt in the biotite-hornblende granite in the Jabal Bitrān quadrangle. Both observations seem to be resolvable in the context of ages cited above, but they show that more study is needed before the sequence of geologic events in this part of Arabia is satisfactorily understood.

Peridotite is shown to intrude the Murdama Group in the Bi'r Ghamrah quadrangle (Overstreet and Whitlow, 1972a). That peridotite, like the ultramafic rocks in the Jabal Bitrān quadrangle, is interpreted to have risen from great depth along a major fault zone. However, the fault in the Bi'r Ghamrah quadrangle is thought to be somewhat younger than the overthrust faults which cause rocks of the Halaban Group to be pushed over the ultramafic rocks of the Bi'r Khountina Group in the Jabal Bitrān quadrangle. Thus, the ultramafic rocks west of the Idsas Range were already in place before the fault in the Bi'r Ghamrah quadrangle was filled with peridotite.

A pipe, a dike, and float of basalt in the Jabal Bitrān quadrangle, all too small to show at the scale of the map, raise the possibility that the ultramafic rocks are younger than the biotite-hornblende granite. A pipelike mass of basalt about 1.5 m across intrudes brown silicified marble southeast of the Selib mine. The basalt is unaltered, but the ultramafic rocks around Selib mine are extensively altered to serpentinite, and the marble is altered to dolomite and is silicified. No contact between this basalt and serpentinite was found. In the extreme southeastern corner of the Jabal Bitrān quadrangle, 4 km west-northwest of an ancient mine, a body of gabbro and pyroxenite is intruded by biotite-hornblende granite, and the granite is intruded by a small dike of vesicular basalt. It is possible that the dike is part of the swarm of andesite and diabase dikes farther north, but similar vesicular basalt was not seen there. At a point 6 km due west of the dike of vesicular basalt, float fragments of schistose basalt with strungout amygdules are present. The schistose basalt is at the greenschist facies but associated hornblende schist is at the amphibolite facies. It is inferred that this basalt was intruded later than the metamorphism of the associated hornblende schist, but was deformed in late Bi'r Khountina movements. The three basaltic rocks have inherent similarities, and they may have been emplaced during the same volcanic episode. This is thought to be later than the intrusion of peridotite west of the Idsas Range, because the basalt plug near Selib mine is unaltered, whereas the peridotite is altered. Thus, the ultramafic rocks are here interpreted to be older than the biotite-hornblende granite.

Biotite-hornblende granite

Gray, locally pink or red, massive to faintly gneissic biotite-hornblende granite underlies the east-central part of the quadrangle. Locally the rock is biotite-free or hornblende-free, and at some places, as west of Jabal Bitrān, it has considerable accessory epidote. Marginal parts of the rock tend to be granodioritic, or even dioritic, and near the contacts a strong primary flow banding is found. Inclusions of Halaban and Bi'r Khountina layered rocks may be present, and inclusions of diorite and gabbro are common locally. At one place in the southeastern part of the quadrangle pink to red biotite-hornblende granite contains a distinctive array of inclusions of diorite, gabbro, and amphibolite, some of which are large enough to map individually. Areas where inclusions are particularly conspicuous have been indicated on plate 1.

Oriented clots of biotite and oriented hornblende crystals form lineation on the planes of flow banding. Generally the lineation plunges directly down the dip of the planes. Scattered limonite pseudomorphs after pyrite are common.

The borders and contacts of the unit generally do not show a distinctive decrease in grain size, but Kahr (1962, p. 13) reported that in the Jabal Idsas area a stock of pink to pinkish-gray orthoclase granodiorite, a phase of the biotite-hornblende granite, intrudes amphibolite and magnetite-bearing andesite of the Halaban Group and sericite schist of the Bi'r Khountina. At one place a very distinct, fine-grained, border facies of the granodiorite was seen.

Pink and gray biotite granite facies of the unit tend to develop numerous small caves and hollows during weathering. The geologic control for this cavernous weathering was not determined.

The pluton at Bi'r El Ankeriya shown as biotite-hornblende granite on plate 1 is a complex rock possibly formed from the hornblende-biotite granite gneiss and diorite, andesite, and amphibolite of the Halaban by potassic metasomatism leading to feldspathization and the development of a pink color. Very little biotite-hornblende granite as such is present except nebulous, non-hornblendic masses that grade into pink lenticles and veins of orthoclase, quartz, and epidote. Hornblende in the older hornblende-biotite granite gneiss is extensively altered to biotite. The pluton probably is the product of potassic metasomatism in an area of contact between the hornblende-biotite granite gneiss and the amphibolite of the Halaban. The metasomatism is thought to be later than the gneiss or Halaban, and is thought to have tended toward formation of diorite from the Halaban amphibolite and gray to pink biotite granite, aplite, and felsite from the gneiss. Interestingly, the radioactivity in the biotite-hornblende granite 2 km south of Bi'r El Ankeriya is 4.5 times background, which is the highest observed in the quadrangle. It is inferred that the radioactivity may be associated with allanite possibly developed during the metasomatism.

Dikes of pink felsite and pegmatite intrude the biotite-hornblende granite, but it is not certain whether a given body of pegmatite or felsite is genetically related to this granite or to younger peralkalic granite. Inasmuch as the volume of younger granite is small, probably most of the pegmatite dikes seen in the biotite-hornblende granite are interior dikes genetically related to that granite. The dikes are mineralogically simple. They grade from pegmatite to felsite and to white quartz veins, some of large size. Commonly the walls are coated with epidote. Felsite and pegmatite dikes in the biotite-hornblende granite that cut through the dikes in the swarm of andesite, diabase, and rhyolite in the granite are either related to the rhyolite or are younger and are related to the peralkalic granite.

The biotite-hornblende granite and the dike swarm in it are shown in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) to be older than the Murdama Group, because detrital fragments of the granite, andesite, and rhyolite are in conglomerate at the base of the Murdama. No independent evidence to show this relation was seen in the Jabal Bitrān quadrangle; therefore, the stratigraphic position assigned to the biotite-hornblende granite is extended north into the Jabal Bitrān quadrangle from the Bi'r al Badrīyah quadrangle.

The intimate association of the biotite-hornblende granite with the hornblende-biotite granite gneiss is only indicated by plate 1; actual contacts between the two rocks are much more complicated than can be shown from the brief field work described here.

If the biotite-hornblende granite and the hornblende-biotite granite gneiss are separated geologically by at least an interval equal to all of Halaban and part of Bi'r Khountina time, as is shown in plate 1, then some factor must control the close spatial association of the two rocks. That factor may be the origin of the biotite-hornblende granite itself. Possibly the biotite-hornblende granite is remobilized hornblende-biotite granite gneiss brought to an intrusive phase during regional metamorphism in late Bi'r Khountina time, which reached no greater intensity than the albite-epidote amphibolite facies or the lower subfacies of the amphibolite facies. The biotite-hornblende granite seems to have been very dry and free from volatiles when emplaced. Perhaps this is further evidence that the granite formed from the gneiss instead of from a magma, because the hornblende-biotite granite gneiss might be expected to be leaner in volatiles than a magma. Volume change in the passage from hornblende-biotite granite gneiss to biotite-hornblende granite may in part be responsible for some of the faults in the granite and gneiss.

Andesite, rhyolite, and granite dikes

A swarm of generally southward-arcuate dikes trends from southwest to northwest across the eastern part of the quadrangle. The dikes are most easily seen in the hornblende-biotite granite gneiss and biotite-hornblende granite where they form conspicuous ridges, but they also intrude all units of the Halaban Group and intrude the Idsas, Fawara, and Badrīyah Formations of the Bi'r Khountina Group.

Andesite and rhyolite are the most widespread dikes, but andesite porphyry, diabase, fine-grained diorite, and rhyolite porphyry grading into microgranite and granite are common locally. A plug and dikes of dark-gray microdiorite and dikes of fine-grained diorite are also present.

The mafic dikes are generally massive, unmetamorphosed and of dark green, dark brown, and dark gray color. The texture of the mafic dikes varies with the thickness; the thickest dikes have phenocrysts of, variously, feldspar, pyroxene, hornblende, and biotite, but the thin dikes tend to be aphanitic. Porphyries, microdiorite, diorite, and diabase are common among the thick dikes. Ordinarily the walls of the dikes are finer grained than the cores. Smaller size of feldspar crystals as the walls of the dikes are approached is particularly marked. Pyrite cubes are more plentiful in the coarse-grained dikes than in the fine-grained dikes, but this may be more a feature of visibility than of actual abundance. Pyrite seldom makes up as much as 0.5 percent of the dikes. Many radial fibrous bundles of epidote that locally replace feldspar phenocrysts in andesite have a cube of limonitized pyrite at the core.

Massive and unmetamorphosed dikes of andesite, diabase, microdiorite, and diorite are commonly present in variably metamorphosed andesite flows, granodiorite, diorite, and amphibolite. These relations are here interpreted to show that the mafic dike swarms are younger than the mafic flows of the Halaban Group, and younger than some of the flows of the Bi'r Khountina Group. In the dike swarms, mafic dikes tend to be intersected by felsic dikes more commonly than the felsic dikes are cut by the mafic dikes. From these relations emplacement of the mafic dikes is thought to have started a little earlier than the felsic dikes. However, many striking examples are present of andesite, diabase, or diorite dikes intruding dikes of rhyolite, microgranite, granite, and pegmatite, and pegmatite grading into quartz veins. Several of the prominent quartz knobs shown on plate 1 are intruded by unmetamorphosed mafic dikes. The quartz tends to be brecciated for 30 to 40 cm from the walls of the dikes, and the breccia is cemented with quartz. Each of the varieties of felsic dikes has been seen to cut one or more varieties of the mafic dikes, and the varieties of mafic dikes are mutually cross-cutting.

The felsic dikes are gray, brown, and dark red. These dikes are generally massive and unmetamorphosed, but where the rhyolite is involved in N.70°W.--trending faults, a cataclastic foliation has developed in the rhyolite. Brownish-red phenocrysts of primary garnet are present in some undeformed rhyolite, and many rhyolite dikes have phenocrysts of feldspar and biotite. Rhyolite dikes in the western and southwestern parts of the main dike swarm in the granitic area have few phenocrysts of quartz. This is marked contrast to the dikes farther east in this swarm, which have conspicuous quartz phenocrysts. Possibly the presence of quartz phenocrysts in the eastern rhyolite dikes indicates that these dikes are among the earliest rhyolites to be emplaced in the swarm, and that they were intruded while the melt was oversaturated with silica. As the melt advanced in differentiation with time, the surplus silica was precipitated as early quartz phenocrysts. When a balance of quartz was achieved in the melt, then biotite and feldspar began to crystallize as phenocrysts in the younger dikes.

The wall zones of thick rhyolite dikes tend to be finer grained than the cores. Among the thicker dikes a gradation to microgranite and granite porphyry takes place inward from the walls. Pink granite dikes grade to felsite and pegmatite, and the pegmatite grades to quartz veins. Some of this granite and felsite seems to be older than both the rhyolite and andesite dikes, because it is intruded by both. These older granitic dikes with gradations to felsite, pegmatite, and quartz veins are probably late phases related to the biotite-hornblende granite that intruded the biotite-hornblende granite before the emplacement of the swarm of rhyolite and andesite dikes. Other dikes of pink to red granite that grade into felsite, pegmatite, and milky quartz veins intrude the dike swarm and the older granites. These granitic dikes are not intruded by other elements of the dike swarm. From these relations it is here inferred that the youngest dikes of granite, felsite, and pegmatite with associated quartz veins shown in this map unit are actually genetically related to the peralkalic granite. Separation of the dikes into three components by probable age was not possible in the time available for mapping.

Murdama Group

The Murdama Group underlies most of the western part of the Jabal Bitrān quadrangle. As mapped by Bramkamp and others (1956), these rocks were identified as sericite and chlorite schist and minor lenses of quartz and marble, and the unit was not named. Subsequently (U.S. Geological Survey-Arabian American Oil Company, 1963), these rocks were named the Abt Schist. Work in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) disclosed that the term Abt Schist had been applied to pelitic sediments and conglomerate of two distinct formations where these formations are both at the greenschist facies of regional metamorphism. The lower formation is in the Bi'r Khountina Group. The upper formation is in the Murdama Group, named in the Bi'r Ghamrah quadrangle (Overstreet and Whitlow, 1972a) where the usage of Jackson and others (1963) was modified from Murdama Formation to Murdama Group. The name Murdama Group is here extended northward into the Jabal Bitran quadrangle for the conglomerate, graywacke, and marble that overlies the Bi'r Khountina Group. In the Jabal Bitrān quadrangle the Murdama Group is regionally metamorphosed to the greenschist facies. Locally the metamorphic grade has been advanced slightly through contact metamorphism along the edge of intrusive peralkalic granite, but the biotitic schist thus formed at the contact is still in the greenschist facies owing, apparently, to low thermal energy and sparse volatile constituents. The major part of the Murdama Group in the area of plate 1 is chlorite-sericite schist, named here The Abt Formation in a revision of the original term Abt Schist (U.S. Geol. Survey - Arabian American Oil Co., 1963).

