UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Reconnaissance geology of the Jabal Dalfa quadrangle, sheet 21/43 C, Kingdom of Saudi Arabia

by

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Open-File Report 83-333

Prepared for the Ministry of Petroleum and Mineral Resources
Deputy Ministry for Mineral Resources
Jiddah, Kingdom of Saudi Arabia

1/ U.S. Geological Survey, Reston, VA 22092

1983

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RECONNAISSANCE GEOLOGY OF THE JABAL DALFA QUADRANGLE, SHEET 21/43 C, KINGDOM OF SAUDI ARABIA

by

Robert C. Greene

ABSTRACT

The Jabal Dalfa quadrangle (sheet 21/43 C) is part of the Najd province in west-central Saudi Arabia. The quadrangle is mostly a plain, tilted gently northeastward, but local inselbergs and two areas of dissected uplands rise as much as 200 m above the plain. Wadi Bishah and Wadi Ranyah terminate in the quadrangle.

The quadrangle is underlain by Precambrian metavolcanic, metasedimentary, and plutonic rocks. The gneiss outcrops in the northeast and east-central parts of the quadrangle are apparently the oldest rocks. After they were emplaced, a wide variety of metavolcanic and metasedimentary rocks were deposited at Jabal Dalfa and Umm Shat, and in the northeast part of the quadrangle as the Arfan formation. Subsequently, granite gneiss was emplaced in the west part of the quadrangle and intruded by gabbro. Metabasalt and meta-andesite were extruded in a wide north-trending belt through the middle of the quadrangle and at Jabal Silli. Intrusion of small bodies of granitic rocks and Najd faulting conclude the Precambrian history of the area.

Surficial deposits include sand and gravel covering the plains, alluvial fans, and voluminous dune sands.

In the southeast part of the quadrangle, the layered rocks strike north and dip steeply. They are oriented parallel to the Nabitah fault zone. In the northeast and east-central parts of the quadrangle, layered rocks and gneiss are sheared into slices by the southernmost faults of the major Najd fault zone. Bedding and foliation in these slices strike northwest, parallel to the faults. Gneiss in the west part of the quadrangle also strikes northwest, and dips steeply to vertically; layered rocks underlying Jabal Silli strike northeast.

Layered metamorphic rocks in the Jabal Dalfa quadrangle are mostly in the greenschist facies.

Projection of data from other quadrangles suggests that the oldest gneiss is about 780 Ma old and the Arfan formation, Umm Shat, and Jabal Dalfa layered rocks are about 775 to 745 Ma old. The gneiss of Shaib Hadhaq is probably about 720 Ma old, the gabbro is 640 to 625 Ma old, and the granite of Jabal ash Shayal and Jabal Hadad is about 600 Ma old.

The airborne magnetometer survey suggests that considerable additional gabbro underlies the west part of the quadrangle. Concealed serpentinite bodies, particularly in the Nabitah fault zone, are also suggested. Elongate anomalies and linear gradients indicate that the northeast part of the quadrangle is probably part of the Najd fault zone.

A number of gold-bearing quartz veins in the quadrangle were mined in ancient times, and one at Jabal Umm Matirah has been drilled and found to be uneconomic. A nickel-copper prospect has proved uneconomic. A geochemical survey for additional deposits of metals was completed in 1982.

INTRODUCTION

The Jabal Dalfa quadrangle (sheet 21/43 C) is on the Najd plateau in west-central Saudi Arabia between lat 21°00' N. and 21°30' N. and long 43°00' E. and 43°30' E. and has an area of approximately 2,865 km^2. The middle of the quadrangle is about 300 km due east of At Taif (fig. 1).

The quadrangle is sparsely populated by bedouin who raise sheep, goats, and camels. No permanent settlements are found in the quadrangle, but several villages collectively named Ranyah lie along Wadi Ranyah just west of the quadrangle boundary.

A main ungraded track connects the west edge of the quadrangle south of Jabal Silli with Ar Rawdah, 15 km to the west and the principal village of the Ranyah community. A paved highway connects Ar Rawdah with At Taif, a road distance of about 360 km. The main track goes east from Jabal Silli, passes south of Jabal Dalfa, then southeast to Jabal Hadad, and on to Jabal Ishmas and Al Khamsin outside the quadrangle boundary. Most of the quadrangle is served by minor tracks and is accessible except where sand dune fields and sandy wadis form local barriers.

Previous work and present study

The Jabal Dalfa quadrangle and adjacent areas have been mapped at 1:500,000 scale (Jackson and others, 1979). Additional reconnaissance work was done by Hadley (written commun., 1977). Quadrangles in the area that have been mapped

