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RECONNAISSANCE GEOLOGY OF THE WADI SHUQUB QUADRANGLE, SHEET 20/41 A, KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

The Wadi Shuqub quadrangle (sheet 20/41 A) lies in the high mountainous part of the Hijaz plateau in west-central Saudi Arabia. The quadrangle is underlain chiefly by Precambrian layered metasedimentary and metavolcanic rocks that are intruded by plutons ranging in composition from gabbroic to granitic.

The metasedimentary rocks include quartzite, phyllitic quartzite, phyllite, slate, argillite, granulite, schist, and marble. The metavolcanic rocks are mostly greenstone and greenstone tuff but include meta-andesite and metadacite. The rocks are in the greenschist and greenschist-amphibolite transition facies.

The major plutonic rocks are tonalite and quartz diorite, which form a large batholith in the western part of the quadrangle. Smaller bodies of diorite and gabbro, granite, and complexes of mixed rocks are also present.

The layered rocks are divided into six units that have been described in outcrop order, from east to west: 1) nearly all greenstone, 2) mixed metasedimentary and metavolcanic rocks, 3) nearly all metasedimentary rocks, 4) greenstone in eastern part, metasedimentary and metavolcanic rocks in western part, 5) nearly all metasedimentary rocks, and 6) metavolcanic rocks containing subordinate amounts of metasedimentary rocks.

The layered rocks have a northerly strike throughout the quadrangle except near the southwest corner where they strike northwest. The rocks are steeply dipping to vertical. Major deformation has produced isoclinal folds and shears, strike faults, and subordinate cross faults. A second stage of deformation resulted in local open folds.

Basalt of Quaternary age covers the Precambrian rocks near the eastern margin of the quadrangle, and alluvium underlies major wadis and flats.

The main part of the Wadi Bidah mining district, including at least four ancient mining sites, is in the southeast part of the quadrangle. The district has produced gold from gold-quartz veins, and has some potential for producing gold, silver, copper, zinc, and lead from massive sulfide deposits.

INTRODUCTION

The Wadi Shuqub quadrangle is in the Hijaz plateau of west-central Saudi Arabia and encompasses an area of about 2,805 km^2. The north boundary is about 85 km east-southeast of At'Taif, and about 270 km from Jiddah. A modern paved highway, part of the At'Taif-Abha road, traverses the quadrangle from northwest to southeast. Other major routes, though only ungraded tracks, run southeast and then south from Al Jibub near the northwest corner of the quadrangle into Wadi Bidah, where one branch continues south toward Al Bahah and another branch continues southeast toward Bishah.

The quadrangle is sparcely populated. No villages but several tea houses and gas stations are on the highway. Several villages having the general name of Al Haddad are located on the highest ground near the southwest corner of the quadrangle, and several villages are in Wadi Bidah and along the track between Al Jibub and Wadi Bidah.

Previous work

The area is covered by the 1:500,000-scale geologic map of the Southern Hijaz quadrangle (Brown and others, 1963) and several adjacent quadrangles have been geologically mapped (fig. 1) at a scale of 1:100,000 (Gonzalez, 1973; Cater, 1977; Hadley, unpub. data; Greenwood, 1975a, b).

The geology and mineral potential of the Wadi Bidah district has been studied by Earhart and Mawad (1970). Their report includes a geologic map which covers an area extending about 33 km north and 16½ km west from the southeast corner of the quadrangle. We did not attempt to adopt Earhart and Mawad's rock units, but are indebted to them for structural data.

Further studies in the Wadi Bidah district were done by Jackaman (1972). Jackaman's map covers a block extending about 23 km north by 15 km west from the southeast corner of the quadrangle. Jackaman's mapping is somewhat more detailed than Earhart and Mawad's in this smaller area.

Mineral exploration in the Wadi Bidah district from 1972 to 1976 is reported by Kiilsgaard and others (1978). Modified geologic and geophysical maps of some of the ancient mine sites are included.

Present study

Gonzalez (USGS) commenced the study of the Wadi Shuqub quadrangle in 1970. He did field work in the spring and fall