Abt Formation

The name Abt Formation of the Murdama Group is here given to the seemingly monotonous and uniform sequence of pelitic schist and phyllite composed of chlorite, sericite, and quartz. As used here the term Abt Formation is adapted from the original usage (U.S. Geol. Survey-Arabian-American Oil Co., 1963) and restricted to chlorite-sericite schist and associated rocks stratigraphically above the Bi'r Khountina. In the Bi'r Ghamrah and Wadi Mahraghah quadrangles where the unit is less metamorphosed, Overstreet and Whitlow (1972a, 1972b) show that the original rocks were dominantly pelitic graywacke, calcareous graywacke, rythmically bedded shale, and tuffaceous shale. Variations in the original composition of these rocks give the present variation in relative abundance of chlorite and sericite in the schists. Some chlorite-rich parts of the schist may originally have been mafic lava. Parts of the schist presently occupied by short, small, but numerous quartz-chlorite-carbonate veins and carbonate veins probably were calcareous shale, calcareous graywacke, and tuffaceous marl originally.

Evidently the Abt Formation overlies the Bi'r Khountina Group in the Jabal Bitrān quadrangle with pronounced angular unconformity, because the Abt appears to transgress eastward across all units of the Bi'r Khountina except the basalt conglomerate, and it may originally have overlapped that. A major fault at the contact between the Idsas Formation of the Bi'r Khountina Group and the Murdama Group prevents establishing with certainty that the Murdama Group also overlapped the Idsas Formation. In the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972), the Z'reiba Formation of the Murdama Group was found to contain detrital fragments of the major kinds of rocks in the Bi'r Khountina and Halaban Groups, but this conglomerate was not observed in the Jabal Bitrān quadrangle. From the components of this conglomerate to the south, however, it can be seen that both the Bi'r Khountina and Halaban Groups were exposed to erosion in Murdama time. Thus, the Abt Formation could have overlapped fully across the Bi'r Khountina and rest on the Halaban.

Folds several kilometers across can be seen on aerial photographs of the Abt Formation and small-scale folds can be observed in nearly every outcrop (Kahr, 1962, p. 7-8). Most fold axes plunge steeply. The chlorite-sericite schist is intensely cleaved, and its fabric indicates that more than one deformation plane is present. Where weathered, the schists display pencil structure. On aerial photographs the chlorite-sericite schists can be distinguished easily from other rocks by their characteristic conifer-branch pattern. This pattern results from erosion along several directions of cleavage and the intersections of cleavage planes and joint sets with folded sedimentary bedding. On smaller scale it is these features that give the pencil structure in weathered outcrop.

The several joint sets strike in different directions and range in angle of dip from vertical to horizontal. Some joints are coated by white quartz, and small veins and stringers of quartz are common throughout the unit.

Pyrite cubes are rather common in some of the darker parts of the schist. Locally the cubes are deformed and stretched parallel to steeply plunging lineation in the schist. In this respect they resemble stretched pebbles and cobbles in intraformational lenticles of conglomerate in the schist. The pyrite cubes are drawn out into streaks as much as 1 mm x 10 mm. Pressure shadows around less deformed pyrite cubes are occupied by quartz and chlorite.

Quartz in veins and pod-shaped masses tends to be white, very fine grained, and locally granular. Schist along the walls of the veins may be unaltered, or may display brown-colored zones of alterations up to 10 cm thick, or the veins may have selvages of chlorite along the walls. The principal minerals in the veins, other than quartz, are chlorite, calcite, ankerite, siderite, and pyrite. Locally the veins are drusy, and the druses are lined with small, stubby terminated quartz crystals and sparse pyrite. A very few quartz veins in the schist have minor muscovite, or possibly margerite, at the walls.

The Abt Formation around the north, east, and south sides of a small pluton of peralkalic granite in the southwestern quarter of the quadrangle is raised in an aureole of contact metamorphism to biotite-muscovite schist. Muscovitic schist, nearly greisen, is adjacent to the small intrusive of biotite granite porphyry and pink quartz porphyry 12 km to the northeast of the aureole of biotite-muscovite schist, but is too small to show at the scale of plate 1. This type of alteration was not noted around other masses of peralkalic granite in the western part of the quadrangle.

Marble

Several layers of white to dark gray marble were observed in the Abt Formation, and layers that are probably marble were identified on aerial photographs and plotted on plate 1. This marble is folded harmoniously with the rest of the Abt and offset locally on faults that also offset the Abt, but heavily silicified beds of marble like those of the Fawara Formation near the base of the Bi'r Khountina Group were not seen in the Murdama Group. Ultramafic rocks are not associated with the marble in the Murdama.

Peralkalic granite, quartz, porphyry, and aplite

Fine-grained, gray to pink, generally quartz-poor, biotite granite, and locally, biotite granite porphyry, is mapped as peralkalic granite on plate 1. Hypabyssal plugs of fine-grained quartz porphyry and liparite, and aplite dikes, thought to be genetically related to the peralkalic granite, are also shown but dikes so identified on the geologic map represent only a few of the many dikes in the area.

Jabal Bitrān is composed of peralkalic granite intrusive into the older biotite-hornblende granite and the Halaban Group. Hornfels has developed at contacts with the Halaban, which is here thought to indicate that emplacement of the pluton at Jabal Bitrān was accompanied by higher temperature than is indicated for the pluton in the southwest corner of the map. The southwest face of Jabal Bitrān is composed of fine-grained pink biotite granite that is locally sheared and mylonitized; the mylonite has been silicified. Epidote is common in the non-mylonitized parts of the pluton.

Small peralkalic plutons 3 or 4 km across in the southwestern and northeastern corners of the quadrangle have had only moderate contact-metamorphic effects on their wallrocks. Chloritic schists adjacent to the southwestern granite pluton were converted to biotitic rocks in a narrow aureole. In the northeast the peralkalic granite plutons have distinctive chilled margins against their wallrocks, and inclusions of gabbro are altered to chloritic aggregates.

A small plug of biotite granite porphyry and pink quartz porphyry intrudes phyllite of the Abt Formation about 21 km southwest of Jabal Bitrān. Locally the wallrocks are converted to greisen and coarse-grained muscovite schist. The porphyry contains inclusions of diorite, andesite, and schistose andesite not present in the immediately adjacent wallrocks. Much of the andesite and some of the diorite is epidotized, as is the porphyry at its contacts with the inclusions. Veinlets of porphyry also cut across epidotized parts of some inclusions, suggesting that either some epidotization of the andesite preceded the intrusion of the porphyry, or that the epidotization was completed before the porphyry solidified. More important than the epidotization, however, is the fact that these inclusions are not derived from the immediately adjacent wallrocks. It is here inferred that the inclusions of diorite, andesite, and schistose andesite are from the Bi'r Khountina Group and associated intrusives, and that the Bi'r Khountina at this locality underlies the Murdama but is not exposed. The porphyry on its way toward the surface is inferred to have plucked pieces of Bi'r Khountina at depth and transported them upward to the present level in the Murdama.

Dikes of pink quartz porphyry too small to show on the map are associated with the pluton of peralkalic granite 23 km east of Jabal Bitrān. They have chilled margins against both the peralkalic granite pluton and the gabbro, showing that the dikes are younger than either.

They are interpreted as being genetically a part of the peralkalic granite.

At the extreme edge of the map and intrusive into agglomerate of the Idsas Formation are two small plugs of intensely fractured quartz porphyry or possible liparite. The easternmost is snow-white liparite, or quartz trachyte, that contains white feldspar and large quartz idioblasts. Because it is extensively fractured, the rock might be hydrothermally altered, and might have been green dacite originally. It is intruded by a few unaltered, fine-grained green mafic dikes that are probably lamprophyre.

White to pink aplite dikes thought to be genetically related to the peralkalic granite cut the chlorite-sericite schist of the Abt Formation. Similar aplite dikes, which grade into pegmatite and white quartz veins, are present in the swarm of dikes in the eastern part of the quadrangle. Their probable relation to the peralkalic granite in the region of the dike swarm is indicated by the fact that they are not intruded by the andesite or rhyolite of the swarm.

Quartz knobs

Eleven white quartz knobs of possibly different ages and relations are shown in the southeastern quarter of the quadrangle, where they form conspicuous features in the landscape. Some rise as conical knobs to about 50 m above their surroundings. Others are much lower. They are seemingly barren white quartz veins; irregular masses of pink perthitic pegmatite are rarely present in them. Most of the knobs are associated with northwest-trending faults younger than the swarm of andesite and rhyolite dikes, but one or two of the quartz hills are older than the dike swarm and are cut by the dikes.

A quartz knob in the Abt Formation in the northwestern part of the quadrangle is distinctive for the platy aspect of the quartz, which causes it to resemble kyanite.

Lamprophyre(?)

Young, moss green lamprophyre(?) dikes are reported by Kahr (1962, p. 15) to cut all other rock units in the quadrangle. These dikes are not individually shown on plate 1, but are represented by some of the lines showing distinctive lineaments as seen on aerial photographs.

Quaternary rocks

Two units of Quaternary sedimentary rocks are shown on the geologic map. The younger is silt which consists of fine-grained sedimentary material deposited by water in the major wadi courses in the southwestern corner of the quadrangle. The older is sand consisting of alluvial sheet wash, and aeolian sand throughout the quadrangle. Included with the sand unit are sparse deposits of older terrace gravel and coalescing alluvial fans locally present along the flanks of the Idsas Range.

STRUCTURE

The major structural elements in the Jabal Bitrān quadrangle are a mantled gneiss dome in the east separated from a northerly plunging synclinorium of Murdama and Bi'r Khountina in the west by a narrow dejective zone of the Halaban and lower Bi'r Khountina much modified by imbricate overthrusts and accompanying tear faults.

Mantled gneiss dome

The composite pluton of hornblende-biotite granite gneiss and biotite-hornblende granite occupies most of the eastern part of the quadrangle. It is known from the work of Bramkamp and others (1956) to extend 25 km north of the northern edge of the Jabal Bitrān quadrangle. Its eastern and southern extent, in the Ayn Qunay and Sabkhat Muraysis quadrangles (Overstreet and others, 1972a; 1972b) is nearly 20 km beyond the Jabal Bitrān quadrangle. Altogether the composite pluton is a north-northwesterly elongated mass about 100 km by 40 km in size. Precambrian rocks adjacent to it dip off steeply but centrifugally. In the area shown on the Jabal Bitrān, Bi'r al Badrīyah (Overstreet, Whitlow, and others, 1972), Ayn Qunay (Overstreet and others, 1972a), and Sabkhat Muraysis (Overstreet and others, 197 b) quadrangles, planar structures in mafic phyllite and meta-rhyolite on the east, in the gneiss and granite, and in amphibolite, volcanic rocks, and metamorphosed sedimentary rocks on the west side are interpreted here to show that the composite pluton has the structural aspect of a dome. The composite pluton is here thought to be an example of the structure referred to by Eskola (1949) as a mantled gneiss dome.

The hornblende-biotite granite gneiss makes up the limbs of the dome, in a general way, and the biotite-hornblende granite makes up the core of the dome. The biotite-hornblende granite core is somewhat eccentric, and seems to occupy more of the southern half of the dome than of the northern half. The hornblende-biotite granite gneiss on the limbs is inferred to be overlain by, or intruded by, all other rock units. It contains, however, boudins of schistose mafic dikes, and, more important from a stratigraphic viewpoint, inclusions of layered parageniss and skarn, which may represent relicts of a sedimentary sequence older, possibly much older, than the hornblende-biotite granite gneiss.

The biotite-hornblende granite in the core of the mantled gneiss dome is younger than all units except the upper part of the Bi'r Khountina Group and the Murdama Group, and is thought to be remobilized hornblende-biotite granite gneiss brought to an intrusive phase during mid-Bi'r Khountina regional metamorphism of no greater intensity than the albite-epidote amphibolite facies or lower subfacies of the amphibolite facies.