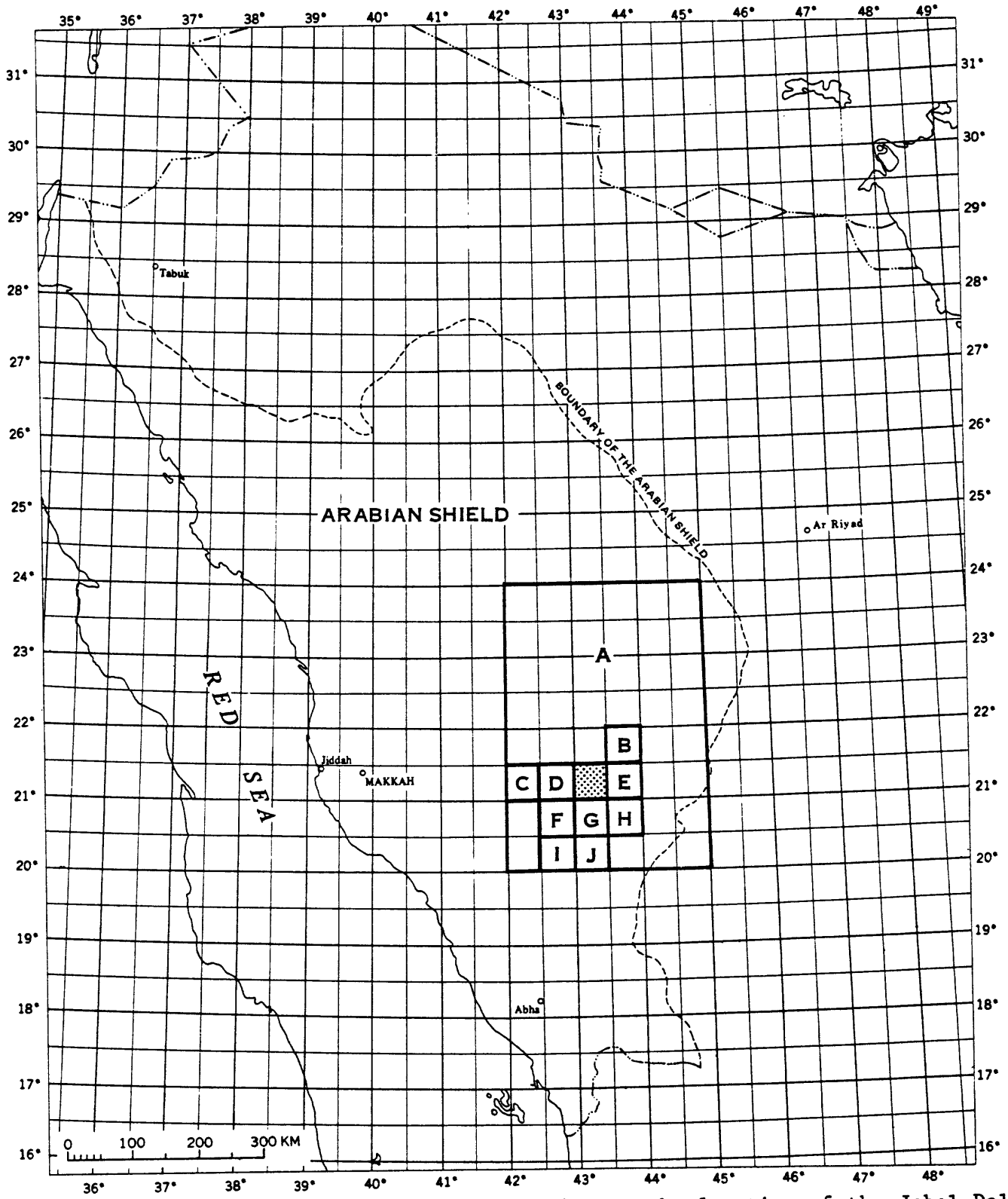


Figure 1.--Index map of western Saudi Arabia showing the location of the Jabal Dalfa quadrangle (shaded) and other quadrangles cited in this report: A--Southern Najd (Jackson and others, 1979); B--Jabal as Sukkah (Brock, *in press*); C--Harrat Nawasif (Greene, *1982*); D--Ranyah (Greene, *in press*); E--Bir Juqjuq (Hadley, 1976); F--Wadi al Miyah (Schmidt, *in press*); G--Jabal Ishmas (Gonzalez, 1975); H--Jabal Yafikh (Schmidt, *in press*); I--Al Junaynah (Schmidt, 1981a); J--Jabal al Qarah (Schmidt, *in press*).

at 1:100,000 scale include Jabal as Sukkah (sheet 21/43 B, Brock, in press), Bir Juqjuq (sheet 21/43 D, Hadley, 1976), Jabal Yafikh (sheet 20/43 B, Schmidt, in press), Jabal Ishmas (sheet 20/43 A, Gonzalez, 1975), Wadi al Miyah (sheet 20/42 B, Schmidt, in press), Ranyah (sheet 21/42 D, Greene,), and Harrat Nawasif (sheet 21/42 C, Greene, 1982). A small amount of reconnaissance work has been done in the quadrangles to the north and northwest of Jabal Dalfa (Hadley, written commun., 1977; Greene, unpublished data).

The Jabal Dalfa quadrangle was mapped in October, November, and December 1977. Additional field checking was done in November 1980. Most of the area was covered by helicopter traverses, and foot traverses were made in several areas. This report was prepared in accordance with a work agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey (USGS). Rock nomenclature is from Streckeisen (1973).

Analyses

Samples from the Jabal Dalfa quadrangle were analyzed in the Directorate General of Mineral Resources (DGMR)-USGS laboratory in Jiddah, by Ibrahim Baraja and Saeed Osman Qubia under the direction of K. J. Curry. Thirteen samples of carbonate rocks were analyzed for total iron as Fe_2O_3, MgO, and CaO, using carbonate-fraction solutions prepared by cold extraction with 2*M* HCl. Forty-one samples of granitic rocks were fused and analyzed for SiO_2, CaO, Na_2O, and K_2O by colorimetry and atomic absorption.

A computer program was devised to convert the partial analyses of granitic rocks into calculated light-mineral modal compositions. Because the rocks contain only a few percent dark minerals, these calculations give a reasonable approximate mode. All CaO, Na_2O, and K_2O were put into normative anorthite (an), albite (ab), and orthoclase (or), respectively, and excess SiO_2 into quartz (Q). Barth (1951) has shown that the alkali feldspar of most granite contains about 30 percent albite. It is necessary to add 43 grams of albite to 100 grams of orthoclase to get a feldspar that is 70 percent orthoclase and 30 percent albite; therefore, alkali feldspar (A-fsp) = 1.43 Or and plagioclase (plag) = An + Ab - .43 Or. Quartz = Q.

Where chemical data are presented in tabular form, the Rock Analysis Storage System (RASS) data-bank numbers for the samples are given in addition to the author's field numbers.

PHYSIOGRAPHY

The Jabal Dalfa quadrangle is part of the Najd physiographic province of the Arabian Shield. Most of the quadrangle is a plain, tilting gently northeastward. The altitude of the plain ranges from 900 to 950 m in the southwest part of the quadrangle, decreasing to 830 m at Wadi Rayyaniyah in the northeast.

Two large wadis enter the quadrangle and break up into distributary systems. Wadi Ranyah rises at the Red Sea escarpment near Jabal Balas east of Biljurshi and flows about 300 km to the border of the Jabal Dalfa quadrangle north of Jabal Silli. Surface flow is rare in the wadi east of this point; the channel becomes more poorly defined and breaks up into distributaries, some of which reach Wadi Rayyaniyah. Wadi Bishah rises at the Red Sea escarpment south of Khamis Mushayt and flows about 450 km to the border of the Jabal Dalfa quadrangle southwest of Jabal Dalfa. The main channel breaks up into many distributaries at Jabal Dalfa; some continue to Wadi Rayyaniyah east of the quadrangle boundary (Hotzl and others, 1978).

Much of the plain has a gravel surface, locally covered with sand dunes, some of which are large. Parts of the plain are gently sloping pediments.

Rising above the plain are inselbergs of various sizes and two areas of dissected uplands. The smaller inselbergs are single granite jabals, rising less than 100 m. The larger granite inselbergs, Jabal Hadad and Jabal ash Shayal, are more complexly formed and rise 100 to 200 m above the surrounding plain. Jabal Dalfa is underlain by metabasalt and is about 200 m above the plain. Its distinct black color makes it the most prominent feature of the area.

The dissected uplands, Jabal Silli and Umm Shat, are underlain by metavolcanic rocks. They rise 100 to 200 m above the plain and consist of a series of ridges with more or less accordant summit levels. Jabal Umm Matirah, a prominent inselberg partly in the quadrangle, is an outlier of higher dissected uplands to the east, which culminate in Jabal Arfan (Bir Juqjuq quadrangle, Hadley, 1976).

Hotzl and others (1978) suggest that the courses of Wadi Ranyah and Wadi Bishah are fault controlled; however, the accordant summit levels of the uplands in the Jabal Dalfa and Ranyah quadrangles plus the presence of the Al Khaniq water gap near Ranyah lead the author to believe that Wadi Ranyah and Wadi Bishah are superposed streams (Greene, in press, p. 42).

PRECAMBRIAN ROCKS

Metavolcanic and metasedimentary rocks

Metabasalt of Jabal Dalfa

Metabasalt of Jabal Dalfa (mbd) underlies Jabal Dalfa and flats to the north of the jabal. Outcrop is abundant and the weathered surface of the rock is black.