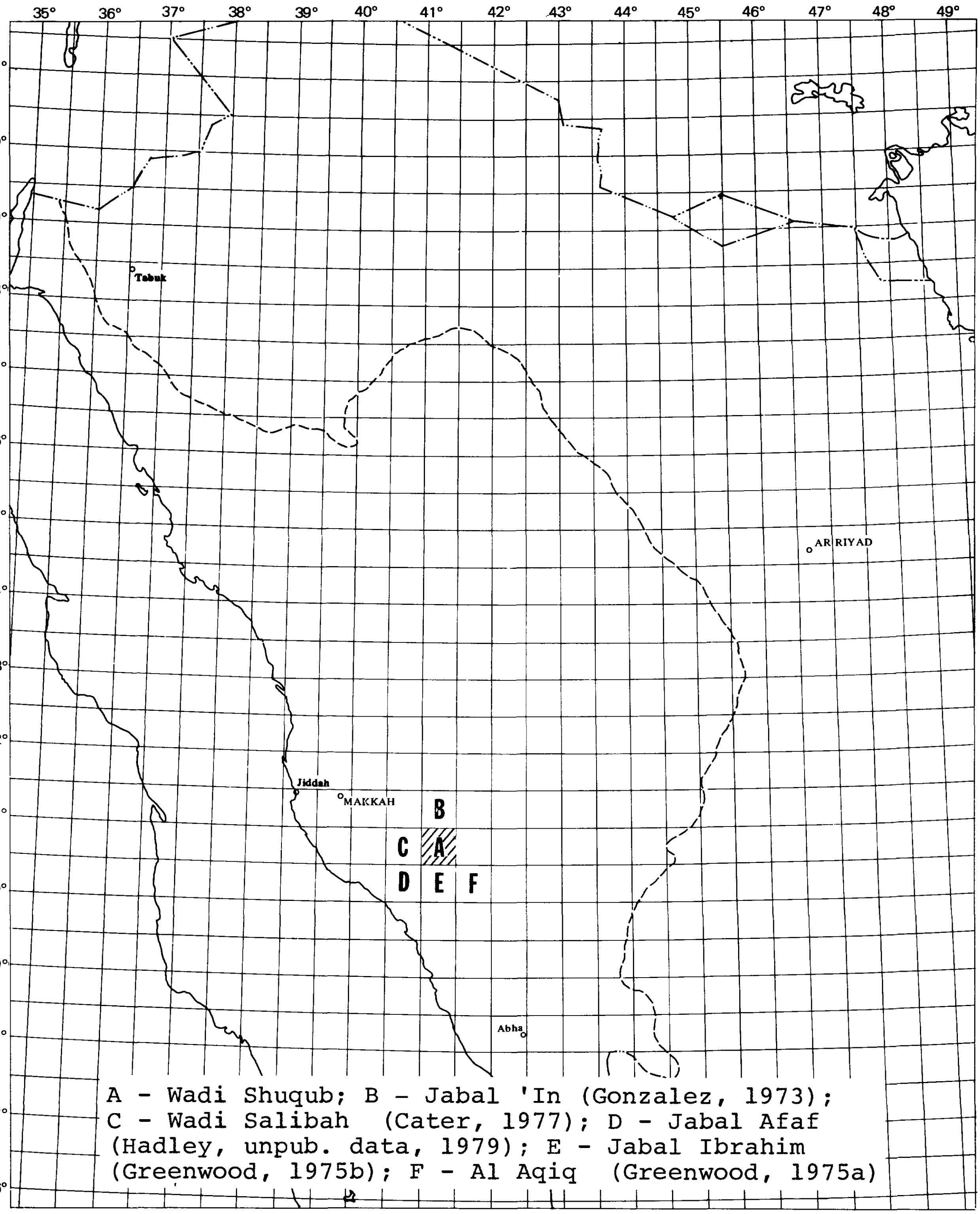

Figure 1.--Index map showing location of Wadi Shuqub and adjacent geologically mapped quadrangles.

of that year, and prepared a preliminary map and report. The project was resumed by Greene (USGS) in 1977. Greene did additional field work, collected more rock samples, and restudied Gonzalez' samples. A total of 303 thin sections were studied by Greene, and 24 X-ray diffractometer charts of fine-grained metamorphic rocks were prepared and interpreted by Mohammed Naqvi (DGMR). These data were used to prepare a new map and report. The work leading to this report was undertaken by the U.S. Geological Survey in partial fulfillment of an Agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

PHYSIOGRAPHY

The Hijaz plateau is a mountainous area in the Wadi Shuqub quadrangle. Most of it consists of valley and ridge topography in which north-trending ridges dominate the eastern half of the area, and northwest-trending ridges dominate the southwestern part. This topography is the reflection of alternating resistant and nonresistant layers in the underlying steeply dipping metamorphic rocks. The general level of ridge crests rises and the relief between adjacent ridges and valleys increases from northeast to southwest, culminating in altitudes of about 2,000 m at the top of the Red Sea escarpment near Al Haddad. A small part of the escarpment, which has extremely steep slopes and knife-edge ridges facing the Red Sea, is in the southwest corner of the quadrangle. Wadi headwaters at the base of the scarp are at an altitude possibly less than 1,000 m.

The northwestern part of the quadrangle has irregular topography, resulting from the irregular structure of the underlying plutonic rocks. Along the eastern margin of the quadrangle a flat tableland is underlain by basalt and strewn with boulders.

North-draining Wadi Turabah is the trunk stream in a well-integrated wadi system that drains most of the quadrangle. The principal tributaries are north-draining Wadi Bidah in the eastern part of the quadrangle and northeast-draining Wadis Shuqub, Buwah, and Durah in the central and northern parts of the quadrangle. Water has cut deep canyons along much of these wadi courses. Water flows on the surface in parts of each of these wadis during much of the year. Wadi Turabah is a permanent stream in parts of its course. Surface flow normally reaches a point about 4 km south of the highway crossing, and reappears at intervals downstream. The altitude where Wadi Turabah leaves the quadrangle in the northeast corner is about 1,225 m.

PRECAMBRIAN ROCKS

Layered rocks

Layered rocks in the Wadi Shuqub quadrangle consist of a wide variety of metasedimentary and metavolcanic rocks. For the purpose of geologic mapping, these were divided into six units and are described in order from east to west. The true stratigraphic order of the units, however, is uncertain.

Unit 1

Unit 1 crops out east of the shear zone that extends along Wadi Bidah and continues north-northwest to the circular intrusive structure in the northeast part of the quadrangle. It includes the older metavolcanic rocks and the lower and middle units of the metasedimentary rocks of Earhart and Mawad (1970), and the equivalent Sharq and Bidah groups of Jackaman (1972). Unit 1 is continuous with that part of the Jof formation of the Baish group lying east of Wadi Bidah in the Jabal Ibrahim quadrangle to the south (Greenwood, 1975b), and with greenstone of the Baish group on the Jabal 'In quadrangle to the north (Gonzalez, 1973).

Unit 1 consists mostly of greenstone, which locally contains interbedded chlorite schist, phyllite, and marble. In the northeastern part of the quadrangle, the unit underlies relatively low ground of only slight relief, whereas, in the southeastern part, relief is greater because of the presence of resistant tuff beds in the unit.

The greenstone is medium to dark greenish gray and on the surface has a black desert patina. It is micrograined to aphanitic and generally very foliate, having a strong mineral alinement but little banding. The southeastern-most outcrop area in the quadrangle consists of greenstone tuff and breccia that have fragmental texture.

Typical greenstone consists of actinolite or hornblende, plagioclase, epidote, and minor opaque minerals (table 1). Some is amphibolite that contains more than 50 percent amphibole. Calcite may be present, and quartz is an important component of some greenstones. Another type of greenstone consists mostly of quartz, chlorite, and epidote, with minor opaque minerals and calcite. These greenstones were derived from mafic to intermediate lavas and tuffs.

Less common rocks in Unit 1 include marble, which forms several layers, each a few meters thick, notably near the Mulgatah mine. Metasedimentary rocks of nonvolcanic derivation

Table 1.—*Estimated modes of rocks from Unit 1*
[tr, trace; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Sericite	Biotite	Chlorite	Actinolite	Hornblende	Epidote	Opaque minerals	Calcite
Greenstone	39-3	5	5	...	...	45	tr	...	45	tr	tr
Greenstone	39-1	25	...	...	...	25	...	...	50	...	...
Greenstone	100-3	40	10	5	...	25	...	...	20	tr	tr
Greenstone	101-1	2	...	...	...	20	...	...	40	5	30
Greenstone	208-C	5	...	...	3	2	...	...	88	...	2
Greenstone	226-H	...	20	...	...	5	...	50	20	2	...
Amphibolite	123	...	5	...	...	...	80	...	15	1	...
Amphibolite	208-B	...	15	...	...	...	60	...	...	...	...
Amphibolite	107	...	35	...	...	...	...	65	tr	tr	...
Greenstone	103-2	...	40	...	...	...	...	30	30	...	...
Greenstone	122-2	30	2	...	...	...	...	10	50	1	5
Amphibolite	266-G	40	tr	...	...	...	...	50	10	...	tr
Greenstone	208-A	15	40	...	...	...	40	...	...	5	...
Calc-silicate marble	266-I	5	...	...	...	...	5	...	40	...	50
Marble	100-4	tr	...	...	...	...	...	...	...	...	100

are rare, but "quartz-graphite, siliceous, and limey schists" are reported by Earhart and Mawad (1970) adjacent to Wadi Bidah.