Central dejective zone

A narrow but strikingly defined central arcuate belt of steeply dipping and generally north-northwest striking metamorphosed sedimentary and volcanic rocks forms the western mantle on the gneiss dome in the Jabal Bitrān quadrangle. This belt includes the most highly metamorphosed and most sheared rocks in the quadrangle, and appears to have occupied a buffer position between the gneiss dome and the immense thickness of less metamorphosed schists of the Bi'r Khountina and Murdama Groups. For this structural element in the Jabal Bitrān quadrangle the term "dejective zone," used by Osborne (1948, p. 103) in the Canadian Shield, is here introduced. The Jabal Idsas dejective zone includes an area of complex deep, steep faults, deep folds, intrusions of alpine-type ultramafic rocks, and west-riding imbricate overthrust faults. The Jabal Idsas dejective zone is, therefore, a feature along which tectonic activity was focussed for a long period of geologic time.

The synclinal character of the dejective zone is shown best in the northwestern part of the quadrangle north of the Mashaliya mine. There both the east and west limbs of a south-plunging syncline in the Bi'r Khountina Group are preserved, as defined by exposures of the Farawa Formation. The lowest part of the west limb, presumably originally occupied by the Idsas Formation, is missing owing to overthrust faulting toward the west, but on the east side of the structure the Idsas Formation is present. Southeast of the Farawa mine almost all the Bi'r Khountina rocks are missing because of the overthrusting toward the west.

Synclinorium

The western third of the quadrangle is underlain by pelitic schists in which minor folds several kilometers across can be seen on aerial photographs. Along the southwestern and west central parts of the quadrangle older rocks of the Bi'r Khountina Group are overlain by the Abt Formation, the exposures of which widen toward the north. These relations suggest that the gross structure is a north-plunging synclinorium of regional magnitude. Only a low grade of metamorphism is reached, even in the core of the synclinorium, but the grade is remarkably uniform and must, therefore, be part of the regional pattern of deformation. A few small stocks of post-tectonic peralkalic granite pierce the pelitic schists in the core of the synclinorium and contain rafted inclusions of andesite typical of the Bi'r Khountina Group. These inclusions are evidence that the andesitic Badrīyah Formation of the Bi'r Khountina Group underlies the Abt Formation in the core of the synclinorium. They also suggest that the folds in the synclinorium may be rather shallow, a characteristic that might also be inferred from the low metamorphic grade of the schists.

The east edge of the synclinorium is more complexly folded than the core. Along this edge the rocks enter the Jabal Idsas dejective zone and are much modified by the imbricate overthrust faults.

Imbricate overthrusts and tear faults

The imbricate overthrusts faults along the west side of the Idsas Range have caused blocks of hornblende-biotite gneiss, biotite-hornblende granite, and rocks of the Halaban Group to ride westward over large segments in the lower part of the Bi'r Khountina Group. Various blocks in the upper plates have moved differentially westward onto the schists of the Abt Formation. These relations are shown by the disappearance southward of the marble and ultramafic rocks forming the two limbs of the south-plunging syncline of Bi'r Khountina Group rocks in the northwestern part of the quadrangle discussed in the section on the central dejective zone.

Both limbs of this syncline are preserved in the northwestern part of the quadrangle, and at that locality the western limb is the most westerly overthrust part of the ultramafic rocks in the quadrangle. The northeast-trending fault near Mashaliya mine seems to be a tear fault separating an overthrust block of folded Bi'r Khountina in the north from undisplaced Murdama in the south. It is likely that an extension of this tear fault enters the hornblende-biotite granite gneiss just south of Jabal Bitrān, but it was not seen. The syncline of Bi'r Khountina to the north of the tear fault is bounded on the west by a steep overthrust fault or reverse fault which has carried westward the syncline in the Bi'r Khountina. The relative motion is east side up. This fault block is regarded as the oldest overthrust block in a sequence of imbricate faults which extends south of the tear fault.

A somewhat younger, steep, overthrust fault extends southeastward along the west side of the Idsas Range to a point about 2 km northwest of the Fawara mine. There the overthrust fault appears to grade into an east-southeast striking tear fault which reaches eastward across the quadrangle. Between the Mashaliya mine and Fawara mine most of the Bi'r Khountina Group is missing. The Idsas Formation of the Bi'r Khountina Group and parts of the Umm Mushraha Formation of the Halaban Group are brought into fault contact with the Abt Formation. Possibly some Abt Formation even emerges east of the fault in the area labelled Abu Sawarir Formation of the Bi'r Khountina Group southwest of Jabal Idsas, but the relations are uncertain. This imbricate block between the Mashaliya and Fawara mines, composed of minor amounts of Idsas

Formation and minor amounts of the Umm Mushraha Formation, with major biotite-hornblende granite and hornblende-biotite gneiss, is here inferred to be younger than the thrust block north of Mashaliya. The block between the Mashaliya and Fawara mines is here inferred to have wholly overridden a now hidden lower thrust block of the Farawa Formation and Abu Sawarir Formation that did not move as far west as the block north of the Mashaliya mine. The imbricate block between Mashaliya and Fawara was thrust westward onto Murdama.

A third imbricate block can be defined between a point about 2 km northwest of the Fawara mine to the tear fault about 2 km south of Selib mine. This block includes the southern extension of the west limb of the syncline in the Bi'r Khountina Group present north of the Mashaliya mine. This west limb is composed of Farawa Formation, Abu Sawarir Formation, and ultramafic rocks and has ridden westward on an overthrust thought to be the same age as the overthrust northwest of Mashaliya. This lower plate has moved differentially westward over Badrīyah Formation and Abt Formation. The core and east limb of the syncline in the lower block were in turn overridden westward by a younger block composed of Idsas Formation, Umm Mushraha Formation, gneissic granodiorite, gabbro, hornblende-biotite granite gneiss, and biotite-hornblende granite. The entire east limb of the syncline seen northeast of the Mashaliya mine is missing between Fawara and Selib mines, but some of the schist in the core of the syncline is exposed between the ultramafic rocks on the west and the westward overthrust Umm Mushraha Formation in the central part of the lower plate.

South of the Selib mine the Idsas and Fawara Formations and sparse ultramafic rocks of the west limb of the above-described syncline are overthrust westward onto younger volcanic rocks of the Badrīyah Formation. West-northwest-trending tear faults separate the two inbricate overthrust blocks between the Fawara and Selib mines from the overthrust block south of Selib mine. The overthrust block south of Selib mine is the most southerly in the quadrangle. It is in an area where the Halaban Group commences to widen eastward as it begins to close around the southern end of the mantled gneiss dome. The Jabal Idsas dejective zone may die out as a definable structure in the widening of the Halaban, but its trend seems to persist southeastward in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) as the fault zone along the contact between the Bi'r Khountina and Halaban Groups.

GEOLOGIC RELATIONS OF SELECTED ELEMENTS

Samples of wadi sand, concentrates, and detrital magnetite were collected at 56 localities in the Jabal Bitrān quadrangle. The samples were analyzed for selected elements; the principal results are represented on the geologic map (plate 1).

Procedure

Samples weighing about 10 kg were dug from the upper 30 cm of dominantly water laid wadi sand. These samples were sieved on stainless steel screens to get 100 g of -30 mesh +80 mesh sand, and the tailings from sieving were panned. The heavy-mineral concentrate from panning was examined under ultra-violet light for scheelite and powellite, and magnetite was separated from the concentrate.

Chemical and spectrographic analyses were made of the sieved sand, and chemical analyses were made of the magnetite and concentrate at the Jiddah Laboratory of the Directorate General of Mineral Resources, Kingdom of Saudi Arabia. Semiquantitative spectrographic analyses of the sieved wadi sand were made by C. E. Thompson, U.S. Geological Survey, and Kamal Shahwan, Directorate General of Mineral Resources, for 27 elements. Chemical analyses of the sand and detrital magnetite, for copper, zinc, and molybdenum, and of the concentrates for these three elements plus tungsten, were made by Thompson, and L. Aldugaither. Methods of spectrographic analysis (Theobald and Thompson, 1968, p. 2) were adaptations of techniques used by the U.S. Geological Survey, and the wet chemical analyses followed normal procedures for trace-elements analysis.

Results

The results of the analyses are shown by histograms (figs 2 and 3). Figure 2 gives the 16 elements present in detectable amounts in wadi sand. Eleven other elements were looked for but not found. These elements and their limits of detection are: silver, 1 ppm (part per million); beryllium, 2 ppm; bismuth, 20 ppm; cadmium, 50 ppm; germanium, 20 ppm; lanthanum, 20 ppm; niobium, 50 ppm; antimony, 200 ppm; tin, 10 ppm; tungsten, 50 ppm; zinc, 100 ppm. The abundances of the 16 detected elements were compared with the results of 321 similar samples of wadi sand from the Precambrian area of the southern Tuwayq quadrangle, and nine elements were found to reach threshold 1/ amounts in some samples a small positive anomaly for nickel was found in one sample (table 1). The wet chemical analyses of the wadi sand (fig. 3) confirm the results of the spectrographic analyses for copper, zinc, and molybdenum. Chemical analyses of the concentrates (fig. 3) disclosed seven times as many threshold values for copper as were found in the analyses of the sand, and the only chemical data on tungsten came from analysis of the concentrates (table 2). The two samples of magnetite having threshold values for copper and molybdenum do not coincide with samples in the other media. The anomalous sample and most of the threshold samples are from localities in the dejective zone.

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

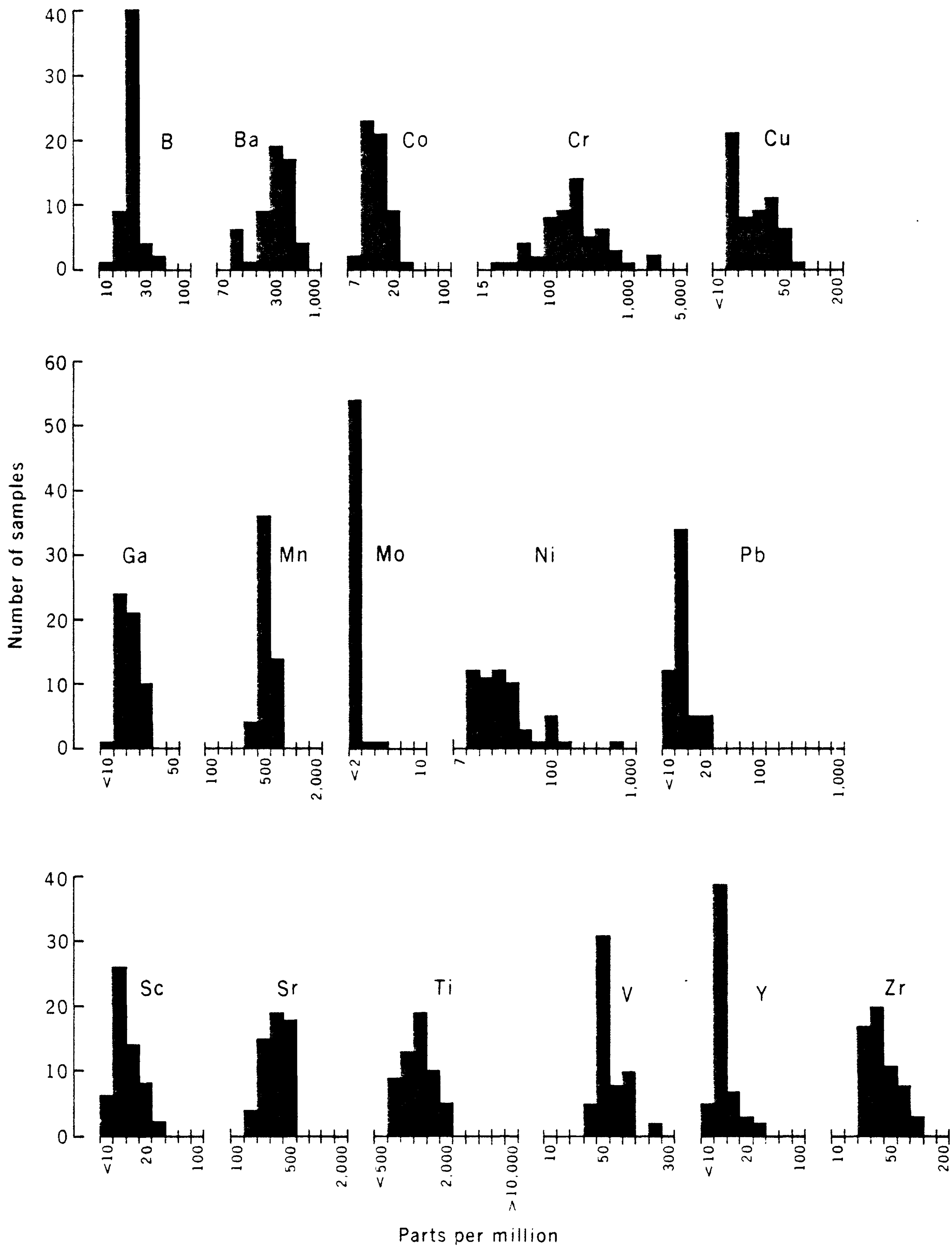


Figure 2. Histograms of 56 spectrographic analyses of wadi sand, Jabal Bitran quadrangle