The unit is composed of dark-gray to black, fine- to medium-grained metabasalt and amphibolite that locally contain a strong lineation of hornblende or actinolite needles. The rock consists principally of plagioclase, amphibole, and clinopyroxene (table 1). If a rock contains more than 50 percent amphibole, it is termed amphibolite. Some of the amphibole is actinolite, colorless or nearly so in thin section with nil to weak pleochroism. Other amphibole is strongly colored and pleochroic hornblende.

Most of the rocks contain relict igneous clinopyroxene. Commonly, clinopyroxene is surrounded by metamorphic actinolite. These rocks are in upper greenschist to amphibolite facies.

The contact between the metabasalt of Jabal Dalfa and the gneiss of Shaib Hadhaq (gbh) is faulted and tectonically mixed in most places. However, the gneiss locally intrudes, and therefore postdates, the metabasalt.

Metasiltstone and carbonate rocks

Two small areas east and north of Jabal Dalfa are pediments, with sparse, low outcrops, underlain by metasiltstone and carbonate rocks (msc). Metasiltstone predominates and is medium dark gray and very fine grained. It has prominent planar foliation and bedding and weathers to slabs. The rock consists of various amounts of quartz, plagioclase, actinolite, chlorite, calcite, and opaque minerals.

Carbonate rocks are locally interbedded with the metasiltstone. Most of the carbonate rocks are light gray crystalline marble. Analysis of the carbonate fraction of a sample of this rock showed it to be a calcite marble with less than 10 percent $MgCO_3$ (table 2, fig. 2). A less common brown marble contains quartz and phlogopite. Analysis of its carbonate fraction showed nearly 10 percent $FeCO_3$ (table 2, fig. 2).

The mineral assemblage in the metasiltstones suggests metamorphism to greenschist facies, chlorite grade; the metadolomite attains biotite grade.

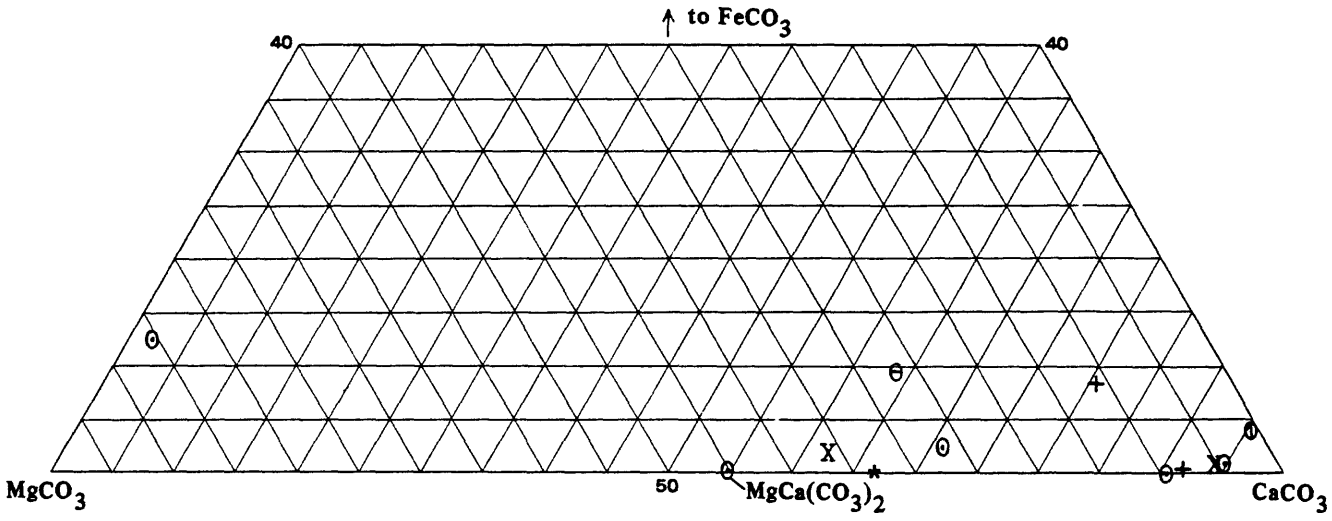
Table 1.--*Estimated modes of metabasalt of Jabal Dalfa (mbd)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Amphibolite				Metabasalt					
Field sample number	678	723-1	734-4	956	727-1	732-1	858	943-1	946	953-3
Quartz	--	--	--	10	--	--	--	--	--	--
Plagioclase	25	35	35	10	40	45	30	30	50	45
Actinolite	65	--	65	80	--	--	50	--	10	40
Hornblende	--	65	--	--	50	35	--	30	--	--
Clinopyroxene	10	--	Tr	--	10	20	20	40	40	15
Opaque	--	Tr	--	--	Tr	Tr	Tr	--	--	Tr

Table 2.--*Partial analyses of carbonate fractions of samples from metasiltstone and carbonate rocks (msc), and serpentinite, marble, and metabasalt (smb), including calculated percent of carbonates in samples, and proportions of $FeCO_3$, $MgCO_3$, and $CaCO_3$ in carbonate fraction*

RASS sample number	Field number	Unit	Fe_2O_3 (percent)	MgO (percent)	CaO (percent)	Calculated total carbonates (percent)	$FeCO_3$ (percent of total carbonate)	$MgCO_3$	$CaCO_3$
138,189	693-3	msc	2.22	2.07	16.79	39.03	8.25	11.1	80.7
138,190	693-4	msc	.33	3.56	43.72	89.89	.54	8.3	91.2
138,191	702	smb	.09	4.22	46.17	95.51	.13	9.2	90.7
138,193	770-1	smb	4.75	23.21	.69	56.73	12.12	85.6	2.3
138,194	771-1	smb	1.24	10.77	32.18	84.66	2.13	26.6	71.3
138,195	777-1	smb	.37	1.90	42.46	84.10	.63	4.7	94.6
138,196	778	smb	.40	18.24	24.49	84.65	.69	45.1	54.2



\+ Metasiltstone and carbonate rocks (msc)
⊙ Serpentinite, marble, and metabasalt (smb)
◐ Dacite and dacite tuff (ds)
* Metabasalt, meta-andesite, carbonate rock, and serpentinite (bcas)
X Serpentinite, and metavolcanic and carbonate rocks (sbc)
ϴ Tonalite gneiss (gnt)

Figure 2.--Ternary diagram showing the composition of the carbonate fraction of selected rocks from the Jabal Dalfa quadrangle.

Quartzite

A small outcrop area southeast of Jabal Silli consists of dark-yellowish-brown, very fine grained quartzite (q). The rock consists of quartz with about 10 percent plagioclase and a few percent of sillimanite. Micas are absent.

Serpentinite, marble, and metabasalt

Areas in the southeast-central part of the quadrangle and near the southeast corner east of the Nabitah fault are underlain by a complex of serpentinite, marble, and metabasalt (smb). In general, the areas are low lying with scattered outcrops, many of them sheared and weathered, so that an estimate of the relative importance of the various rock types is not possible. However, from lat 21°09' N. to 21°11' N., long 43°22' E. and at two isolated occurrences directly to the south, prominent inselbergs are underlain by exceptionally resistant serpentinite.