Unit 2

Unit 2 underlies a central continuous belt extending in a northerly direction across the Wadi Shuqub quadrangle. The southeast part includes the upper unit of metasedimentary rocks and younger metavolcanic rocks of Earhart and Mawad (1970), and the equivalent Gharb group of Jackaman (1972). Unit 2 is continuous with part of the Jof formation of the Baish group west of Wadi Bidah in the Jabal Ibrahim quadrangle (Greenwood, 1975b) and with greenschist of the Bahah group in the Jabal 'In quadrangle (Gonzalez, 1973).

The unit consists of both metavolcanic and metasedimentary rocks, perhaps in near equal proportions, although the proportion of metasedimentary rocks appears to increase to the west. It thus differs from the dominantly metavolcanic Unit 1 to the east and the dominantly metasedimentary Unit 3 to the west. Terrain underlain by Unit 2 has rugged valley and ridge topography and outcrops are abundant. Altitude is generally higher than adjacent belts but the northeast-draining wadis cut across it.

Phyllitic quartzite, phyllite, schist, and greenstone are the principal types of rocks in Unit 2 (table 2) . Quartz porphyry, other light-colored metavolcanic rocks, and marble are also present.

Phyllitic quartzite and phyllite are light-greenish-, brownish-, or neutral-gray rocks that are fine grained to aphanitic and generally strongly foliate. Banding is not apparent in hand specimen but is observable in thin section. Where the rocks are greenish gray, they weather with a black patina; elsewhere, weathered surfaces are gray to rusty brown. Phyllitic quartzite and phyllite consist mostly of quartz, sericite, and chlorite, with minor opaque minerals and calcite. Micas are well alined and generally somewhat concentrated in bands. Rocks that contain no more than 15 percent mica are nevertheless foliate and micaceous enough in appearance to be called phyllite. Rocks of similar composition but sufficiently coarse grained so that mica flakes can be distinguished in hand specimen are designated schist.

Other types of rock abundant in Unit 2 include greenstone and meta-andesite (table 2). Some of these rocks consist mostly of quartz, chlorite, and epidote, and grade into chlorite-rich phyllite. Greenstones rich in plagioclase, actinolite, epidote and/or chlorite resemble those of Unit 1.

An important minor type of rock in Unit 2 is quartz porphyry, long considered an ore control in the Wadi Bidah district (Earhart and Mawad, 1970, p. 26-27). Two samples from within the Wadi Bidah district are rich in quartz, plagioclase or sericite, and epidote (table 2), and represent

Table 2.—*Estimated modes of rocks from Unit 2*

[tr, trace; p, phenocrysts; g, groundmass; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Sericite	Biotite	Chlorite	Actinolite	Hornblende	Epidote	Opaque minerals	Calcite
Phyllitic quartzite	68-3	90	tr	2	...	5	...	...	2	...	...
Phyllitic quartzite	67	85	...	15	...	tr	...	...	...	tr	tr
Phyllite	47-1	75	...	8	...	7	...	...	10	...	...
Schist	66-3	50	...	10	...	40	...	...	...	...	tr
Phyllite	40-4	50	...	50	...	1	...	...	...	tr	tr
Phyllite	74-2	30	10	15	...	40	...	...	...	...	5
Meta-andesite(?)	95-2	50	5	tr	tr	10	...	...	25	...	10
Phyllite-greenstone(?)	96-4	40	...	...	...	15	...	...	25	tr	20
Greenstone	72	20	10	tr	...	35	...	...	30	tr	5
Greenstone	43-5	5	20	...	...	25	tr	...	50	tr	tr
Meta-andesite	96-1	40	10	...	...	13	...	...	35	...	2
Greenstone	97-2	15	2	...	...	...	5	...	75	...	...
Greenstone	40-12	5	p-1 g-45	...	...	30	...	5	10	tr	5
Greenstone	40-8	5	15	...	...	20	...	30	30	...	...
Greenstone	143-1	10	30	...	...	...	40	...	20	...	...
Greenstone	260	1	35	...	...	15	...	50	...	1	...
Quartz porphyry	49-2	p-5 g-35	p-tr g-5	25	...	...	...	...	30	tr	...
Quartz porphyry	47-10	p-1 g-30	60	...	...	1	...	...	8	tr	...

thin, unmappable layers interbedded with other rocks. Greene believes that these quartz porphyrys are metatuffs. Another layer of quartz porphyry, 1.5 m thick, and obviously a sill, is present in the canyon of Wadi Shuqub near the western margin of Unit 2. This rock contains 25 percent plagioclase phenocrysts and 10 percent quartz phenocrysts set in a micrograined groundmass of quartz, plagioclase, muscovite, and minor biotite and chlorite.

A little marble is present, mainly near the Sha'ab El Tare mine.

Unit 3

Unit 3 extends from the south boundary to the central part of the quadrangle, where it is terminated by tonalite and quartz diorite. The unit is continuous with part of the Ras formation of the Bahah group in the adjacent Jabal Ibrahim quadrangle (Greenwood, 1975b).

Unit 3 consists chiefly of metasedimentary rocks: quartzite, phyllitic quartzite, phyllite, argillite, slate, and granulite.1/ Metavolcanic rocks are rare and the unit thus differs from the more heterogeneous Units 2 and 4 to the east and west. The unit mostly underlies terrain of low relief, but the southernmost part forms rugged valley and ridge topography.

The most characteristic rocks of this unit are slate and argillite: medium-dark-gray to dark-olive-gray and brownish-gray aphanitic rocks that have strong slaty cleavage and fissility and grade into nonfoliate rocks of similar composition. Although the slate and argillite are relatively nonresistant to erosion, they form abundant outcrops and shed platy to blocky debris. These rocks are composed of quartz, possibly feldspars, sericite, chlorite, biotite, and opaque minerals; amounts of these are generally uncertain because much material is too fine grained to identify, even in thin section.

Other rocks in Unit 3 include quartzite, phyllitic quartzite, and phyllite similar to those described from Unit 2 (table 3). Also present are quartz-plagioclase granulites containing minor sericite, biotite, and opaque minerals (table 3). These are dark-gray, fine-grained, foliate but nonfissile rocks that may be metagraywackes.

Metavolcanic rocks are rare in Unit 3, but some greenstone and amphibolite are present, particularly at the northernmost tip of the outcrop area.

1/Granulite as used in this report means a metamorphic rock which has an even granoblastic texture and little preferred orientation of mineral grains. These rocks do not belong to the granulite metamorphic facies of Turner (1968).