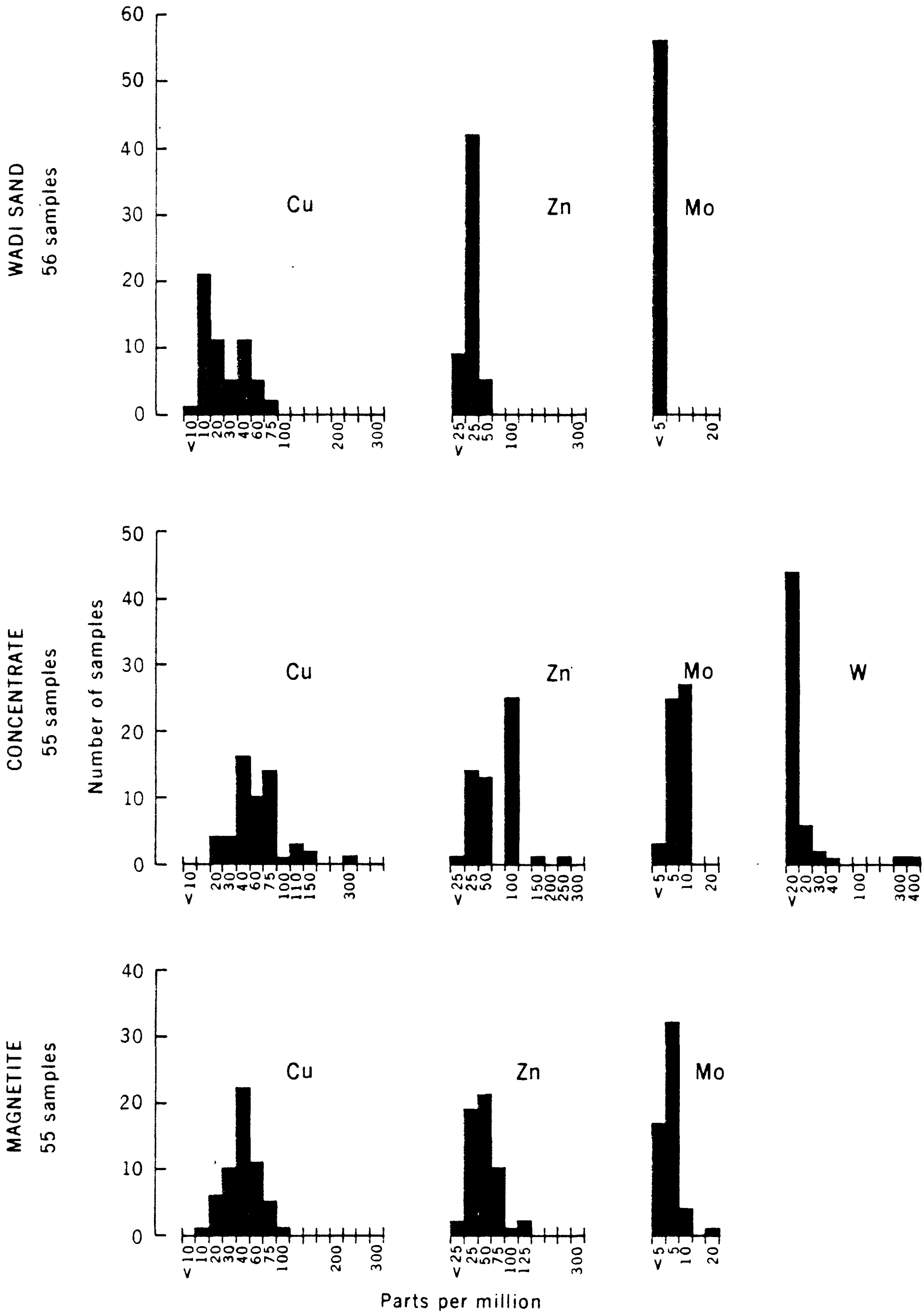


Figure 3. Histograms of wet chemical analyses of magnetite, concentrate, and wadi sand, Jabal Bitran quadrangle

Table 1.--Threshold values for selected elements in wadi sand, Jabal Bitran quadrangle, Kingdom of Saudi Arabia
(Analyses by C. E. Thompson and Kamal Shahwan)

Element	Regional threshold in Southern Tuwayq quadrangle (ppm)	Number of samples at or above regional threshold value, Jabal Bitrān quadrangle
B	50	2
Co	30	1
Cr	1,000	3
Cu	70	1
Mo	3	1
Ni	70	8 (a)
Sc	30	2
V	150	2
Y	30	2

(a) Includes one sample with the anomalous value of 700 ppm.

Table 2.--Threshold values for copper, zinc, molybdenum, and tungsten by wet chemical procedures, Jabal Bitrān quadrangle, Kingdom of Saudi Arabia
(Analyses by C. E. Thompson and L. Aldugaither)

Element	Regional threshold in Southern Tuwayq quadrangle (ppm)			Number of samples at or above regional threshold value, Jabal Bitrān quadrangle		
	Sand	Concentrate	Magnetite	Sand	Concentrate	Magnetite
Cu	75	100	100	2	7	1
Mo	5	20	20	--	--	1
W	--	60	--	--	5	--
Zn	75	150	150	--	2	--

Metals by multiple analyses

The abundances of copper, zinc, and molybdenum were determined in wadi sand, concentrate, and detrital magnetite by chemical analyses and in the sand by spectrographic methods. Tungsten was sought and detected chemically only in the concentrates, but it was also sought, although not found, in wadi sand by spectrographic methods. The results of the spectrographic determinations are shown on plate 1, where it can be seen that one sample has 70 ppm copper and one has 3 ppm molybdenum. Zinc was below the limit of spectrographic detection in all samples. Wet chemical analyses disclosed threshold amounts of copper in two samples of sand, sparse threshold values in one sample of magnetite each for copper and molybdenum, a real increase in the numbers of samples with threshold copper and zinc in concentrates, and five threshold values for tungsten in concentrates (table 2). No metal in these samples forms a positive geochemical anomaly.

<u>Copper</u>.--Threshold values for copper in the various sample media group in two areas. One area is the contact zone between hornblende-biotite granite gneiss and gabbroic rocks and amphibolite at the south edge of the mapped area. The other is the dejective zone west of the Idsas Range from a point 2 km north of Selib mine to the south side of the major tear fault near the Mashaliya mine (plate 1). At none of these localities is threshold zinc associated with threshold copper, but at one locality, where powellite was seen in the concentrate, a low threshold for molybdenum occurs with copper. Threshold values for tungsten were found at two places where copper thresholds were detected. None of the copper values in any of the sample media is thought to indicate the presence of exploitable copper, but they confirm megascopic evidence, known since 1955-56 (Schaffner, 1955; 1956a; 1956b), that traces of copper are present in the Idsas Range and in the mafic rocks southeast of the range.

Chemical analyses disclosed copper threshold values at the southeastern edge of the quadrangle in two samples of wadi sand taken at the contacts between biotite rich hornblende-biotite granite gneiss and gabbro and amphibolite. At the southeastern most of these two samples, 18 km southeast of Selib mine, a concentrate from the sand also had threshold copper, and the concentrate from a sample taken 1.3 km to the northeast was also copper bearing. A copper-bearing concentrate was obtained from a small body of gabbro about 2 km north of the two small mines 19 km southeast of Selib mine. The only sample of magnetite found to have threshold copper in this quadrangle was taken from the area of fault contact between biotite-rich hornblende-biotite granite gneiss and gabbro 12 km south-southeast of Selib mine.

Threshold copper in the dejective zone was found principally in concentrates, but threshold copper was also found in one spectrographic analysis of sand. Concentrates from a source in andesite, conglomerate, and ultramafic rocks in the fault zone 1.6 km north of Selib mine contain 300 ppm copper, thus this concentrate is the most copper-rich detrital sample analyzed in the Jabal Bitrān quadrangle. It is equalled only by one concentrate from the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972) and is exceeded in quantity of copper only by one concentrate from the Bi'r Ghamrah quadrangle, which has 600 ppm copper (Overstreet and Whitlow, 1972a). A low threshold quantity of 70 ppm copper was detected spectrographically in concentrates from the fault contact between the Idsas Formation and the Abt Formation 4 km northwest of Fawara mine. The largest number of threshold values for copper in concentrates is in the northern part of the dejective zone south of the major tear fault south of the Mashaliya mine. A concentrate from the Abt Formation, and one from the fault zone in the Mashuton(?) mine, contain 150 ppm copper. A concentrate from the area of contact between the Badrīyah Formation and ultramafic rocks east of the Mashaliya mine contains 100 ppm copper.

The tendency of the concentrates to be the source of more threshold values for copper than the sand or magnetite is thought to result from concentration of copper carbonate minerals in the heavy-mineral fraction. At most places where threshold copper was found in the concentrate, minor amounts of copper carbonate minerals were seen on joints and fractures or in quartz-carbonate-chlorite stringers.

Zinc.--Threshold amounts of zinc were detected in two concentrates from a mineralized part of the dejective zone. A concentrate having 250 ppm zinc came from the immediate area of the northern workings of Selib mine and included material washed off the dumps and tailing piles plus normal erosional debris from the Badrīyah Formation and from ultramafic rocks. No other sample in the Jabal Bitrān quadrangle, nor in the quadrangles to the east and south (Overstreet and others, 1972b; Overstreet, Whitlow, and others, 1972; Overstreet and Whitlow, 1972a; 1972b), contains as much zinc as this. The other zinc-bearing concentrate is from an area of Fawara Formation 1 km south of Selib mine.

Molybdenum and tungsten.--Fifteen localities are shown on the geologic map (plate 1) at which scheelite and/or powellite were detected in concentrates by their fluorescence under ultra-violet light, and three localities are shown where only powellite is present in the concentrate. Wadi sand from the powellite locality 4 km northwest of Fawara mine contains 3 ppm molybdenum by spectrographic analysis, but neither the powellite-bearing concentrate nor the magnetite was found by chemical procedures to contain molybdenum. The other places where only powellite was found in the concentrate, but where molybdenum was not identified chemically, are 9 km northwest of Fawara mine on the fault contact between the Umm Mushraha and Abt Formations, and the small stock of biotite granite porphyry 12 km west of Selib mine.

A sample of magnetite from peralkalic granite on the south side of Jabal Bitrān was found to contain 20 ppm molybdenum. Concentrates at this locality are among the most scheelite-rich in the quadrangle, but chemical analyses of the concentrates failed to disclose either tungsten or molybdenum. Threshold quantities of molybdenum were not found in other concentrates from the Jabal Bitrān quadrangle, but magnetites with equal abundances of molybdenum are known in the Bi'r Ghamrah and Wadi Mahraghah quadrangles (Overstreet and Whitlow, 1972a; 1972b), where they are associated with even younger igneous rocks than the peralkalic granite.

Powellite was found with scheelite in the east-central part of the quadrangle in the concentrates from skarn 18 km southeast of Bi'r el Ankeriya (plate 1) and from biotite-hornblende granite 24 km southeast of Bi'r el Ankeriya. In the northwestern part of the quadrangle powellite is associated with scheelite in a concentrate from the Mashuton (?) mine on a fault zone in the Abt Formation. At the skarn locality the powellite dominates over scheelite; elsewhere where the two minerals occur together, scheelite is dominant. The presence of powellite is not indicated by above-background abundances of molybdenum.

Threshold quantities of tungsten were detected chemically in five concentrates, of which three were identified as scheelite bearing. Thus, two tungsten-bearing concentrates did not contain scheelite, and 12 of the 15 scheelite-bearing concentrates contained less than threshold quantities (table 2) of tungsten. The most tungsten-rich concentrate in the Jabal Bitrān quadrangle, one with 400 ppm tungsten, is from the area of the Mashuton (?) mine. Both scheelite and powellite are present in the concentrate, but only tungsten is above background in the analysis. The next greatest amount of tungsten, 300 ppm, was found in a scheelite-bearing concentrate from peralkalic granite on the south side of Jabal Bitrān. Magnetite from this source has threshold amounts of molybdenum, but powellite is not in the concentrate.