Serpentinite underlying the lowlands is greenish black where fresh, and very fine grained. However, it is commonly weathered to a brown mass of clay minerals and iron oxides, crisscrossed with carbonate veins. The serpentinite underlying the inselbergs is light greenish gray where fresh, but commonly mottled with brownish gray. It is fine to very fine grained with interlocking fibers, and consists of 85 to 100 percent serpentine; the rest is opaque oxides and carbonate minerals.

Marble is light to dark gray, commonly with light-gray streak and mottle, and is medium to fine grained. It is locally partly serpentinized; elsewhere it is nearly all carbonate with traces of tremolite and opaque minerals. An unusual variety contains about 25 percent actinolite and 10 percent mica, probably clintonite.

Analyses of the carbonate fractions of five samples of marble from this unit reveal a wide range of proportions of calcium and magnesium carbonates (table 2, fig. 2). Samples numbered 702 and 777-1, from outcrops far from serpentinite or metabasalt, are calcite marble with less than 10 percent $MgCO_3$; sample 778 from a similar environment is stochiometric dolomite. Samples 770-1 and 771-1 crop out close to metabasalt and serpentinite in the Nabitah fault zone; the latter consists of calcite and dolomite in nearly equal proportions, and the former is magnesite with 12 percent $FeCO_3$.

Metabasalt and meta-andesite are found in scattered, low outcrops. These rocks are medium dark gray to greenish gray, very fine grained, and uniform. Locally, (table 3) these contain no plagioclase but consist of mafic minerals and

Table 3.--*Estimated modes of metavolcanic rocks from serpentinite, marble, and metabasalt (smb)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Amphibolite	Metabasalt			
Field sample number	776	772	783-2	784-1	784-2
Quartz	30	5	10	Tr	20
Plagioclase	--	--	40	65	40
Actinolite	--	40	--	--	--
Hornblende	70	--	30	35	40
Chlorite	--	Tr	10	Tr	--
Epidote	--	50	10	--	Tr
Calcite	--	2	--	Tr	Tr
Opaque	1	Tr	--	Tr	--

accompanying quartz; metavolcanic rocks consisting of plagioclase and hornblende with minor quartz, epidote, and calcite crop out elsewhere.

In the area near the southeast corner of the quadrangle, marble and metabasalt are the dominant rocks and serpentinite crops out only near the Nabitah fault.

Ultramafic-carbonate rocks

Several small areas of pediment underlain by altered ultramafic-carbonate rocks (umc) are north of the main area of outcrop near the southeast corner of the quadrangle. The pediments have low relief; outcrop is abundant, but fresh rock scarce. The rocks sampled include anthophyllite-carbonate rock, and altered serpentine-carbonate rock, grading into brown gossan. The anthophyllite-carbonate rock is brown, fine grained, and crisscrossed by carbonate veins. It consists of 40 to 55 percent each of anthophyllite and carbonate minerals, and about 5 percent brown oxides and hydroxides. The serpentine-carbonate rocks are also brown and fine grained and consist of serpentine and iron oxides and hydroxides, locally crisscrossed with carbonate veins.

Siltstone and sandstone

Several low outcrops of siltstone and fine sandstone (sis) lie near the center of the east margin of the quadrangle. The outcrops are elongated parallel to the northwest strike. The siltstone is dark gray to black, very fine grained, and uniform with strong cleavage. The rock consists of angular, broken grains of plagioclase and quartz in a matrix of biotite, chlorite, other clay minerals, and calcite. The sandstone is light brownish gray with pinkish mottle and contains the same minerals.

Metabasalt and meta-andesite of Umm Shat

A series of north-trending ridges known as Umm Shat lie near the southeast corner of the quadrangle. The ridges are as much as 300 m above the surrounding plain and are topped by bold outcrops of metabasalt and meta-andesite (mbas). The rocks are characteristically coated black by desert varnish and contrast sharply with the pink to brown coloration of Jabal Hadad to the west. These rocks are continuous with the upper volcanic and lower clastic units of the Halaban group of Gonzalez (1975) in the adjacent Jabal Ishmas quadrangle.

The metabasalt and meta-andesite are mostly medium to dark greenish gray and fine to very fine grained. Locally, they are mostly medium light to medium dark gray and porphyritic. The rocks consist principally of plagioclase, actinolite, epidote, and quartz, with and without chlorite or

biotite (table 4). Alteration of plagioclase to epidote and quartz is more prevalent in these rocks than in the meta-basalt and meta-andesite of the central belt.

Much of the rock is thoroughly sheared and dips are steeply eastward to vertical. Few minor fold axes were identified. The stratigraphic section is probably repeated by either strike-slip or vertical faulting.

Dacite and dacite tuff

Several areas in the west part of Umm Shat are underlain by silicic volcanic rocks (ds). The rocks are mostly dacite and dacite tuff but include some rhyodacite, andesite, and marble. These silicic volcanic rocks generally crop out in bold ridges; however, in the southernmost part of the unit, at the quadrangle boundary, the rocks form a flat pediment with low outcrop.

Dacite and dacite tuff are medium to dark gray and have aphanitic groundmass. Some rocks contain a few percent plagioclase phenocrysts. Some show faint 1- to 5-mm-thick bedding in hand specimen, rarely discernable in thin section. The groundmass is mostly plagioclase, quartz, actinolite, biotite, chlorite, opaque minerals, and secondary calcite, insufficiently resolvable to estimate proportions.

A hill in the north part of this unit is underlain by medium-gray rhyodacite containing about 1 percent plagioclase and traces of quartz phenocrysts in cryptofelsite groundmass. Adjacent low ridges are composed of meta-andesite, similar to that in the Umm Shat ridges, and dark-gray, fine-grained marble. The marble is composed of calcite containing 4 percent $FeCO_3$ and negligible $MgCO_3$ (table 5, fig. 2).

Arfan formation

The Arfan formation was established by Hadley (1976) in the adjacent Bir Juqjuq quadrangle. It was named after Jabal Arfan, which lies 15 km due east of the point where Wadi Rayyaniyah leaves the Jabal Dalfa quadrangle. In the northwest part of the Bir Juqjuq quadrangle, the Arfan formation is 12 to 16 km wide. It consists of "volcanic flow rocks, pyroclastic and volcaniclastic rocks, graywacke, and conglomerate" and is subdivided into 10 members. Hadley (1976) assigned the Arfan formation to the Halaban group; however, the name Halaban is no longer being used in its type area (Delfour, 1979) and, therefore, further use of the name Halaban is best discontinued.