Table 3.—*Estimated modes of rocks from Unit 3*

[tr, trace; m, minor; figures in percent; leaders (...) indicate not present]

Rock Type	Sample number	Quartz	Plagioclase	Sericite	Biotite	Chlorite	Epidote	Garnet	Opaque minerals	Calcite
Quartzite	14-1	99	1?	tr	...	...	...	...	m	...
Phyllitic quartzite	93-1	60	15	20	tr	...	5	...	...	...
Phyllitic quartzite	142	70	...	25	...	m	5	...	...	tr
Argillite	23-4	65	...	5	30	...	...	1	...	...
Argillite	21-3	60	...	20	20	...	tr	...	...	...
Quartzite	141-2	55	...	12	...	3	30	...	...	...
Phyllite	219-K	50	...	45	5	...	...	...	m	...
Phyllite	22-2	50	...	40	10	tr	...	...	...	...
Granulite	257	55	30	tr	5	...	...	tr	10	...
Granulite	251	53	40	2	5	tr	...	...	tr	...
Granulite	253	40	35	tr	20	...	...	...	5	tr

Unit 4

Unit 4 extends about 25 km northwest from the south-central margin of the quadrangle and terminates in the tonalite-quartz diorite mass. It is continuous with part of the Ras formation of the Bahah group and part of the Jof formation of the Baish group in the adjacent Jabal Ibrahim quadrangle (Greenwood, 1975b).

Unit 4 underlies an area that has rugged valley and ridge topography. Lithologically, it is perhaps the most heterogeneous of all the units designated. Quartzite, phyllitic quartzite, phyllite, metasiltstone, argillite, greenstone, greenstone tuff, and amphibolite are present (table 4). The unit appears to consist of metasedimentary and metavolcanic rocks in nearly equal proportions, but greenstone and greenstone tuff are dominant in the eastern part, metasediments in the central part, and amphibolite in the western prong. The rocks are as described for Units 1 and 3.

Unit 5

Unit 5 is a narrow belt of rocks extending from the southern boundary of the quadrangle northwestward to the western margin and then northward before terminating in plutonic rocks. It is continuous with part of the Ras formation of the Bahah group in the Jabal Ibrahim quadrangle (Greenwood, 1975b) and with quartzite and micaceous quartzite in the Wadi Salibah quadrangle to the west (Cater, 1977).

Like the adjacent units of layered rocks, Unit 5 underlies an area of rugged valley and ridge topography. Its topography contrasts with the somewhat lower and more subdued relief on the tonalite-quartz diorite and granite to the east.

Unit 5 consists predominantly of metasedimentary rocks. As no samples were collected from the northern one-third of the unit, the composition of that part is unknown, but it is presumed to be similar to that of the rest of the unit.

Phyllitic quartzite and schist are the principal rocks of Unit 5, and quartzite, phyllite, marble, and greenstone are also present (table 5). Phyllitic quartzite, similar to that in previously described units, grades into schist as grain size and degree of segregation of micas increases. The schists are medium- to dark-gray, fine- to medium-grained rocks that have prominent foliation and parting, and commonly weather to a rusty color. Some contain traces of garnet.

This unit also contains calc-silicate schist and granulite which grade, through increase in calcite, into impure

Table 4.—*Estimated modes of rocks from Unit 4*

[tr, trace; p, phenocrysts; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Sericite	Biotite	Chlorite	Actinolite	Hornblende	Epidote	Scapolite	Opaque minerals	Calcite	Potassium-feldspar	Sphene
Quartzite	221-B	99	tr	tr	...	...	...	...	...	...	...	...	...	...
Phyllite	222-F	75	...	...	...	20	...	...	...	...	tr	5	...	...
Phyllitic quartzite	60-3	75	5	20	...	...	...	...	...	...	tr	...	...	...
Phyllite	230-E	70	...	30	...	...	...	...	...	...	...	...	...	...
Meta-siltstone	225-B	70	...	10	...	...	...	...	20	...	...	tr	...	...
Phyllite	52-1	65	p-tr	35	...	...	p-tr	...	...	...	...	...	...	...
Phyllite	223-D	50	...	20	20	...	...	...	...	...	10	...	...	...
Calcareous siltstone	230-J	50	2	...	...	15	...	...	12	...	...	20	...	...
Calcareous argillite	233-B	25	...	35	...	...	...	...	1	...	...	40	...	...
Argillite	233-C	10	tr	40	...	20	...	...	30	...	...	1	...	...
Graywacke or tuff	221-A	...	30	...	...	60	...	...	10	...	...	...	...	...
Greenstone	229-A	...	30	...	...	50	5	...	15	...	...	tr	...	...
Amphibolite	233-A	...	25	...	...	...	...	50	10	...	...	tr	15	...
Amphibolite	61	15	5	...	...	tr	...	50	10	20	...	...	...	tr
Amphibolite	220-C	...	5	...	...	...	95	...	...	...	...	...	...	...

Table 5.—*Estimated modes of rocks from Unit 5*

[tr, trace; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Sericite	Biotite	Chlorite	Hornblende	Epidote	Garnet	Opaque minerals	Calcite	Sphene	Potassium feldspar
Quartzite	231-B	90	tr	...	10	...	...	...	...	tr	...	...	...
Phyllitic quartzite	231-C	85	...	5	10	...	...	tr	tr	tr	...	...	...
Schist	234-F	78	15	2	5	...	...	...	tr	...	...	...	...
Phyllite	221-D	78	...	1	20	...	...	...	tr	1	...	...	...
Phyllitic quartzite	181	75	...	15	5	...	...	...	...	5	...	...	...
Phyllitic quartzite	196	70	...	20	tr	10	...	...	...	1	1	...	...
Schist	82-1	60	tr	5	35	...	...	...	...	tr	...	...	...
Schist	84-2	40	25	15	20	...	...	...	...	...	...	...	...
Calc-schist	235-C	30	40	5	10	...	...	15	...	...	...	tr	...
Calc-granulite	235-D	15	40	...	2	...	25	12	...	...	1	...	5
Marble	82-3	30	...	...	1	...	3	5	...	...	60	tr	...
Marble	235-B	1	...	1	...	...	...	...	...	tr	98	...	...
Greenstone	179	35	...	...	...	30	...	25	...	...	10	...	...

marble (table 5). These calcareous metasedimentary rocks are apparently confined to Unit 5, and are dissimilar to the pure calcite marble of Units 1 and 2, which is associated with greenstone.

Unit 6

Unit 6 underlies a wedge-shaped area in the southwest corner of the quadrangle. It is continuous with belts of undivided Bahah and undivided Baish groups in the Jabal Ibrahim quadrangle (Greenwood, 1975b). The northern part is continuous with quartzite and micaceous quartzite and the southern part is continuous with amphibolite, hornblende gneiss, and schist on the Wadi Salibah quadrangle (Cater, 1977).