Low threshold quantities of tungsten were reported for three concentrates from areas of the Abt Formation in the northwestern quarter of the quadrangle near the western edge of the dejective zone. Concentrates with 40 ppm tungsten, and also displaying threshold copper, were taken at the locality 2 km southeast of the Mashaliya mine. Concentrates with 30 ppm tungsten were taken at a scheelite-bearing locality 8.6 km west-northwest of Mashaliya mine and at a locality lacking scheelite 1.6 km west of Mashara mine. At these three localities the Abt Formation has stringers and podlike masses of quartz-carbonate-chlorite vein material thought here to be of metamorphic segregation origin. The sparse tungsten may be from these veins, but tungsten minerals were not identified in them.

Anomalous nickel

An anomalous value of 700 ppm for nickel was found in a sample of sand derived from ultramafic rocks 1.2 km west of Mashaliya mine at the west edge of the dejective zone. This is the only metal detected in anomalous quantity in the quadrangle. Threshold nickel, described below, is also restricted to the west edge of the dejective zone and is dominantly associated with the younger ultramafic rocks.

The ultramafic rocks from which the sand having the positive nickel anomaly is derived are serpentinite and metabasalt, with which sparse asbestos and magnesite are associated. The nickeliferous sample also contained 30 ppm cobalt, which is the only threshold value for cobalt in the quadrangle. The ultramafic rocks represented by the sample may be slightly enriched in nickel, but no nickel or cobalt minerals were seen at this locality. Further search of the ultramafic rocks in the vicinity of the Mashaliya mine should be made for nickel minerals. At the same time, these ultramafic rocks should be examined for possible platinum-group metals.

Threshold elements

Semiquantitative spectrographic analyses of wadi sand revealed threshold abundances of cobalt, chromium, nickel, scandium, vanadium, yttrium, and boron (table 1), in addition to the threshold abundances of copper and molybdenum discussed above.

Strong geologic similarities exist in the distribution of most of the threshold elements in wadi sand. Cobalt, chromium, and nickel are associated in the dejective zone, where they are in sand derived from ultramafic rocks. Scandium is associated with the Umm Mushraha Formation, gneissic granodiorite, and older gabbro southeast of the dejective zone. Vanadium and yttrium occur in samples from the upper plate of the youngest overthrust fault in the dejective zone.

<u>Cobalt, chromium, and nickel</u>.--Cobalt, chromium, and nickel in threshold amounts are dominantly associated with the ultramafic rocks at the west edge of the dejective zone. However, only chromium and nickel are in the northern part of the zone.

Cobalt is an extremely scarce element in the quadrangle despite the amount of mafic rocks. The single occurrence of threshold cobalt is at the above described positive anomaly for nickel, which is also the source of the highest radioactivity observed in the quadrangle.

Three samples having threshold chromium are in the vicinity of the Selib mine in the southern part of the dejective zone where the samples also contain 100 ppm nickel. Samples having 2,000 ppm chromium were obtained at Selib mine and at a point 7 km northwest of the mine. A sample 1 km south of Selib mine contains 1,000 ppm chromium. All three samples are derived from ultramafic rocks, but magascopic chromite was not seen. The analytical values for chromium are in the ordinarily expectable range for ultramafic rock debris.

The threshold values for nickel range from 70 to 150 ppm, most values being at 100 ppm. As previously stated, three of the 100 ppm values are in chromium-bearing samples from sand in the area of the Selib mine where the sources of the sand are ultramafic rocks at the west edge of the dejective zone. These values are not exceptional for debris from ultramafic rocks. Two samples having 100 ppm nickel and one of 150 ppm nickel come from the Abt Formation close to or on faults along the west edge of the dejective zone in the northwestern quarter of the quadrangle. A single sample of 70 ppm nickel is from the Abu Sawarir Formation in the syncline in the northern part of the dejective zone. The sample having 150 ppm nickel is from a fault zone at Mashuton (?) mine where concentrates contain 400 ppm tungsten. Tungsten is also present in concentrates from samples having 100 ppm nickel in the area of the Abt Formation. No geologic reason for the association is known.

Scandium.--Two samples having the threshold value of 30 ppm scandium are derived from contacts of older gabbro, gneissic granodiorite, and Umm Mushraha Formation with the hornblende-biotite granite gneiss in the southeastern quarter of the quadrangle. The samples are on the southeast side of the dejective zone, and they appear to be a northerly extension of threshold values for scandium associated with older mafic rocks in the Bi'r al Badrīyah quadrangle (Overstreet, Whitlow, and others, 1972). Unlike some scandium occurrences in the Bi'r al Badrīyah quadrangle, none in the Jabal Bitrān quadrangle is related to tungsten minerals. Doubtless the threshold scandium in the southern part of the Jabal Bitrān quadrangle is associated with hornblende in mafic rocks.

Vanadium and yttrium.--Three of the four threshold vanadium and yttrium samples are from sand from the upper plate of the younger overthrust fault in the dejective zone. Both vanadium samples are from the southern flank of Jabal Idsas, representing essentially opposite ends of the magnetite-rich area. The magnetite has not been analysed for vanadium, but it is likely that unusual abundances of detrital magnetite in the wadi sand contributed to the 200 ppm vanadium in these samples. The eastern of the two lacks any other threshold element, but the northwesterly of the two has threshold boron, copper, and molybdenum.

Both threshold samples of yttrium are from the northwest quarter of the quadrangle, and both contain 30 ppm yttrium. The southern of the two is sand from the Umm Mushraha Formation just east of the younger overthrust fault in the dejective zone. The northern threshold sample for yttrium is from peralkalic granite at Jabal Bitrān in the younger overthrust plate of the dejective zone. No genetic relation is known to exist between the two yttrium-bearing samples or the yttrium-bearing samples and vanadium-bearing samples. The relation to the upper plate is thought to be spatial and fortuitous.

Boron.--A distinctive association between threshold boron and an aplite dike intrusive into the Abt Formation probably exists at the westernmost of two samples of threshold boron, about 20 km west of Selib mine. The eastern of the two, 20 km northwest of Selib mine, is associated with threshold copper, molybdenum, and vanadium. Fine-grained granitic dikes are present at the eastern of the two, but the dikes are probably older than the aplite in the Abt Formation, and they also seem to contribute too little detritus to the total sample to influence the abundance of boron. In the eastern occurrence the geologic source of the boron is not known.

RADIOACTIVITY

Radioactivity higher than 2.5 times background in the area of the Jabal Bitrān quadrangle is shown by the results of airborne scintillometer surveys made by Hunting Survey Corporation, Ltd. (1962). No areas of outstanding radioactivity were detected.

Spot scintillometer readings were made at 66 localities in the Jabal Bitrān quadrangle during the present reconnaissance mineral survey. Four localities having greater than 2.5 times background radioactivity were found.

The most radioactive location is 2 km south of Bi'r el Ankeriya in the center of the quadrangle where pervasive potassic metasomatism appears to have produced biotite-hornblende granite from hornblende-biotite granite gneiss. At the contact zone between the biotite-hornblende granite and the Umm Mushraha Formation the radioactivity is 4.5 times background. Allanite in the biotite-hornblende granite is possibly the source of the radioactivity.

The second most radioactive spot measurement was made at the sample locality about 1 km west of the Mashaliya mine. Radioactivity at this locality reached 3.8 times background. Although anomalous nickel and the only threshold value for cobalt found in the quadrangle were detected here, actual evidence of mineralization in the serpentinite and metabasalt was not seen. Possibly the radioactivity is caused by small amounts of uranium associated with sulfide minerals.

Two localities about 0.4 km apart near the west edge of the biotite-hornblende granite 14 km east of Selib mine showed 3.3 times background radioactivity. The area is underlain by biotite-hornblende granite intruded by andesite dikes which are intruded by dikes of rhyolite and rhyolite porphyry. This sequence is intruded by dikes of gray to pink feldspathic biotite granite which may be part of the peralkalic granite unit. The rhyolite dikes tend to have phenocrysts of biotite and feldspar. Radioactive minerals were not observed. Possibly the higher than background radioactivity is caused by allanite.

Of these spot locations of above-background radioactivity, the one in the northwestern part of the quadrangle seems to be most interesting geologically. A local ground scintillometer survey should be made to determine the size of the area of anomalous radioactivity, and the minerals and elements responsible for the radioactivity should be determined.

MINERAL DEPOSITS

The most prominent evidence for mineral deposits and potential mineralization in the area of the Jabal Bitrān quadrangle are the at least nine abandoned ancient gold mines, the outcrops of massive and disseminated magnetite, the large outcrops of garnet, the prominent quartz knobs, and the conspicuous but minor localities of secondary copper minerals. Indirect evidence of potential mineralization is given by airborne and ground magnetometer and scintillometer surveys (Agocs, 1961; Hunting Survey Corporation Ltd., 1962; Davis and Allen, 1967; Davis and others, 1970), and the results of geochemical and heavy-mineral reconnaissance.

These data show a strong preferred regional distribution of evidence of mineralization along the dejective zone. The five named mines are associated with the dejective zone, as are eight of the nine minor surface displays of copper minerals. Magnetite, asbestos, and magnesite crop out in the dejective zone. Two of the four anomalously radioactive areas detected by ground measurements are in the dejective zone. The single anomalous element and 29 of the 40 threshold amounts of metals are in the dejective zone, as are nine of 18 occurrences of scheelite and/or powellite. This concentration of direct and indirect data on possible mineralization along the dejective zone far surpasses the evidence for mineralization in the other parts of the quadrangle. The southwestern part of the mantled gneiss dome, including the area of gabbro and amphibolite on the southwest side of the dome, is the next most important area of mineralization in the quadrangle. The least mineralized area is the synclinorium in the Murdama Group.

Localization of mineralization along the dejective zone may be attributed to two factors. Much of the mineralization, or evidence for mineralization, is associated with ultramafic rocks, and the ultramafic rocks are virtually confined to the dejective zone. Many of the gold veins were formed by hydrothermal deposition along faults, and the major faults in the quadrangle are in the dejective zone.

Gold and base metals

Gold seems to have been the principal metal sought by the ancients in the area, but a little copper and iron may have been taken.

Dejective zone

Five named, abandoned, ancient mines thought to have been opened for gold, and one regarded in the literature as a former copper mine (Saudi Arabia Ministry of Petroleum and Mineral Resources, 1965, p. 23-26) are associated with faults, marble, and ultramafic rocks along the west side of the dejective zone. The ancient gold mines exploited white quartz in hydrothermal veins, and gold in silicified, dolomitized, or serpentinized rocks in the walls of the veins. Commonly the wallrocks are tan silicified marble, serpentinite, and peridotite. The veins and altered zones that were opened tend to be less than 1 m wide. Generally the openings were short but several are many hundreds of meters in length. At a few mines, altered zones as much as 2 km long were explored by a succession of short trenches.

Fawara mine is the largest ancient gold mine in the Jabal Bitrān quadrangle. It is followed in size by Selib mine, which is larger than the Mashuton(?), Mashaliya, and Mashara mines, all of which are presumed to have been worked for gold. Near the center of the quadrangle is a prominent slag pile and ancient ruined buildings to which the name Idsas mine is applied. Idsas mine is regarded in the literature (Schaffner, 1956b; Saudi Arabia Ministry of Petroleum and Mineral Resources, 1965, p. 26) as a copper mine, but the interesting possibility exists that Idsas was principally an iron furnace (see p. 50). Minor but common displays of copper minerals are, however, fairly common in the dejective zone.

<u>Fawara mine</u>.--The Fawara mine, also called Fawarah and Fawarah Hills in earlier reports (Schaffner, 1955; MacLean, 1958a; Directorate General of Mineral Resources, 1959; Saudi Arabia Ministry of Petroleum and Mineral Resources, 1965), is near the center of the quadrangle at and near the crest of a conspicuous north-trending ridge of dolomite, dolomitic schist, serpentine, sheared, possibly spilitic, andesite, and chlorite-sericite schist of the Bi'r Khountina Group. The ridge is about 2.5 km long, and the open trenches and shallow stopes of Fawara mine are strung southward along the ridge for about 2.1 km.

The larger openings, which reach about 200 m in length, are generally less than 5 m deep, and rarely over 1-1.5 m wide. They tend to be oriented along silicified north-trending fractures. Subsidiary openings follow a second set of silicified fractures at about N. 70° W., a few trend less nearly west. These two sets of fractures are parallel to the major regional fault directions. Many of the trenches are inclined westward. The westward incline is here thought to follow bedding directions in the west limb of a regional, south-plunging syncline, the east limb of which is covered by the younger overthrust plate of the dejective zone. The quartz veins appear to have replaced dolomitic marble and dolomitic schists on the west side of greatly disturbed serpentinite containing boudins of co-magmatic felsic rock, and thin stringers and masses of magnesite. Extensive magnesian metasomatism appears to have affected marble and ultramafic rocks prior to the formation of the vein deposits, because the quartz veins replace and fill fractures in dolomite and cut across magnesite, but how early the magnesia metasomatism took place is uncertain.