Table 4.--*Estimated modes of metabasalt and meta-andesite of Umm Shat (mbas)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts; p, phenocryst; g, groundmass]

Name	Meta-andesite tuff	Metabasalt			Porphyritic metabasalt		Meta-andesite	
Field sample number	754	755	762-1	774	758-2	762-3	766-2	769
Quartz	20	--	20	20	5	20	25	10
Plagioclase	30	30	--	--	p-10	p-5	20	40
Actinolite	--	70	60	70	p-Tr g-55	55	20	15
Hornblende	1	--	--	--	--	--	--	--
Chlorite	2	--	1	--	--	Tr	15	20
Biotite	10	Tr	--	--	--	--	--	--
Epidote	40	--	20	10	30	20	20	15
Calcite	Tr	--	Tr	Tr	Tr	--	--	--
Opaque	--	1	Tr	--	--	1	--	--

Table 5.--*Partial analyses of carbonate fractions of samples from dacite and dacite tuff (ds), metabasalt, meta-andesite, carbonate rock, and serpentinite (bcas), serpentinite, and metavolcanic and carbonate rocks (sbc), and tonalite gneiss (gnt), including calculated percent of carbonates in samples, and proportions of $FeCO_3$, $MgCO_3$, and $CaCO_3$ in carbonate fraction*

RASS sample number	Field number	Unit	Fe_2O_3 (percent)	MgO (percent)	CaO (percent)	Calculated total carbonates (percent)	$FeCO_3$ (percent of total carbonate)	$MgCO_3$	$CaCO_3$
138,192	753-2	ds	1.84	.13	33.57	65.86	4.03	.4	95.6
138,188	645-7	bcas	.09	16.07	36.37	101.93	.12	33.0	66.9
138,198	877-2	sbc	.21	1.74	35.68	70.83	.42	5.1	94.4
138,199	880-2	sbc	1.20	12.44	23.99	72.77	2.39	35.8	61.8
138,200	925	gnt	5.66	10.77	28.68	84.50	9.70	26.7	63.6

In the Jabal Dalfa quadrangle, the Arfan formation consists of metabasalt, meta-andesite, metadacite, sandstone and conglomerate, minor carbonate rock, and serpentinite and is divided into 8 informal units. They crop out in the northeast part of the quadrangle. With the exception of Jabal Umm Matirah, these rocks underlie a flat pediment. Outcrop is locally abundant, especially where strike lines are indicated on the geologic map (pl. 1). A description of each unit follows.

Metabasalt, meta-andesite, carbonate rock, and serpentinite.--Rocks of this unit (bcas) form the southwesternmost exposed band of the Arfan formation in the Jabal Dalfa quadrangle. Metabasalt is most common and is dark gray to dark olive and greenish gray and has fine-grained and breccia texture. Mineralogy is varied; most metabasalt contains 35 to 50 percent saussuritized plagioclase; the rest is actinolite, epidote, carbonate minerals, and opaque minerals; some contains unaltered clinopyroxene.

Meta-andesite is light olive gray with cataclastic texture and consists of about 75 percent saussuritized plagioclase and 25 percent actinolite. Carbonate rocks include medium-light-gray, brecciated marble and rusty-weathering marble containing 35 percent tremolite. An analysis of the gray marble shows it to consist of 75 percent dolomite and 25 percent calcite with negligible iron (table 5, fig. 2). Serpentinite is dark olive gray and very fine grained with boxwork texture. It consists of serpentine and minor opaque minerals.

Sandstone, conglomerate, and meta-andesite.--This unit (scg) forms a continuous band, locally as much as 3 km wide. The sandstone is grayish red, medium to coarse grained, and contains closely packed angular grains. Quartz and plagioclase each compose 5 to 10 percent of the grains and the remaining 80 to 90 percent is volcanic rock fragments, mostly andesite and dacite. The matrix is patchy quartz, chlorite, and opaque minerals. Sandstone grades into medium-dark-gray to brownish- or greenish-gray conglomerate of similar composition. Pebbles in some rocks are 2 to 10 mm in diameter, elsewhere 1 to 3 cm, and locally as much as 8 cm in diameter.

Meta-andesite contains traces of plagioclase and clinopyroxene phenocrysts in a groundmass of alined plagioclase microlites and dark, indeterminate matrix.

Meta-andesite.--This unit (ma) forms a distinct light-colored band on aerial photographs that is terminated by faults after a strike length of 4.5 km. The meta-andesite is dark greenish gray, very fine grained, and

porphyritic. It contains 5 percent hornblende phenocrysts in a groundmass of 70 percent plagioclase microlites, 10 percent epidote, 10 percent chlorite, and 5 percent opaque minerals.

Metaquartzose sandstone and serpentinite.--This unit (sss) consists almost entirely of metaquartzose sandstone grading to quartzite, and forms a continuous band locally as much as 2 km wide. The sandstone is olive to greenish gray, very fine grained, strongly foliated, and lineated. Closely spaced cleavage planes show minor folds and crenulations, and vein quartz is abundant. The microtexture is cataclastic. Typically the sandstone contains 40 to 60 percent quartz, and 5 to 25 percent plagioclase, both in angular grains; its matrix consists of actinolite, epidote, chlorite, and calcite. Some sandstone contains as much as 95 percent quartz.

Serpentinite crops out at one locality near the base of Jabal Umm Matirah. The sample studied is a cumulate containing 25 percent serpentine and 75 percent opaque minerals.

This unit, the meta-andesite unit, and the sandstone, conglomerate, and meta-andesite unit described above, are continuous with part of the lower conglomeratic and volcanic member of the Arfan formation in the Bir Juqjuq quadrangle (Hadley, 1976).

Metabasalt.--Metabasalt (mba) forms a lens about 3 km long. This rock is medium gray to grayish olive green and aphanitic and is commonly a breccia and mylonite. It consists of indeterminate proportions of plagioclase, quartz, epidote, chlorite, actinolite, and calcite.

Metadacite and meta-andesite.--This unit (mda) underlies Jabal Umm Matirah and its immediate surroundings. The metadacite is light brownish gray, aphanitic, and exceptionally resistant. Some contains as much as 3 percent euhedral plagioclase microphenocrysts. The groundmass is about 75 percent plagioclase microlites with interstitial quartz and a few shreds of actinolite. The meta-andesite is darker and contains more ferromagnesian minerals. This unit is continuous with the lower volcanic and tuffaceous member of the Arfan formation in the Bir Juqjuq quadrangle (Hadley, 1976).

Sandstone and conglomerate.--Sandstone and conglomerate (cgg) form a narrow lens about 2 km long. The unit is significant because the conglomerate contains apparent granitic pebbles. Sandstone is medium dark gray and contains angular framework grains that are 60 percent plagioclase and 10 percent quartz in a recrystallized matrix of 30 percent actinolite and minor epidote, calcite, and opaque minerals. Some

composite grains contain quartz and feldspar, possibly potassium feldspar. Conglomerate has a similar matrix supporting subangular pebbles of light-colored, apparently granitic rocks. The pebbles are 0.5 to 2 cm, rarely as much as 4 cm, in diameter.

Metadacite and meta-andesite.--Metadacite and meta-andesite (adm) crop out in a west-northwest-trending band near the northeast corner of the quadrangle and extend into the adjacent quadrangle to the north. The unit also forms a small lens at the north boundary 6 km to the west of the main band. Metadacite is light olive to brownish gray and contains microphenocrysts of plagioclase, quartz, and hornblende in an aphanitic groundmass consisting of mostly plagioclase, quartz, and shreds of actinolite. Meta-andesite is medium-dark to dark gray and also microporphyritic. It contains 5 percent plagioclase and 10 to 20 percent hornblende phenocrysts in an aphanitic groundmass of plagioclase, quartz, opaque oxides, and locally, epidote, actinolite, and calcite.