The part of the unit east of the Red Sea escarpment underlies rugged valley and ridge topography at the headwaters of streams that flow southeast between the ridges and northeast across them. Weathering and erosion in the relatively humid climate have created flat valleys and hillslopes that have sufficient soil for intense cultivation. West of the top of the escarpment, the land drops precipitately to wadi headwaters below. No samples were taken from the face of the escarpment, but samples taken along strike to the east indicate the probable character of the rocks of the scarp-face.

Unit 6 consists predominantly of metavolcanic rocks. Amphibolite and greenstone are most abundant and are interlayered with gneiss, and, locally, with metasedimentary rocks (table 6).

Some amphibolite is greenish gray, has indistinct foliation and lineation, and consists of weakly pleochroic actinolite, plagioclase, epidote, and opaque minerals. This type of rock grades into greenstone as the actinolite content decreases. Other amphibolite is dark gray to black, is speckled light gray, and has very strong lineation. It consists of strongly pleochroic hornblende, plagioclase and/or quartz, epidote, and opaque minerals.

Interlayered with amphibolite and greenstone are quartz-plagioclase-biotite gneiss and granulite (table 6). These are light-gray medium-grained rocks with or without foliation and layering. Those that contain 35 percent or less quartz are probably metadacite, but higher quartz content in others suggests a metasedimentary origin.

Other metasedimentary rocks locally present include quartzite, phyllitic quartzite, phyllite, schist, and marble (table 6) similar to those described in other units.

Table 6.—*Estimated modes of rocks from Unit 6*

[tr, trace; m, minor; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Sericite-muscovite	Biotite	Chlorite	Actinolite	Hornblende	Epidote	Garnet	Staurolite	Opaque minerals	Calcite	Tourmaline
Quartzite	221	90	...	tr	10	...	...	...	...	tr	...	...	...	...
Phyllitic quartzite	163	60	15	20	1	1	...	...	...	...	...	5	...	tr(?)
Phyllite	174	70	...	20	5	...	...	...	...	...	...	5	...	...
Schist	152	65	...	20	5	...	...	...	...	1	10	...	...	...
Schist	224-A	60	...	1	20	20	...	...	...	...	...	...	...	...
Granulite	195	55	28	2	15	...	...	...	...	tr	...	...	...	...
Gneiss	202	35	50	1	15	...	...	...	...	tr	...	1	...	...
Gneiss	215	30	60	tr	10	...	...	...	...	...	...	tr	...	...
Schist	237	25	35	...	35	...	...	...	...	...	...	tr	tr	...
Greenstone tuff	231-2	...	50	...	...	...	...	35	tr	...	...	15	...	...
Greenstone	238	...	45	...	tr	...	50	...	5	...	...	2	...	...
Amphibolite	166	30	10	...	...	...	...	55	2	...	...	1	...	...
Greenstone tuff	235	5	...	...	...	...	65	...	30	...	...	...	...	...
Amphibolite	227	...	30	...	...	...	65	...	...	...	...	5	...	...
Amphibolite	234	...	...	...	...	5	95	...	tr	...	...	...	...	...
Marble	157	1	...	m	m	...	...	...	...	...	...	2	92	5

Plutonic rocks

Tonalite and quartz diorite

Tonalite, quartz diorite, and a small amount of diorite underlie about one-third of the Wadi Shuqub quadrangle. A large batholith consisting of these rocks occupies much of the western half of the area and several stocks, disconnected at the present erosion level, are present in the south-central part. Similar rocks penetrate the greenstones of Unit 1 near the northeast and southeast corners of the quadrangle. These rocks may be parts of larger bodies that are mostly concealed by Quaternary basalt.

Tonalite[1/] is the most abundant rock of this unit, and quartz diorite is next in abundance. Typical tonalite is coarse grained, and the dark and light minerals create a striking black and white speckled appearance in freshly broken rock. Where quartz is less abundant and mafic minerals more abundant the rocks are darker, duller, or greener; plagioclase is saussuritized, biotite is altered to chlorite, and hornblende is altered to epidote. Much of the rock is structureless, or nearly so, but some is very foliate. In general, where strike lines are indicated on the map, the rocks are foliate to gneissic; elsewhere they are evenly granular.

These rocks are moderately resistant to erosion and underlie rough, knobby country of low relief. They weather to rusty brown and disintegrate to gruss.

Light minerals in the tonalite and quartz diorite are: plagioclase 45-75 percent, potassium feldspar, 0-5 percent, and quartz 5-35 percent. Part or all of the plagioclase in a few samples is clear oligoclase or andesine but most is albite penetrated by flakes of white mica and blebs of epidote (saussuritized).

Potassium feldspar commonly takes the form of sparse lamellae in plagioclase (antiperthite); in rocks containing several percent of the mineral, it forms independent grains that show grid twinning. Potassium-feldspar-bearing tonalites are apparently restricted to the southernmost part of the batholith, the adjacent stocks, and the intrusive body in the southeast corner of the quadrangle.

[1/]Plutonic rock nomenclature is that of the International Union of Geological Sciences (1973); nomenclature diagram also in Hadley (1976).

Most of the rocks contain both hornblende and biotite as primary dark minerals (table 7). Hornblende (<1-15 percent) is characteristically unaltered and pleochroic from light brown to medium green. Biotite (<1-20 percent) is pleochroic from pale straw to medium olive brown and commonly is partly altered. Secondary mafic minerals include chlorite and epidote, each ranging from less than 1 percent to 15 percent. Chlorite may be interleaved with biotite or has replaced it completely. Epidote may be in blebs in plagioclase or biotite but most commonly forms independent anhedral masses. Accessory minerals in trace amount include sphene, apatite, sparse zircon, and opaque minerals. Textures of the tonalite and quartz diorite range from hypidiomorphic-granular in structureless rocks to lepidoblastic and cataclastic in gneissic rocks.

The contacts between the tonalite-quartz diorite and the adjacent metamorphic rocks are commonly gradational. Sills of tonalite are interlayered with metamorphic rock and screens of the metamorphic rock are found within the tonalite. Digestion of parts of the country rock by tonalite is indicated by the presence of nonquartz-bearing diorite in the marginal phases of the batholith at several localities where it intrudes greenstone or amphibolite. Diorite sills intrude the tonalite and quartz diorite adjacent to the younger diorite stock near the northwest corner of the quadrangle, and much granite and pegmatite are present near the granite body in the southwest corner.

Structure.--The tonalite and quartz diorite are in part gneissic, having foliation generally conformable to the surrounding rocks, and in part are structureless and irregularly penetrative into surrounding rocks. At least two episodes of tonalite injection are indicated. The principal episode was apparently contemporaneous with isoclinal folding of the layered rocks, and was followed by a less widespread late-tectonic episode.