The veins consist of quartz, and they apparently contained free gold, although gold was not actually seen in the veins by the writers. Rare copper carbonate stain and more common iron oxide stain is present in the veins and along the walls but sulfide minerals are uncommon. From the fact that large masses of vein material were locally untouched by the ancient miners, and parts of the altered wallrocks were selected, it is assumed that former mining was closely controlled by sampling, and that the material taken was the richest in free gold that could be found. Little or no base metals seem to have been produced at Fawara mine, and the assays in the records of the Ministry of Petroleum and Mineral Resources (Schaffner, 1956b) show gold averages of only 0.07 oz/ton, and silver at 0.17 oz/ton.

Reconnaissance geochemical samples of wadi sand, concentrate, and magnetite taken in the Fawara area during the present investigation were below threshold values (table 2) for copper, lead, zinc, molybednum, tungsten, cobalt, nickel, and chromium. Further surface sampling for gold and more detailed geochemical sampling than was done by Schaffner (1956b) and followed in this work is needed to complete an examination of the Fawara area, but the present results indicate that a low priority can now be attached to Fawara in the national mineral exploration program.

Selib mine.--Selib mine is in the south-central part of the Jabal Bitrān quadrangle about 16 km south-southeast of Fawara mine. Variations in the spelling of the name of the mine, noted in assay reports, maps, and records of the Directorate, include Salib and Saleeb, but the published version is Selib (Ministry of Petroleum and Mineral Resources, 1965, p. 24)

The former workings at Selib mine include shallow trenches on quartz veins and shallow placer openings on alluvial fans and wadi fill close to the veins. Most of the workings, both vein and placer, are between the northeast-trending faults shown on plate 1, but placer tailings are to the north and south of the faults, and several small veins are south of the southern fault. The openings on the veins range in length from a few tens of meters to about 350 m; most of the major trenches are 50 to 100 m long. The trenches do not exceed 2 to 3 m in depth and are generally about a meter wide. The trenches are in white quartz veins having accessory calcite closely associated with tan carbonate rocks in a generally north-trending sequence of sheared spilitic(?) andesite and chlorite-sericite schist of the Badrīyah Formation intruded by serpentinized ultramafic rocks. The quartz veins occupy shears in the schist and andesite.

At the southern workings of the Selib mine, layers of brown silicified marble are interbedded with sheared andesite, keratophyre, and quartz keratophyre (Kahr, 1962, p. 9). The sheared volcanic rocks are also fractured along vertical planes at N. 80° E., and these fractures are strongly altered and filled in part with jasper. The concordant silicified carbonate layers grade into silicified andesite. Milky quartz veins are in the silicified carbonate layers, and the veins contain copious calcite with sparse pyrite. Pyrite is also present in the silcified andesite.

The north and largest workings follow milky quartz veins and pod-shaped masses in serpentinite. The serpentinite incompletely replaces ultramafic rocks. At the surface the serpentinite is generally altered to a brown color, possibly from oxidation of pyrite. The pod-shaped masses of milky quartz are oriented en echelon along a trend of about N. 10° E., but the individual masses of quartz, which are as much as 70 m long and 8 m wide as exposed, are elongated at N. 50° E. The elongation is about parallel to the northeast faults crossing the area of the mine (plate 1), but the en echelon orientation of the quartz masses is slightly east of the strike of the rock units and main faults. Lenticular masses of gray to white carbonate rock are veinlike in habit, strike N. 30° E., and dip 35° W. in serpentinite. They are possibly of metamorphic origin.

Practically no copper stain was seen in the northern workings at Selib mine, but small amounts of a soft, bright-green secondary mineral were found in silicified serpentinite and brown silicified marble. The mineral is thought to be garnierite. Spectrographic analyses of sand from both the northern and southern parts of the Selib area disclosed 100 ppm nickel. Such an abundance of nickel in wadi sand is to be considered normal around serpentinite. The same sands contain from 1,000 to 2,000 ppm chromium, also regarded as expectable from a source including ultramafic rocks. Concentrates from the northern part of the Selib area contain 250 ppm zinc and concentrates from south of the mine had 150 ppm zinc. These are the largest amounts of zinc found in the quadrangle, but the quantities do not form a positive anomaly for zinc, and zinc minerals were not identified in the veins or altered wallrocks.

No free gold was seen in the veins or wallrocks at the Selib mine, but evidently this is the mineral that was sought, both in the rocks and in the placers. Mining methods used at Selib resemble the practices at Fawara, except that at Selib the trenches tend to be longer and less deep than those at Fawara. Available assays disclose very little gold in either the veins or the placers; however, more systematic sampling seems to be needed. D. F. Schaffner (1956a) reported gold at 0.65 oz/ton and silver at 0.15 oz/ton in one channel sample of vein, and gold average of 0.13 oz/ton and silver averages of 0.11 oz/ton for four grab samples. W. R. MacLean (1958a) found gold at only 0.03 oz/ton and silver at 0.18 oz/ton in one sample of white quartz. He also reported gold averages of 0.04 oz/ton and silver averages of 0.22 oz/ton for two samples of tailings from stopes and averages of a trace of gold per ton and 0.22 oz/ton of silver for 15 samples from tailings in the ancient placers.

Adequate sorting action is unlikely to have taken place in the alluvial fans and wadi sands to cause much concentration of gold, but the results of former sampling of tailing piles at the old placers is not much indication of the gold tenor of the alluvium. At the least, future work in the Selib area should include pitting of the unmined placer ground to evaluate this possible source. A more comprehensive geochemical investigation than the reconnaissance report here might be undertaken at the same time for base metals, nickel, cobalt, and chromium.

Mashuton(?) mine, Mashaliya mine, and Mashara mine.--Three ancient workings in the northwestern quarter of the quadrangle (plate 1) are identified from south to north as the Mashuton(?) mine, the Mashaliya mine, and the Mashara mine by coordinates tabulated by the Ministry of Petroleum and Mineral Resources (1965, p. 24).

Some doubt attaches to the appropriateness of the name given the southernmost of the three, because the location found in the field does not fit the coordinates used by the Ministry. However, no mine was found by the writers at the position listed for Mashuton(?), whereas more than two dozen small openings on quartz-calcite veins were found in the sheared and altered area shown as Mashuton(?) on plate 1. The area at Mashuton(?) where the little openings are scattered is about 100 m wide and 500 m long. It is the most intensely altered part of a larger alteration zone of ill-defined width but about 2,000 m long.

The alteration is along shears that trend in a general northerly direction but are part of a longer and somewhat arcuate fault zone in chlorite-sericite schist of the Abt Formation. Locally, the shears have been filled with quartz-calcite veins, and the wallrocks are partly silicified.

Some of the veins have been mined from narrow, shallow trenches. Gold probably was sought, because copper is very sparse, being only 150 ppm in one concentrate from the area. This concentrate also contained scheelite, which contributed 400 ppm tungsten to the analysis. Probably the scheelite originated in the quartz-calcite veins in the alteration zone, but scheelite was not seen in them. The threshold amount of 150 ppm nickel was detected in sand from the area of the mine, but nickel minerals were not found.

Mashaliya mine, also known as Al Mashalia in some records, is two sets of workings 4.4 km north-northeast of the Mashuton(?) mine. The eastern set consists of three short trenches, none over 20 m long, opened in north-trending, pod-shaped quartz veins with traces of malachite. The western set of workings comprises about two dozen little pits, a short trench, and what may be old tailings from placer mining. The veins are in sheared and altered chlorite-sericite schist of the Abu Sawarir Formation east of a mass of serpentinite and north of a major tear-fault. Calcite veins and masses are also present, but quartz was principally sought in the mining. Gold appears to have been the mineral sought at these small workings. Analyses were not made of material from Mashaliya mine.

Mashara mine is the most northerly of the three. It consists of a trench on a quartz-calcite vein in chlorite-sericite schist and phyllite of the Abu Sawarir Formation between beds of silicified marble on the east and intrusive ultramafic rocks on the west. A single sample of sand from the area of the mine had only background amounts of the metals (fig. 2).

None of the three ancient workings in the northwestern quarter of the quadrangle opened deposits that seem likely to be more than a succession of small, low-grade, quartz veins with sparse gold and essentially no base metals. Possibly of greater future economic potential is the mass of ultramafic rocks just west of Mashliya mine. A sample of sand from the west side of the mass contained 700 ppm nickel, an amount regarded as a low positive anomalous quantity in this area, and the low threshold value of 30 ppm cobalt. The area was 3.8 times background in radioactivity. Further work should be done at this ultramafic mass to determine the sources of the nickel, cobalt, and radioactivity, and to learn if platinium metals are present.

Copper mineralization.--Copper mineralization in the Idsas Range has been commented on by Schaffner (1956b), Short (1957), the Directorate General of Mineral Resources (1959), and Kahr (1962). Most of the reports indicate disseminated secondary copper minerals in sheared conglomerate, meta-andesite, and amphibolite in the fault zones along the west side of the range (Kahr, 1962, p. 17; Short, 1957), particularly where north-trending faults are intersected by east-trending faults. Short and Kahr both reported minor secondary copper minerals in the core of small zones of hydrothermally kaolinized and sericitized rocks, commonly mylonite, in sharp, narrow canyons as much as 3 km south of Jabal Idsas.

To these can be added six exposures of sparse secondary copper mineralization in a variety of rocks on the west side of the dejective zone, two on the east side of the zone, and an exposure in the synclinorium in the Murdama west of the zone. From north to south on the west side of the dejective zone they are: (1) rare traces of copper carbonate in fractured quartz porphyry exposed 5 km northeast of Mashara mine; (2) copper stain in conglomerate and chalcopyrite in greenish-gray intrusive rock exposed 4.4 km east of Mashara mine; (3) trace of copper stain in the 2000-m long alteration zone beyond the workings at Mashuton(?) mine; (4) copper stain north of silicified marble 6 km east-northeast of Mashuton(?) mine; (5) chalcopyrite in epidotized rhyolite and in a lenticular mass of calcite 1.6 km east-southeast of Idsas mine; and (6) sparse copper stain in brown silicified marble 1 km southeast of Selib mine.

On the east side of the dejective zone, at a point 10 km east of Fawara mine, calcite stringers 1 cm across are present but scarce in fractures in an andesite dike in the Halaban Group. Rare specks of bornite are in the calcite and in the andesite adjacent to the calcite. Malachite partially rims the grains of bornite. Nine kilometers east of Fawara mine and just north of the major tear fault, copper stains are on reddish gray sericitized quartzite.

A quartz vein with a trace of malachite is exposed in strongly fractured chlorite-sericite schist near a dike of peralkalic granite 6 km southwest of Idsas mine.

None of these exposures of secondary copper minerals is large enough to have priority in the exploration program.

Complex of gabbro and amphibolite

Three groups of ancient workings in quartz-chlorite veins were discovered in the complex of gabbro and amphibolite on the southwestern flank of the mantled gneiss dome. One of these groups may be on the northernmost extension of the phyllonite zone found in the Bi'r al Badrīyah quadrangle. The others seem to occupy lodes and fracture fillings.

Openings 12.6 km southeast of Selib mine.--Fifteen small and partly filled open cuts, shallow trenches, and small pits are on the southern and southwestern end of a hill of amphibolite, gabbro, minette, and pyroxenite 12.6 km southeast of Selib mine. About six lesser openings are on the western flank of the hill.

The lowest and southernmost openings are the deepest, penetrating on a N. 55° E. incline of 10° to 20° to depths of at least 10 m. They are possibly three or four times that deep, to judge by the size of the dumps. High on the southwestern flank of the hill two deep openings may connect underground with the lower workings. The dumps are estimated to contain 4,000 cu m of waste rock. Three small, circular piles on the floor of the wadi about 200 m southwest of the southern end of the hill may indicate that the ore was sorted there, or they may be tailings left from sporadic placer mining. Neither ore nor slag is present in the dumps around the mine.

The openings follow lodes in the altered amphibolite. The lodes are rarely greater than 2 m across. They are composed of quartz-chlorite-pyrite veins and stringers as much as 8 cm thick. The lodes extend N. 40° W. and dip 60° N. across extensively chloritized amphibolite and across minette and pyroxenite partly altered to vermiculite. The alteration is most intense adjacent to the veins and stringers in the lodes, and decrease away from the veins. Owing to the closeness of the veins in the lode system, the wallrocks are thoroughly chloritized in the lode. Pyrite is common in the chloritized and vermiculite-bearing rocks, but sulfides of copper, lead, and zinc were not seen. Calcite is present in some quartz-chlorite veins, and is particularly common in veins filling fractures in minette dikes in amphibolite.