Metabasalt and meta-andesite of central belt

Areas underlain by metabasalt and meta-andesite (mbac) extend from the north-central to the south-central part of the quadrangle. Metabasalt and meta-andesite underlie pediments of low relief, and angular, black outcrops are abundant. A characteristic fine dendritic drainage pattern is visible on the aerial photographs. That the drainage pattern extends to adjacent areas lacking outcrop suggests that they, too, are underlain by metabasalt and meta-andesite.

The rocks of this unit are medium to dark gray and greenish gray and fine grained to aphanitic. Their mineralogy and textural characteristics vary widely (table 6). Their metamorphic grade ranges from greenschist to amphibolite facies. Many rocks are composed of plagioclase and actinolite containing some or no epidote. Other rocks contain significant quantities of quartz and chlorite; in some, all the plagioclase is altered to quartz, epidote, and chlorite. Some rocks contain hornblende in place of actinolite. Biotite, calcite, sphene, and opaque oxides are locally present. The rock is locally porphyritic, containing a substantial portion of flow-alined plagioclase phenocrysts. Fragmental texture is clear in some rocks and suspected in others.

Conglomerate

A single band of conglomerate (cc) in the metabasalt and meta-andesite in the southeast-central part of the quadrangle consists of volcanic pebbles, locally as large as 10 cm, in a dark reddish-brown siltstone matrix.

Table 6.--*Estimated modes of metabasalt and meta-andesite of central belt (mbac)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts; p, phenocryst; g, groundmass]

	Metabasalt					Porphyritic metabasalt		Basalt tuff	Meta-andesite tuff	Meta-andesite
Field sample number	639	640-4	643	719	735-1	640-1	681	717	803	928
Quartz	--	2	Tr	20	--	Tr	Tr	2	12	10
Plagioclase	35	40	50	--	50	p-25 g-20	p-35 g-15	43	65	45
Actinolite	65	40	40	--	50	20	--	--	--	10
Hornblende	--	--	--	60	--	--	40	55	--	--
Chlorite	--	--	2	Tr	--	--	--	--	18	10
Biotite	--	5	--	1	--	--	--	Tr	2	--
Epidote	--	10	2	20	--	p-10 g-25	10	Tr	--	20
Calcite	--	--	Tr	--	--	--	--	--	Tr	5
Sphene	--	1	--	--	--	--	--	--	--	--
Opaque	2	--	2	1	1	--	--	--	3	--

Amphibolite

Three small areas near the northwest corner of the quadrangle are underlain by amphibolite (am). The outcrop areas form low, rough ridges, protruding above flats covered by surficial deposits. The amphibolite is dark greenish gray with light gray streak and mottle. It contains about 65 percent coarse-grained hornblende, 25 percent fine-grained interstitial plagioclase, and 10 percent small grains of diopside distributed equally in the hornblende and the plagioclase. Small amounts of epidote are also present. The amphibolite is interpreted as correlative with the metabasalt and meta-andesite of the central belt.

Serpentinite, and metavolcanic and carbonate rocks

The area immediately to the south of Jabal Silli, in the west-central part of the quadrangle, is underlain by a complex of serpentinite, and metavolcanic and minor carbonate rocks (sbc). The unit extends into the Ranyah quadrangle to the west (Greene, *in press*).

Isolated outcrops form small inselbergs protruding above gravel plains. Most are partly sheared and brecciated serpentinite; some are more massive metavolcanic rocks; carbonate is locally present.

The serpentinite is light to dark greenish gray, commonly streaked brown. Natural sandblasting has caused the serpentinite to have fluted surfaces free of weathering stains. The serpentinite consists of serpentine, calcite, and opaque minerals (table 7). A boxwork texture of fibers is seen in thin section, the spaces of which are filled with random fibers.

The metavolcanic rocks consist of amphibolite, metabasalt, and meta-andesite (table 7). The rocks, similar to those in the complex of Jabal Silli, are composed of plagioclase, hornblende or actinolite, and minor epidote, calcite, and opaque minerals.

Carbonate rocks form minor beds and lenses. They are light gray to light brownish gray and fine grained. Analyses of the carbonate portion of one such rock shows it to be a marble composed of nearly pure calcite (table 5, fig. 2). Another, serpentinized, marble has a carbonate fraction of about 75 percent dolomite, 25 percent calcite, and minor iron.

Table 7.--*Estimated modes of serpentinite, and metavolcanic and carbonate rocks (sbc)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Serpentinite				Amphibolite		Metabasalt		Meta-andesite	
Field sample number	619	620-1	353-2	880-2	620-2	620-3	622	877-1	880-1	353-1
Quartz	--	--	--	--	--	--	--	--	--	20
Plagioclase	--	--	--	--	2	40	55	50	65	30
Actinolite	--	--	--	--	--	--	--	50	35	--
Hornblende	--	--	--	--	95	55	25	--	--	40
Biotite	--	--	--	--	--	--	--	--	Tr	--
Clinopyroxene	--	--	--	--	--	--	20	--	--	--
Serpentine	90	80	85	60	--	--	--	--	--	--
Epidote	--	--	--	--	--	2	--	Tr	--	10
Calcite	--	20	10	40	--	2	--	Tr	Tr	--
Opaque	10	1	5	Tr	3	1	1	--	5	Tr

Mixed intrusive and metamorphic rocks

Meta-andesite and diorite

Meta-andesite and diorite (mad) crop out in a flat pediment isolated between dune fields near the southwest corner of the quadrangle. The rocks continue into the adjacent Jabal Ishmas quadrangle (Gonzalez, 1975), where they are lumped with a unit of granodiorite gneiss.

The meta-andesite is medium dark to dark gray and fine grained to aphanitic (table 8). The rocks are characterized by well-alined plagioclase microlites. One sample contains hornblende and biotite; the other, more altered sample, contains chlorite in a groundmass probably consisting of carbonate and opaque minerals.

The diorite is coarse grained and greenish black with white and pink splotches. It has a color index of about 50 and consists mostly of plagioclase and hornblende, with calcite and quartz in the more altered sample (table 8).

Metagabbro, granite, and metavolcanic and ultramafic rocks

This heterogeneous unit (ggvu) underlies a low relief pediment with abundant outcrop in the southeast part of the quadrangle. It is continuous with the gabbro and pyroxenite, and granite and granodiorite of Hadley (1976) in the Bir Juqjuq quadrangle to the east.

The most distinctive, but probably not the most abundant, rock in this unit is metagabbro. It is mottled dark gray and white and is fine and medium grained. The rock consists of 35 to 50 percent plagioclase, 50 to 65 percent actinolite, and trace amounts of epidote, calcite, and opaque minerals.

Granite, very light gray and medium grained, is abundant and may constitute over 50 percent of this unit. It is similar to, and probably continuous with, the adjacent two-mica granite (bg), and intrudes the other rocks. Quartz veins, probably related to the granite, are also abundant.

Metabasalt and meta-andesite crop out at scattered localities. They are similar to the metabasalt and meta-andesite of other units, and are apparently intruded by metagabbro and granite.