Granite, granodiorite, quartz diorite, and diorite

Rocks of this heterogeneous unit crop out in the northwestern corner of the quadrangle but were studied only in the easternmost part of the outcrop area. The unit is mapped as diorite and quartz diorite on the adjacent Wadi Salibah quadrangle (Cater, 1977).

Rocks examined were mostly strongly foliate gneisses of various compositions: biotite-hornblende diorite, biotite granodiorite (two varieties), and a strikingly pink leucogranite. Estimated modes of these rocks appear in table 8.

Table 7.—*Estimated modes of tonalite and quartz diorite*

[tr, trace; m, minor; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Potassium feldspar	Hornblende	Biotite	Chlorite	Epidote	Sphene	Apatite	Zircon	Opaque minerals
Quartz diorite	33-1	7	70	...	10	10	1	2	tr	tr	...	tr
Quartz diorite	81-1	10	70	...	...	20	...	m	...	tr	...	...
Quartz diorite	87	10	68	...	10	12	...	tr	tr	tr	tr	...
Quartz diorite	215-F	10	55	...	25	2	...	2	...	...	...	3
Quartz diorite	227-C	15	75	...	tr	8	...	2	...	tr	...	tr
Tonalite	213-N	18	60	...	7	15	...	...	...	...	...	...
Tonalite	10	20	50	...	10	15	...	5	tr	tr	...	tr
Tonalite	70	20	40	...	30	...	5	5	...	...	...	tr
Tonalite	77	25	60	...	10	...	3	1	...	...	...	tr
Tonalite	226-D	25	45	...	1	...	15	15	...	...	...	...
Tonalite	222-B	25	65	...	...	5	...	5	...	...	...	...
Tonalite	13	28	60	...	1	8	1	2	m	tr	tr	tr
Tonalite	117	30	50	...	...	...	10	10	tr	tr	...	...
Tonalite	215-D	30	60	...	m	10	tr	m	...	...	...	m
Tonalite	75	15	70	3	2	10	tr	tr	...	tr	tr	tr
Tonalite	225-A	35	45	5	...	...	10	5	...	...	...	...
Tonalite	62	25	67	5	...	2	...	tr	tr	tr	tr	tr

Table 8.—*Estimated modes of granite, granodiorite, quartz diorite, and diorite*

[tr, trace; m, minor; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Quartz	Plagioclase	Potassium feldspar	Hornblende	Biotite	Epidote	Sphene	Apatite	Zircon	Opaque minerals
Diorite	138-2	...	40	...	20	40	...	m	...	...	m
Granodiorite	138-4	20	60	10	tr	5	2	...	tr	tr	...
Granodiorite	138-5	20	65	10	...	5	1	m	...	tr	tr
Leucogranite	139	30	40	30	...	m	tr	...	...	...	...

Diorite and gabbro

Diorite and gabbro crop out in three areas in the northern part of the quadrangle; two are isolated oval stocks and one is a part of a larger crescent-shaped body extending into the adjacent Jabal 'In quadrangle (Gonzalez, 1973). Another oval body, at Jābal Qunnah in the Jabal 'In quadrangle, completes the group.

Diorite and gabbro are now defined (International Union of Geological Sciences, 1973) as phaneritic rocks in which quartz makes up 0-5 percent of light-colored minerals and plagioclase 90-100 percent of total feldspar. Diorite has plagioclase with An<50 and normally contains hornblende and/or biotite, whereas gabbro has plagioclase with An>50 and normally contains pyroxene and/or olivine. Both types of rock are present in the bodies under consideration; they are distinguished chiefly by the mafic minerals present.

Most of the diorite and gabbro are medium- to coarse-grained structureless rocks. Where fresh, they are speckled light or medium gray and black; where altered, they are medium gray and greenish gray. Although the diorite-gabbro bodies are deeply weathered and noncoherent, in most outcrops they form low hills.

The diorites contain 60-85 percent plagioclase that is generally fresh and well twinned (table 9). Hornblende is the principal mafic mineral, makes up 5-30 percent of the rock, and is rarely accompanied by biotite. The hornblende is pleochroic from light brown to olive where fresh, but is commonly altered in part or wholly, to fibrous, weakly pleochroic amphibole. Chlorite (<1 to 15 percent) and epidote (<1 to 5 percent) are the secondary mafic minerals. Opaque and accessory minerals are sparse to absent. Some of the most altered diorites contain minor interstitial secondary quartz.

The gabbros contain 40-60 percent fresh plagioclase and 20-50 percent clinopyroxene. Some contain as much as 20 percent olivine; the olivine is slightly altered to iddingsite and is surrounded by clinopyroxene. The clinopyroxene is in turn rimmed with hornblende. Trace amounts of opaque minerals and secondary calcite are also present. The texture of the diorite and gabbro is hypidiomorphic granular.

The diorite and gabbro intrude the tonalite-quartz diorite unit, the granite, granodiorite, quartz diorite, and diorite unit, and the layered rocks of Units 1, 2, and 5. The diorite and gabbro are in turn intruded by biotite granite. Their structureless nature suggests that they are posttectonic.

Table 9.—*Estimated modes of diorite and gabbro*

[tr, trace; figures in percent; leaders (...) indicate not present]

Rock type	Sample number	Plagioclase	Olivine	Clinopyroxene	Hornblende	Chlorite	Epidote	Calcite	Opaque minerals	Quartz
Olivine gabbro	207-K	40	20	35	5	...	...	...	tr	...
Olivine gabbro	207-G	45	2	50	3	...	...	...	tr	...
Gabbro	211-F	40	...	50	5	...	5	tr	tr	...
Gabbro-diorite	211-M	60	...	20	10	tr	2	tr	tr	...
Diorite	207-H	72	...	...	25	...	...	...	...	3
Diorite	213-M	75	...	...	5	15	5	tr	...	...
Diorite	213-A	80	...	...	12	5	1	...	2	1
Diorite	226-B	80	...	...	15	...	5	...	...	...
Diorite	213-C	88	...	...	5	5	2	...	...	...

Pyroxenite

A small body of pyroxenite is present in the east-central part of the quadrangle. The rock is dark greenish gray and medium grained and the weathered surfaces have black patina. It consists of about 80 percent clinopyroxene and 20 percent hornblende altered from clinopyroxene, with a little altered plagioclase and trace amounts of epidote.

Biotite granite

Biotite granite is found in several bodies in the central and southwestern parts of the quadrangle, and as parts of larger bodies extending into the adjacent Wadi Salibah (Cater, 1977) and Jabal 'In (Gonzalez, 1973) quadrangles. This rock was not studied in detail and no modal analyses were made.