No data on tenor of the ore at this ancient mine are available. It was probably operated for gold.

Workings 19 km southeast of Selib mine.--Two small ancient abandoned workings are about a kilometer apart and 19 km southeast of Selib mine. They may be on the northern extension of the phyllonite zone at Smagh mine in the Bi'r al Badrīyah quadrangle.

The northeasterly working is a sand-filled trench about 15 m long and 2 m wide oriented N. 70° E. The trench explores a hematite-cemented, brecciated milky quartz vein in amphibolite. Possibly the vein is parallel to the line of the trench, but relations are obscured by wind-blown sand. About 150 cu m of broken rock is on the dump. Amphibolite, milky quartz, and hematite-cemented breccia make up the waste. Traces of copper stain are on some pieces of breccia, but sulfide minerals are absent.

The southwesterly working is a sand-filled trench about 30 m long and 3 m wide that extends N. 75° W. About 150 to 200 cu m of waste rock is on the dump. The trench was opened on a brecciated quartz vein in strongly sheared hornblende-biotite granite gneiss which is intruded by sheared andesitic dikes and sheared dikes of quartz-poor biotite granite questionably part of the unit of biotite-hornblende granite. A late shearing imparted a strong cataclastic deformation to all the rocks. Subsequently the mylonite formed during shearing was recrystallized into phyllonite that strikes N. 10° W. and dips vertically. Oriented, elongated clusters of biotite form a distinct lineation that plunges 25° S. in the plane of foliation. The trend of the phyllonitic foliation and the plunge of the lineation resemble cataclastic features at Smagh mine in the Bi'r al Badrīyah quadrangle, and the trends are nearly the same as those in the phyllonite zone at Smagh mine.

The relation of the quartz vein at the southwesterly working to the N. 10° W. shearing was not determined with certainty, because the trench no longer exposes the contacts of the vein. Because the trench strikes across the phyllonite, it is probable that the main shear developed before the vein was emplaced. This is the relation seen at Smagh mine.

The vein consists of brecciated milky quartz cemented by hematite. Adjacent outcrops of gabbro contain pyrite, but sulfide minerals were not seen in the vein. Malachite stain is common but not abundant in the vein, and small amounts of cuprite are present.

Strong joints striking at N. 70° W. dipping 70° N. and vertical joints striking N. 70° E. in the host rocks contain stringers of quartz. The joints and quartz stringers are not offset in the direction of the foliation in the phyllonite; hence, they were formed after the recrystallization in the phyllonite. Possibly the westerly joints are parallel to the vein, because the trench strikes N. 75° W. Inasmuch as the strike of the westerly joints is subparallel to parallel to a major tear fault a few kilometers north of the mines, and the tear faults are part of a regional system of faults with which minor gold and copper are associated in the dejective zone, it is possible these small veins were emplaced after the tear faults formed, and about the same time that the veins were introduced in the dejective zone.

Assay data are not available.

Mine 26 km southeast of Selib mine.--An ancient and abandoned mine 26 km southeast of Selib mine follows an irregularly branching milky quartz vein down dip at least 15 m and along strike at least 40 m. The vein quartz contains pyrite and malachite, but other sulfide minerals were not seen. The vein dips 65° N. and occupies a west-trending fracture zone in amphibolite. Adjacent to the quartz the amphibolite is chloritized for distances to 70 cm, but the alteration is not as intense as that at the first described openings southeast of Selib mine. Where the vein branches into two parts, each part ranges from 30 cm to 1.6 m in width. Possibly more than two branches are present.

Fine-grained gray biotite granite, possibly part of the unit of biotite-hornblende granite, intrudes the amphibolite. Pink felsite grading into pegmatite intrudes both the amphibolite and granite, but its relation to the quartz vein was not determined.

Assay data for the vein and wallrock are unavailable.

Mantled gneiss dome

The main potential ore deposits in the area of the mantled gneiss dome in the Jabal Bitrān quadrangle are garnetiferous skarns described below under garnet. The only ancient mine discovered in the area of the mantled gneiss dome in the quadrangle is a small opening on one of conspicuous quartz knobs in the southwestern part of the dome. However, in the northeastern part of the dome, northeast of the area of plate 1, two small ancient mines were found on barite-rhodochrosite veins 18 km west of Ar Rayn (Overstreet, Whitlow, and Ankary, 1970, p. 7). Similar veins may be present in the mantled gneiss dome in the Jabal Bitrān quadrangle.

Ancient working 17 km southeast of Bi'r el Ankeriya.--At a locality 17 km southeast of Bi'r el Ankeriya (plate 1) a milky quartz vein trends N. 25° W. and caps a ridge of hornblende-biotite granite gneiss intruded by west- to west-northwest-trending andesite dikes that also intrude the vein. The quartz vein contains sparse pyrite and scattered crystals of pink orthoclase to 8 cm long. Copper stain is absent. Drusy fractures in the vein are cemented with a little limonite and are lined with euhedra quartz. Such fractures at the top of the north side of the hill have in former times been prospected, if not actually mined, and about 0.5 cu m of quartz has been broken and removed.

A small mass of pink biotite granite about 1.6 m long and 0.2 m thick occupies a fracture in the quartz vein, and seems to be younger than the vein. Plates of specular hematite 1 mm thick and 4 cm long are sparingly present along the walls of the little mass of granite, but other evidence for mineralization is lacking.

An andeiste dike strikes No. 50° W. across the quartz vein. Adjacent to the dike the vein is brecciated for 30 to 40 cm, and the breccia is cemented with quartz.

The vein has a particularly barren aspect, but analyses are unavailable.

Other quartz veins.--Ten other quartz veins, shown as quartz knobs on plate 1, are in the mantled gneiss dome and adjacent rocks south of the little ancient working described above as 17 km southeast of Bi'r el Ankeriya. Most of them are in the biotite-hornblende granite unit, but several are in the hornblende-biotite granite gneiss. For the most part these veins are associated with northwest-trending faults younger than the swarm of andesite and rhyolite dikes, but several are intruded by these dikes. One of the more radioactive areas of the quadrangle is immediately southwest of a string of these quartz veins oriented parallel to but south of a well-developed northwest trending fault. No connection was detected between the veins and the radioactivity. The veins themselves are generally barren of sulfide minerals and presumably were barren of gold, because they were not mined in former times. However, assays of quartz from these veins are lacking.

This apparently barren quartz resembles the quartz at Fawara mine and Selib mine in color and texture. The gross physical aspects of the barren quartz veins in the gneiss dome also resemble the quartz in the mined veins in the complex of gabbro and amphibolite on the southwest flank of the dome. Inasmuch as part of the ore taken at the mines in the complex and the dejective zone was altered wallrock, and much of the vein quartz was selectively discarded at the mines, the possibility exists that the wall rocks have decisive influence on the tenor in gold of the quartz veins. In the mantled gneiss dome where the wallrocks are principally biotite-hornblende granite and hornblende-biotite granite gneiss, gold did not precipitate in the veins. Outside the dome in dominantly mafic and calcareous rocks, some precipitation of gold took place in the veins and in altered wallrock, and these places were mined.

Iron deposits of the Jabal Idsas area

Magmatic segregations of magnetite in the vicinity of Jabal Idsas have attracted the interests of the Ministry of Petroleum and Mineral Resources since about 1955. This magnetite is the most important potential mineral deposit in the Jabal Bitrān quadrangle. Sedimentary and metamorphic magnetite and specularite in the vicinity of Jabal Idsas appear to be interesting mineralogically instead of potentially exploitable deposits. Some mining for iron may have been done in antiquity at Jabal Idsas, as an ancient spoilage pile and slag show. In recent times magnetite from the spoilage pile and from surface outcrops on the ridges of the Idsas Range has been trucked to Riyadh for use in the manufacture of portland cement.

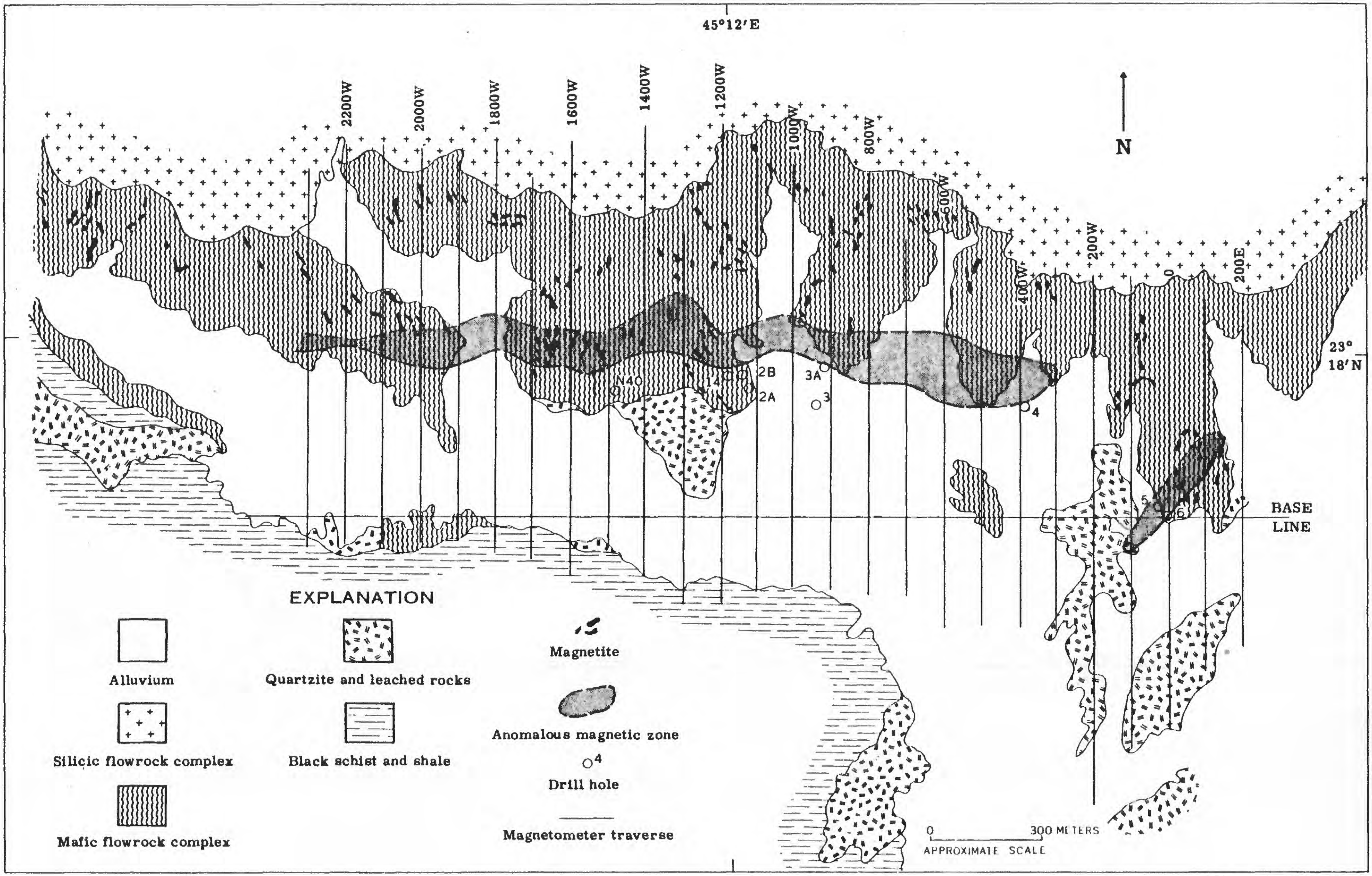
Magmatic segregations

A generalized indication of the distribution of the magnetite segregations west of Jabal Idsas is shown on plate 1, and outcropping masses of magnetite are shown on figure 4. These magnetite deposits have been the subject of a number of investigations by the Ministry (Schaffner, 1956b; Short, 1957; MacLean 1958b; Directorate General of Mineral Resources, 1959; Agocs, 1961; Hunting Survey Corp., 1962; Kahr, 1962; Herness and Kahr, 1963; Keller, 1964; Aerocarto, 1964; Overstreet, Whitlow, and Ankary, 1970; and Davis, Allen and Akhrass, 1970). Estimates of the amount of magnetite present, based on these studies, range from 6 million tons (Schaffer, 1956b) to as much as 135 million tons (Keller, Fred, in Davis, Allen, and Akhrass, 1970, p. 2). These authors also indicated the possibility that the roots of the magnetite lie east of and below the edge of the overthrust plate in which magnetite is exposed.

The magnetite at Jabal Idsas is in variably metamorphosed andesite of the Halaban Group and associated diorite. The magnetite in the Jabal Idsas area is regarded as having originated by primary magmatic segregation and later deformation by intense folding and faulting. No similar concentration of primary magnetite is yet known in the Halaban Group elsewhere in Saudi Arabia.