Ultramafic rocks in this unit include serpentinite and talc schist. Serpentinite is commonly brownish black, fine grained, and uniform; however, it is locally altered, brown, and crisscrossed with carbonate veins. Talc schist occurs

Table 8.--*Estimated modes of meta-andesite and diorite (mad)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts; p, phenocryst; g, groundmass]

	Meta-andesite	Diorite
Field sample number	806-1	806-2
Quartz	Tr	--
Plagioclase	73	45
Hornblende	15	55
Muscovite	--	Tr
Chlorite	--	--
Biotite	10	--
Epidote	--	Tr
Calcite	--	--
Opaque	2	--

only in the northwest part of the outcrop area. It is almost entirely talc, containing about 1 percent opaque and carbonate minerals.

Metabasalt of Jabal Dalfa and gneiss of Shaib Hadhaq

On the east and west flanks of Jabal Dalfa and in the flats to the north, metabasalt of Jabal Dalfa is intimately mixed with gneiss of Shaib Hadhaq (mg). Mixing is in part tectonic and in part intrusive. The character of the rocks is as described for the individual units.

Metavolcanic and granitic rocks of Urayyiq

The metavolcanic and granitic rocks of Urayyiq (vgu) crop out in the southwest part of the quadrangle, south of Jabal Silli. The unit is named for a ridge in the Ranyah quadrangle, adjacent to the west (Greene, in press), and the rocks are continuous into that quadrangle. The field appearance of the rocks is very similar to that of the gneiss of Shaib Hadhaq (description follows), and somewhat arbitrary contacts are drawn between the two units. The bulk of the unit is granite, granodiorite, and tonalite gneiss (table 9). The gneiss is medium to coarse grained, locally fine grained, and light gray to pink. It is composed of the same minerals as the equivalent rocks in the gneiss of Shaib Hadhaq. Rocks interlayered with the gneiss include metabasalt and plagioclase-pyroxene granofels.

The metabasalt is dark gray, fine grained, and consists of plagioclase, hornblende, and minor opaque minerals. The granofels is dark gray, fine or medium grained, and consists principally of plagioclase, hornblende, and both orthopyroxene and clinopyroxene. These rocks are metamorphosed to amphibolite facies.

Metavolcanic and intrusive complex of Jabal Silli

Jabal Silli is a rugged, irregular mountainous area about 7 km long, in the west-central part of the quadrangle. It extends a short distance into the Ranyah quadrangle (Greene, in press). Some of the mountains crest in ridges, but drainage is mostly dendritic. Virtually all rocks underlying the jabal weather to a black desert patina. The rocks break down to abundant angular blocks, which cover the lower slopes, choke the drainage courses, and form a large alluvial apron around the jabal.

Jabal Silli is underlain by a complex of metavolcanic and intrusive rocks (bjs). Metabasalt and amphibolite are most abundant; meta-andesite and rhyodacite are present (table 10). Intrusive rocks include gabbro and pyroxenite.

Table 9.--*Estimated modes of metavolcanic and granitic rocks of Urayyiq (vgu)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Granite gneiss		Tonalite	Metabasalt		Marble	Granofels	
Field sample number	827	831	833-1	818	824-2	828-1	828-2	829-2
Quartz	30	25	20	--	--	--	--	1
K-feldspar	20	40	--	--	--	--	--	--
Plagioclase	50	35	65	40	50	--	50	70
Actinolite	--	--	--	--	--	--	Tr	--
Hornblende	--	Tr	5	60	50	--	20	Tr
Chlorite	Tr	--	--	--	Tr	--	--	--
Biotite	Tr	Tr	10	--	--	--	--	--
Clinopyroxene	--	--	--	--	--	Tr	1	20
Orthopyroxene	--	--	--	--	--	--	30	5
Epidote	--	--	--	--	Tr	--	--	--
Calcite	--	--	--	--	--	90	--	--
Apatite	--	--	Tr	--	--	--	--	--
Zircon	Tr(?)	--	Tr	--	--	--	--	--
Sphene	--	Tr	Tr	--	--	--	--	--
Opaque	Tr	Tr	Tr	Tr	Tr	--	Tr	3
Wollastonite	--	--	--	--	--	10	--	--

Table 10.--*Estimated modes of metavolcanic and intrusive complex of Jabal Silli (bjs)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Amphibolite	Metabasalt				Meta-andesite		Rhyodacite	Gabbro		Pyroxenite	
Field sample number	623	355	357	624-2	834	839-1	839-5	839-2	842	843	840-2	839-6
Quartz	--	--	--	--	--	--	--	25	--	--	--	--
K-feldspar	--	--	--	--	--	--	--	25	--	--	--	--
Plagioclase	30	35	35	55	65	65	70	47	40	40	Tr	10
Actinolite	60	--	--	--	--	--	--	--	60	--	60	20
Hornblende	--	25	35	45	--	35	30	--	--	60	--	--
Muscovite	--	--	--	--	--	--	--	Tr	--	--	--	--
Chlorite	--	Tr	--	--	--	--	--	Tr	--	--	--	--
Biotite	--	--	--	--	Tr	Tr	Tr	3	--	--	--	--
Clinopyroxene	--	35	30	--	25	--	--	--	Tr	--	40	70
Olivine	--	5	10	--	10	--	--	--	--	--	--	--
Epidote	5	--	--	--	--	Tr	--	--	--	--	--	--
Calcite	--	--	Tr	Tr	--	Tr	--	--	--	--	--	--
Sphene	--	--	--	Tr	--	--	--	--	--	--	--	--
Opaque	Tr	Tr	Tr	Tr	Tr	Tr	1	Tr	Tr	--	--	--

Metabasalt and meta-andesite are medium to dark gray and fine grained and generally lack visible foliation or layering. They consist principally of plagioclase and hornblende (table 10); some retain a substantial proportion of clinopyroxene and olivine. The more plagioclase-rich metabasalt and meta-andesite contain biotite. An isolated outcrop of basaltic tuff lies directly east of the jabal.

Rhyodacite and rhyolite were identified at one locality only, near the east end of the jabal, but may be more widely distributed. The rocks are medium-gray to brownish-gray, very fine grained, and consist of plagioclase, potassium feldspar, quartz, and minor amounts of biotite, chlorite, and opaque minerals.

Gabbro and pyroxenite intrude the metavolcanic rocks and appear to be intimately intermixed with them. The gabbro and pyroxenite are dark gray and medium to coarse grained. The gabbro consists of plagioclase and actinolite or hornblende, and has textures suggesting that the latter minerals are replacements of clinopyroxene or olivine. The pyroxenite consists principally of clinopyroxene, in part altered to actinolite, and accompanied by minor plagioclase. The intermingling and similar metamorphic history of the rocks in this complex suggest that they were all formed about the same time.

Intrusive rocks

Hornblende-plagioclase gneiss and plagioclase-quartz gneiss

A wide band of rocks in the Najd fault zone near the northeast corner of the quadrangle consists of interlayered hornblende-plagioclase and plagioclase-quartz gneiss (gnh). A portion of the adjacent Bir Juqjuq quadrangle (Hadley, 1976) is reinterpreted in a later section to account for the presence of the gneiss. The hornblende-plagioclase gneiss is mostly medium dark and dark gray, locally greenish gray, with light gray streak and mottle. Plagioclase-quartz gneiss is light brownish to pinkish gray. The gneiss is very fine to medium grained and has strong foliation and both cataclastic and recrystallized textures. Paper-thin cleavage, minor folds, and lineation are locally present.