The granite is composed of quartz, microcline, plagioclase, and minor amounts, generally 2 percent or less, of biotite, chlorite, and muscovite. Quartz constitutes 20-30 percent, microcline 25-45 percent, and plagioclase 15-50 percent of the rocks. One specimen contains trace amounts of hornblende. Accessories include apatite, zircon, sphene, opaque minerals, and secondary epidote.

Textures of these granites vary from hypidiomorphic granular in structureless bodies to lepidoblastic in gneissic rocks.

The granite in the body near the northwest corner of the quadrangle is coarse grained and structureless and contains conspicuous grains of pink feldspar. It disintegrates readily to gruss and forms a flat pediment surmounted by a few residual hills. A similar granite body near the center of the quadrangle forms several prominent jabals separated by a flat pediment. Granite from the other bodies is more varied in texture and structure.

Felsic dikes

Felsic dikes that form prominent lineaments on aerial photographs are shown in the western part of the quadrangle. No samples of these rocks were studied.

Granite ring dike

A ring dike of granite partly outlines a circular intrusive structure about 12 km in diameter in the northeastern part of the quadrangle. The granite is tough and resistant and crops out as prominent ridges. It is coarse grained, pink and gray, and structureless. The granite contains 25-30 percent quartz, about 50 percent potassium feldspar, 20-35 percent plagioclase, and traces of biotite, altered amphibole(?), and opaque minerals.

Syenite-trondhjemite complex

The circular intrusive structure has a complex of syenite, trondhjemite, and probably other rocks in its central part. Only a few samples were collected and the complex needs further study. The syenite consists of potassium feldspar, about 1 percent each of plagioclase and quartz, and trace amounts of biotite, alkali(?) amphibole, epidote, zircon, and opaque minerals. Trondhjemite consists of plagioclase (60 percent), quartz (40 percent), and traces of biotite, amphibole, zircon, and opaque minerals.

The area underlain by the syenite-trondhjemite complex is a pediment of low relief, but outcrops are abundant.

Radiometric ages

Radiometric ages obtained from rocks in or directly adjacent to the Wadi Shuqub quadrangle are presented in table 10. Sample localities are not plotted on plate 1 because points at the reported latitude and longitude do not fall within the bodies that were presumably sampled. This is probably because of lack of adequate base maps when the samples were collected. An additional age of 635 million years was reported by Aldrich and others (1978) on a granite, but the locality reported is not near enough to any granite body to be sure which one was sampled. His sample is probably of biotite granite from the northernmost Wadi Shuqub or southernmost Jabal 'In quadrangle.

Despite the uncertainty of each of these dates, they do suggest that the rocks of the tonalite-quartz diorite unit are some of the oldest in the Arabian Shield. The age of 550 m.y. for the syenite-trondhjemite complex fits well with that of the Pan-African event (Fleck and others, 1976).

QUATERNARY ROCKS

Basalt

Basalt erupted from vents in Harrat Al Buqum overlies the Precambrian rocks along most of the eastern edge of the quadrangle. Where best exposed, two flows, each 10-15 m thick, can be observed.

Table 10.—*Radiometric ages of some rocks from the Wadi Shuqub quadrangle*
[Samples collected by G. F. Brown]

Rock unit of this report	Latitude	Longitude	Analyst	Method of analysis	Age (m.y.)	Reference
Syenite-trondhjemite complex	20°52' to 20°55'	41°20' to 41°24'	Geochron[1]	Rb-Sr	550	Brown[4]
Tonalite-quartz diorite, small body near center of quadrangle	20°43' to 20°24'	41°14' to 41°33'	Aldrich[2]	Rb-Sr K-Ar	785 615	Aldrich[5]
Tonalite-quartz diorite, southeastern part of quadrangle	20°32'	41°25'	Isotopes[3]	K-Ar	827±16	Brown[5]
Tonalite-quartz, 2 km east of quadrangle boundary near southeast corner	20°32'	41°31'	Isotopes[3]	K-Ar	932±46 821±16 912±18	Brown[5]

[1]Geochron Laboratories, Kureger Enterprises, Inc., Cambridge, Mass.
[2]L. Thomas Aldrich, Carnegie Institution of Washington
[3]Teledyne Isotopes, Westwood, N. J.
[4]G. F. Brown, oral commun.
[5]Aldrich and others, 1978

The basalt is dark gray and micrograined. It consists of 50-65 percent plagioclase, 15-20 percent clinopyroxene, 10-15 percent olivine, 5-10 percent opaque minerals, and 0-5 percent glass. The rock is fresh except for minor alteration of olivine to iddingsite. Two samples of the basalt from localities farther east give K-Ar whole rock ages of 1.72 ± 1.16 m.y., and 0-3 m.y. (G. F. Brown, oral commun.; determined by Geochron).

Alluvium

Alluvium is mapped in major wadis and in a few flat areas in the northern part of the quadrangle where it conceals large areas of bedrock. The alluvium consists of gravel, sand, and silt derived from adjacent bedrock and moved short distances during times of surface water flow. Very little aeolian sand is found in the quadrangle.

STRUCTURE

Earhart and Mawad (1970) believe that the Wadi Bidah district is on the west limb of an anticlinorium whose axis is in plutonic rocks only a few kilometers east of Wadi Bidah. Their division of the rocks into older metavolcanic, metasedimentary, and younger metavolcanic units reflects this view. A nearly identical statement and scheme of subdivision is presented by Jackaman (1972), who divides the rocks into the Sharq, Bidah, and Gharb groups. None of these writers, however, presents evidence for tops and bottoms of sedimentary beds and lava flows or data on axial planes of folds. The present authors therefore conclude that the presence of an anticlinorium remains unproven.

Major structure and sequence in the layered rocks

The Wadi Shuqub quadrangle is part of a major north-south belt of layered rocks in western Saudi Arabia. The rocks strike north in the eastern part of the quadrangle and northwest near the southwestern corner. In most places, local strike of foliation parallels the regional strike, and dips are steep in either direction or vertical. Locally, in the northeastern and south-central parts of the quadrangle, lower dips define open folds. Axes of mesoscopic folds (visible at outcrop scale) are seldom determinable but surely more could be found by detailed mapping.

Little evidence was found for tops and bottoms of beds or of lava flows; features such as graded bedding, cross bedding, ripple marks in sediments or vesicles, and flow surfaces in lava flows have been largely destroyed by metamorphism and shearing. However, more of these features could probably be found by detailed mapping, and from an analysis of these features the amount of folding and thickness of section could be approximated.

The layered rocks are isoclinally folded and sheared and axial planes are parallel to foliation and bedding and are therefore unrecognizable, as are fold axes. If no strata were repeated, the thickness of the layered rock sequence would be very great, about 45 km along the line of the cross section (plate 1).