Individual areas of outcrop of the magnetite at Jabal Idsas were identified by D. F. Schaffner (1956b), A. M. Short (1957), and V. P. Kahr (1962). More than 200 exposures are known in a narrow arcuate belt, about 3/4 km by 3 km, near 23°18' N. x 45°12' E. (fig. 4), and a scattering of exposures extends 9 km to the northwest. The magnetite forms blebs, lenticular masses, and tabular bodies with associated stringers and veinlets of magnetite, all of which are steeply dipping. Many of the larger masses are folded, fractured, and tectonically separated. The tabular bodies range in exposed width from a few centimeters to 10 m and from a few meters to 200 m in length. Much of the magnetite is widely scattered over a large area, but the surface outcrops and magnetic surveys indicate that a zone 75 m wide and 1,700 m long, rich in magnetite, lies beneath the southward protruding ridge of Jabal Idsas (fig. 4), and that a small zone is beneath a low ridge to the east (Davis and others, 1970, p. 1). Within these more magnetic zones the magnetite probably also forms lenticular masses and veins, but they must be more closely spaced and aggregate a larger percentage of the host rock than elsewhere. This zone is in the mafic part of a sequence of volcanic flow. Less mafic flows crop out upslope to the north and northwest. They do not contain magnetite.

According to A. M. Short (1957, p. 1) four or five localities are indicated by surface exposures where as much as 100,000 tons of magnetite each might be found in mineable concentrations. However, an



Geology by V.P. Kahr

Figure 4. - Map showing magnetite deposits and the anomalous magnetic zone at Jabal Idsas (adapted from Davis, Allen, and Akhrass, 1970, fig. 1)

analysis by D. R. Mabey, U.S. Geological Survey, of the total-intensity aeromagnetic anomaly found by the Hunting Survey Corporation Limited (1962) suggested that the anomaly is associated with a deposit of magnetite of commercial size, the top of which is 100 to 200 m below ground level. From ground magnetometer surveys the main magnetic zone was identified (Davis and others, 1970), and the rocks in the zone were estimated to contain as much as 50 percent magnetite and to aggregate many times the tonnage estimated by Short. A reliable estimate of tonnage cannot be given without further subsurface data from drilling (Davis and others, 1970, p. 7-8). Most of the previous drill holes are along the south side of the magnetic zone, and they did not test the richest parts of the magnetic zone. Hole 40 (fig. 5), which was abandoned in November 1964, is correctly located to test the richest part of the magnetic zone, but it must be deepened at least 300 m.

The magnetite deposits are in an overthrust fault block, but outcrops show that the tabular masses and veinlets of magnetite dip steeply southward. Magnetic data also show that the magnetite dips steeply, but an absence of a strong magnetic minimum on the north side was interpreted by Davis and associates (1970, p. 8) to indicate that the major source in the subsurface dips northward and may conform with the fault. Davis and coworkers also suggest that the steep south dips observed in outcrop may indicate the upturned front of a thrust.

The extent to which the magnetite-bearing overthrust has ridden west beyond the presumed roots of magnetite in the lower plate of the fault is not known from the present mapping.

Sedimentary and metamorphic deposits

A little magnetite of metamorphic origin is present in layers and beds in the Bi'r Khountina Group near Jabal Idsas, and some well-rounded cobbles of magnetite derived from the magmatic segregations in the Halaban are in conglomerate of the Idsas Formation at the base of the Bi'r Khountina Group west of Jabal Idsas. None of these is a potentially economic source for iron ore.

Specularite (Kahr, 1962, p. 17) forms small masses and enriched areas, as well as fine disseminated grains, in quartzite. Specularite also fills cavities in leached quartzite. Stringers of specularite and epidote are in the Idsas Formation, and fill small fractures in some of the volcanic flow rocks.

Fine-grained hematite is dispersed in the black and purple shale and pelitic schist west of the Idsas Range (Kahr, 1962, p. 17). The dark color of many of the pelitic rocks is attributable to this hematite None of these is a potentially economic source for iron ore.

Ancient spoilage pile and Idsas mine

An ancient spoilage pile of magnetite pebbles, cobbles, and boulders about 600 m long and nearly 100 m wide was formerly present on one of the alluvial fans west of Jabal Idsas (plate 1). The outline of the pile is clearly visible on 1:60,000-scale aerial photographs made in 1956, but prior to 1964 material from the pile was trucked to Riyadh for use as a blend in the manufacture of portland cement. The pile is said to have been 1 to 2.5 m thick (D. F. Schaffner, oral commun., 1964), to have been composed of very pure fragments of magnetite, and to have rested with sharp disconformity on alluvial fan debris consisting of fragments of the main rocks in the Idsas Range. Rock fragments were said to be absent from the pile.

This heap of magnetite has been referred to as a placer (Peter Curtis, oral communication, 1965), but it was the only such pile known, and no evidence has been found elsewhere of placer concentrations remotely resembling the former pile of magnetite pebbles and boulders (Overstreet, Whitlow, and Ankary, 1970, p. 6). This former pile is here interpreted to have been a spoilage pile made by laborers at a time when the ancient village about 2.5 km to the south was occupied. Hand-picked magnetite float was accumulated in the pile, probably to supply ore to an iron furnace. Possibly the site of the furnace was at the pile of slag 1.4 km northwest of the spoilage pile. The iron operation is inferred to have been abandoned before the magnetite in the spoilage pile was consumed. It is here thought that the iron operation was abandoned in order to divert available labor and fuel north to the Al Amar gold-copper mine (Saudi Arabia Ministry of Petroleum and Mineral Resources, 1965, p. 22-29), some 60 km north of Jabal Idsas, because gold-copper ore smelts at a lower temperature than iron ore, and copper was worth more than iron.

The slag pile north of the magnetite spoilage pile has the approximate position of the Idsas copper mine of record (Saudi Arabia Ministry of Petroleum and Mineral Resources, 1965, p. 26). It may be that the slag was formed during the reduction of iron instead of copper.

Garnet

Garnetiferous skarn in layers up to 5 m thick and several hundred meters long supports conspicuous ridges 16 km east-southeast and 18 km southeast of Bi'r el Ankeriya in the mantled gneiss dome. The geologic relations of the skarn were described in the section on the Halaban Group.

Individual garnet crystals are as much as 10 cm across, but most are 1 to 5 cm across. Many, particularly the larger, crystals are flattened in habit. They are gray to brown. From their color and mode of occurrence they are thought to be andradite. A few isolated garnets in the skarn are of a rich brown color resembling cinnamon-stone. Cinnamon-stone is a semi-precious variety of grossularite, the calcium-aluminum garnet. None of the material seen in the skarn was clear enough, or sufficiently free from cracks, pores, and inclusions, to rate as a gem stone.

Garnet is a common mineral in metamorphic rocks generally, although it is rather uncommon in Saudi Arabia. Large, workable deposits of garnet are said to be scarce (Ladoo, 1949, p. 27), but enough are exploited that market requirements in world trade appear to be satisfied by presently known deposits (Ambrose, 1965, p. 355-359). Most commercially acceptable garnets for abraisive purposes are almandine, but small amounts of andradite are used. Grossularite is not acceptable as an abrasive, nor is andradite, unless it breaks with sharp edges and corners and is tough enough to resist pulverizing. The garnets at the surface of these outcrops tend to pulverize, but that may be because they are weathered.

These two areas of skarn appear to have many tens of thousands of tons of garnet to an assumed depth of 100 m, but the composition and commercial acceptability of the garnet are not known. The deposits are about 160 km from Riyadh, which is the nearest possible point of use. Owing to the large size of the deposits, at least surface samples should be analyzed for composition, and to test crushing properties.

Marble

Marble is present in the three Precambrian layered formations in the Jabal Bitrān quadrangle, and the principal outcrops are mapped. Most of the exposures are dolomitic or siliceous and therefore would have no commercial use. The purest marbles seem to be those associated with the Murdama Group, but none is close enough to a center of population to be quarried for building stone, the manufacture of lime, or other purposes. Chemical analyses have not been made of the marble in the Jabal Bitrān quadrangle.

Other minerals

Indications of several metallic and nonmetallic minerals were seen in the Jabal Bitrān quadrangle that would be valuable if they were present in minable amounts. Several deposits are so poorly understood that further work is needed to evaluate them satisfactorily.

Asbestos, magnesite, and chromite

The serpentinite in the dejective zone locally contains small veinlets of short (less than 1 mm) cross-fiber chrysotile asbestos. Longer, brittle-fiber asbestos has been found in fault zones in metabasalt and serpentinite at the areas of the anomalous nickel in the northwest quarter of the quadrangle. Magnesite in small stringers is a sparse alteration product in the serpentinite at several localities in the dejective zone, including the area of anomalous nickel, serpentinite at a point 6 km east-southeast of Mashara mine, and the southern part of Fawara mine. Some minor disseminated chromite was found by Kahr (1962, p. 9) in the serpentinite of the dejective zone, and he reported several localities of massive chromite in serpentinite south of Jabal Idsas (Kahr, 1962, p. 17). Further exploration will probably show that magnesite, at least, is certainly not present in minable deposits. Possibly better deposits of chrysotile asbestos will be found in the ultramafic rocks in the northwestern quarter of the quadrangle, but no large bodies of chromite are likely to be discovered by further surface exploration.

Nickel, cobalt, uranium, and platinum

A positive anomaly for nickel, with threshold cobalt and 3.8 times background radioacitivity, was found at the west edge of the dejective zone 1.4 km west of Mashaliya mine, associated with ultramafic rocks. Thorium is unlikely to be the source of the anomalous radioactivity in ultramafic rocks in association with cobalt and nickel. The environment suggests the possible presence of uranium. Therefore, the area of ultramafic rocks west of Mashaliya mine should be examined to determine the extent of the radioactivity, the radioactive element and minerals, and the distribution of nickel and cobalt. Inasmuch as a positive anomaly exists here for nickel, further examination of the locality should also include a search for the possible presence of platinum minerals.

Vermiculite

Extensive chloritization and the development of poor-quality vermiculite was noted at the ancient workings 12.6 km southeast of Selib mine. Biotite lamprophyres, probably minette, were the rocks most thoroughly altered to vermiculite, owing to the large amount of biotite available to change to vermiculite. Considerably less alteration to vermiculite had taken place in pyroxenite. None of the vermiculite deposits was suitable for mining for use as lightweight aggregate because of the small size of the altered masses of rock and the generally incomplete conversion of biotite to vermiculite.

Larger deposits of vermiculite may be present in some of the gabbro complexes extensively intruded by granite, but none was seen, and the geologic possibility for their presence does not seem to be really favorable. Vermiculite would be more common if the granitic intrusives had had more volatiles, and if more pegmatite and syenite pegmatite had been present.

Tungsten, molybdenum, and beryllium

Despite the fact that the tungsten and molybdenum minerals scheelite and powellite were found as detrital grains in wadi sand at 18 localities in the quadrangle, and threshold quantities of these elements were detected in seven samples, no economically exploitable occurence of either element was seen. Most of the scheelite is probably associated with the gold-bearing quartz-carbonate-chlorite veins, but this inference is not supported by direct observation. A little tungsten and molybdenum was found around the large masses of skarn in the east-central part of the quadrangle. If more work is done there to evaluate the garnet, then further heavy-mineral and geochemical tests should be made for tungsten and molybdenum. At the same time, additional tests for non-beryl beryllium should be made, because helvite, a beryllium mineral, strongly resembles garnet and has been found elsewhere in skarn. Samples of sand from this area, tested spectrochemically by Thompson and Shahwan, had less than 2 ppm beryllium.

Summary

The magnetite at Jabal Idsas is probably the most valuable potential mineral deposit in the area of the Jabal Bitrān quadrangle. Systematic drilling of already defined magnetic anomalies is recommended. Ancient workings for gold and gold and copper do not appear to be exploitable at the present time, but the largest of them should be examined in more detail than was done in this investigation. Known outcrops of asbestos, magnesite, chromite, and vermiculite are small, but better deposits of short-fiber chrysotile may be present in ultramafic rocks in the northwestern quarter of the quadrangle. A single anomaly of nickel and cobalt associated with above-background radioactivity in the northwest quarter of the quadrangle should be examined in detail for possible nickel, cobalt, uranium, or platinum metals. The large outcrops of garnet have little potential use owing to the remoteness of the locality and uncertainty of market acceptance, but at least the abrasive quality and chemical composition of the garnet should be tested. At the same time further tests of the garnet are made, its host rock should be examined for possible tungsten, molybdenum, and beryllium.

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