The cross section is drawn with folds generally cascading westwards because in each unit a majority of nonvertical dips are to the west. However, this interpretation is correct only if most of the foliation dips approximate bedding and if the average axial plane dips more steeply than the median westerly dip. If these assumptions are true, then Unit 1 is the oldest and the other units successively younger, as shown on plate 1, Correlation of map units. However, it should be emphasized that this interpretation is tenuous.

Although the layered rocks were divisible into units of contrasting lithology, it has not been possible to deduce any broad structures from their pattern. A repeated three-fold sequence in rock distribution is more suggestive of faulting than of open folding. The sequence of metavolcanic rocks (Unit 1)—mixed rocks (Unit 2)—metasedimentary rocks (Unit 3) is repeated in more compressed form by Unit 4 (east part)—Unit 4 (west part)—Unit 5.

Locally, strike and dip define open folds in the layered rocks. One example is north of the circular intrusive structure, where an anticline plunging steeply northeast is succeeded to the east by a structural saddle and then by a box-ended anticline that plunges northwest. In Unit 4, near the south boundary of the quadrangle, there is an apparent south-plunging double syncline. In the central part of Unit 2, local flatter dips suggest the presence of an anticlinorium (cross section, plate 1). However, such a structure is incompatible with the presence of dissimilar rocks (Units 1 and 3, respectively) to either side, and the open folds are interpreted as later structures which refold the earlier isoclinal folds.

Faults

Faults are abundant in the Wadi Shuqub quadrangle, but major, through-going fault structures are lacking. The longest faults are mostly parallel to the strike of foliation in the layered rocks, but crosscut locally. These are apparently strike-slip faults, though whether they are left- or right-lateral faults cannot generally be determined. The Wadi Bidah fault is the largest fault and secondary faulting related to it may be responsible for the remobilization of sulfides in the Wadi Bidah district (Kiilsgaard and others, 1978, p. 22). A set of northwest-striking faults in the south-central part of the quadrangle parallels the strike of foliation in Units 4 and 3 but crosscuts that in Unit 2. Further north, northeast-trending faults cross the foliation nearly at right angles; other faults trending west northwest to east locally break the rocks into a complicated set of fault-bounded fragments.

Faulting probably took place during the waning phases of major deformation and represents adjustments as the rocks became more brittle. Faults that are not parallel to the strike of foliation are probably normal faults.

Intrusive ring structure

The circular structure in the northeastern part of the quadrangle is probably one of cauldron subsidence. After the eruption of volcanic rocks, now removed by erosion, a circular fracture formed and a block of crust foundered into the emptied magma chamber. Subsidence was accompanied by the injection of segments of a ring dike along the circular fracture. Additional stoping and intrusion in the center of the block created the syenite-trondhjemite complex.

METAMORPHISM

Metamorphism of the layered rocks in the Wadi Shuqub quadrangle resulted both from regional and contact effects. Most rocks are in the lower and upper greenschist and the greenschist-amphibolite transition facies, and perhaps a few are in the amphibolite facies proper. Facies designations are in the amphibolite facies proper. Facies designations are according to Turner (1968, p. 268-270).

Metamorphic index minerals were identified in thin section. Determination of metamorphic facies of the aluminous rocks was made easily, but the metamorphic facies of mafic volcanic rocks is more problematical because the amphiboles of these rocks grade continuously from actinolite to hornblende. The criterion used in the present study was: non-pleochroic to weakly pleochroic amphibole is actinolite (greenschist facies), strongly pleochroic amphibole is hornblende (transition or amphibolite facies).

Data are insufficient on rocks from the Wadi Shuqub quadrangle to permit drawing metamorphic isograds (particularly lacking are plagioclase compositions) but some comment can be made on the grade of each unit.

Presence of chlorite without biotite indicates lower greenschist facies in the central and southern parts of Units 1 and 2, where the rocks are farthest from intrusive rocks. Hornblende is present (transition facies) locally in Unit 1 on the east side of the circular intrusive body in the northeastern part of the quadrangle. The northwestern part of Unit 2 is in the upper greenschist facies (biotite grade).

Biotite is present in most rocks of Unit 3 that are coarse enough for mineral identification, and garnet was found in one; these are probably contact-metamorphic minerals. Most of Unit 3, in which very fine grained metasedimentary rocks predominate, is in the lower greenschist facies.

All greenstones of Unit 4 contain actinolite except those at the northwest end of the belt, which contain hornblende; hence most of the belt is in greenschist facies, and the northwest end is probably in the transition facies. Metasedimentary rocks of Unit 4 are partly biotite, and partly chlorite grade. Nearly all metasedimentary rocks of Unit 5 contain biotite, some contain garnet, and nearly all greenstones contain hornblende; hence, this belt is in the transition facies.

More closely spaced samples from Unit 6 reveal that the rocks are in the transition or amphibolite facies and contain hornblende or garnet; one sample contains staurolite. A band through the center of the unit, however, contains actinolite and is thus of greenschist facies.

In summary, the metamorphic grade increases very gradually from the east-central to the southwestern parts of the quadrangle; modifications and reversals may be largely attributable to contact effects.

ECONOMIC GEOLOGY

Wadi Bidah district

The Wadi Shuqub quadrangle includes the northern two-thirds of the Wadi Bidah district, an area containing massive sulfide deposits and several ancient mines. The district was first studied in detail by Earhart and Mawad (1970). In addition to the geologic map of the district, detailed maps of the ancient mine sites were prepared, and limited core drilling was carried out at the Mulgatah, Sha'ab El Tare, Gehab, and Rabathan (Jabal Ibrahim quadrangle) sites. Combined reserves of 2.55 million tons of copper-zinc-gold-silver ore were established for the Gehab and Rabathan localities.

Jackaman (1972) made detailed studies of mineralogy and texture of the massive sulfides. He concluded that they were formed by a syngenetic-diagenetic mechanism.

Kiilsgaard and others (1978) report on additional studies in the district between 1972 and 1976. Electromagnetic and self-potential surveys were conducted at the Mulgatah, Sha'ab El Tare and Gehab sites, and additional mapping and gravity and magnetic surveys were done at the Rabathan site. At each site, additional targets were located and tested by diamond drilling. The drilling indicated additional mineralized reserves totalling 6.341 million tons and averaging 0.95 percent copper.

Studies in the Wadi Bidah district were resumed in 1977 by the Riofinex Geological Mission (1978), and a new copper, lead, and zinc prospect, 4 km south of the Gehab site, is being investigated.

Marble

A marble quarry has recently been in operation at a locality about 1 km north of the Mulgatah mine. The marble bed is only a few meters thick but is of good quality for dimension stone. It is creamy to white and has brown and green banding. Similar marble beds in Units 1 and 2 may also have economic potential.

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