The dark-colored gneiss consists mostly of plagioclase, quartz, and hornblende in varied proportions (table 11). These rocks are the sheared equivalents of mafic tonalite, quartz diorite, and, in the case of the quartz-free sample 656, diorite. Most samples contain epidote, garnet, chlorite, opaque minerals, and apatite. The quartz-free sample contains traces of clinopyroxene and biotite.

Table 11.--*Estimated modes of hornblende and plagioclase gneiss (gnh)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Gneiss									
Field sample number	651-1	652	656	670-2	900	903	904	912	915	916
Quartz	10	20	--	35	40	30	5	30	20	10
Plagioclase	25	25	55	60	20	65	60	60	60	10
Hornblende	40	50	45	--	35	--	32	3	1	70
Muscovite	--	--	--	2	--	2	--	--	--	--
Chlorite	--	3	Tr	1	--	2	Tr	1	Tr	--
Biotite	--	--	Tr	1	--	--	--	--	--	--
Clinopyroxene	--	--	Tr	--	--	--	3	--	--	--
Epidote	20	Tr	--	Tr	5	--	--	3	20	10
Garnet	3	2	--	Tr	2	--	--	Tr	Tr	--
Calcite	--	--	--	--	--	Tr	--	--	--	--
Apatite	Tr	Tr	--	Tr	--	Tr	--	Tr	--	--
Sphene	--	--	--	--	--	--	--	--	--	Tr
Opaque	2	Tr	Tr	Tr	1	Tr	Tr	Tr	--	Tr

The light-colored gneiss consists mostly of plagioclase and quartz (table 11). Some samples contain small amounts of hornblende; others contain muscovite. Small amounts of garnet, chlorite, biotite, epidote, opaque minerals, and apatite complete the mineral assemblages.

This unit and the tonalite gneiss unit described in the next section contain a number of dacite porphyry dikes several meters thick but too short to be mappable. The dacite porphyry is medium to dark gray and contains distinct, light-colored phenocrysts. The phenocrysts are 10 to 15 percent euhedral plagioclase, 1 to 2 percent quartz, and 1 to 15 percent hornblende in an aphanitic groundmass of plagioclase, quartz, epidote, and amphibole.

Tonalite gneiss

A small area in the extreme northeast corner of the quadrangle is underlain by tonalite gneiss (gnt). This rock is light to medium dark gray, fine to coarse grained, and cataclastic. It consists mostly of plagioclase and quartz; one sample contains hornblende, the other biotite. A band of white and brown carbonate rock, only 20 cm thick, is interlayered in the gneiss. Analysis of the carbonate rock showed it to consist of about 70 percent dolomite and 30 percent calcite, with substantial iron (table 5, fig. 2).

Quartz diorite gneiss

A small area in the east-central part of the quadrangle is underlain by cataclastic quartz diorite gneiss (qdg). The rock is found in low outcrops elongate parallel to its northwest strike.

The rock is greenish gray and pinkish gray, fine to medium grained, with strong shear foliation parallel to the Najd faults. The specimen studied contains about 60 percent plagioclase in ovoid and broken grains and about 10 percent interstitial quartz. The remainder is composed of biotite, hornblende, opaque minerals, and secondary chlorite, epidote, and calcite.

Augen gneiss

Near the east boundary of the quadrangle, directly south of the Wadi Bishah distributaries, a small area is underlain by cataclastic augen gneiss (gn). A similar area is 1.5 km to the southeast in the Bir Juqjuq quadrangle. The gneiss has a medium-dark-gray, very fine grained groundmass with distinct pink feldspar augen and streaks, 1 to 2 mm x 2 to 10 mm. The augen contain both potassium feldspar and plagioclase and constitute about 35 percent of the rock. The

groundmass contains potassium feldspar, plagioclase, and quartz, in indeterminate proportions, and small amounts of biotite, epidote, zircon, sphene, and chlorite.

Gneiss of Shaib Hadhaq

The gneiss of Shaib Hadhaq (gbh), in the southwest quadrant of the quadrangle, is a continuation of the gneiss and metabasalt of Shaib Hadhaq in the Ranyah quadrangle to the west (Greene, in press). Projection of the gneiss under alluvium indicates that it may occupy a large part of the western third of the Jabal Dalfa quadrangle. This unit does not contain metabasalt, except where mapped as mixed with metabasalt of Jabal Dalfa.

The gneiss underlies flat to domical pediments with low elongate ridges generally centered on dikes. Outcrop is abundant, and generally has smooth exfoliated surfaces. The commonly strong foliation has little bearing on outcrop shape or appearance.

This unit consists of granite, granodiorite, and tonalite gneiss, irregularly interlayered. The gneiss is mostly medium to coarse grained and has the pink to white, light-gray, and black colors of the component mineral grains. Some of the gneiss is finer grained, and medium gray, pale reddish brown, pinkish gray, and yellowish gray. The plagioclase of these granodiorites and tonalites is commonly as pink as the potassium feldspar of the granites and granodiorites.

Most of the rocks are strongly foliated, and examination of thin sections shows that the rocks are cataclastic. Larger mineral grains are alined, and mica appears in lenticular streaks. Larger feldspar grains are rectangular to ovoid with small broken fragments at their edges. Quartz with mosaic texture fills the interstices between feldspar grains.

The rocks consist principally of quartz, potassium feldspar, and plagioclase (table 12). Biotite and chlorite derived from biotite are the principal dark minerals and constitute 1 percent or less of the rock. Muscovite is in some samples, but may be secondary; hornblende is rare. Accessory apatite, zircon, sphene, opaque minerals, and, rarely, allanite or fluorite complete the mineral suite.

Partial chemical analyses of 23 samples of the gneiss of Shaib Hadhaq are presented in table 13. Calculated modes derived from these analyses are plotted on a quartz-alkali feldspar-plagioclase diagram (fig. 3). The rocks are remarkably uniform in quartz content; nearly all contain between 27 and 34 percent of this mineral. The diagram shows the rocks to be mostly monzogranite, but to range from granodiorite to syenogranite. None of the analyzed samples are tonalite.

Table 12.--*Estimated modes of the gneiss of Shaib Hadhaq (gbh)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Granite gneiss						Granodiorite gneiss		Tonalite gneiss	
Field sample number	720-1	821	845-1	862-1	863-3	866	871	940-1	857	935
Quartz	30	20	30	20	33	30	35	25	30	25
K-feldspar	30	40	40	50	33	30	10	15	--	5
Plagioclase	40	40	30	30	33	40	55	60	67	70
Hornblende	--	--	--	--	--	--	--	--	--	Tr
Muscovite	--	--	--	Tr	--	Tr	Tr	--	Tr	--
Chlorite	Tr	Tr	Tr	--	--	Tr	Tr	Tr	2	Tr
Biotite	Tr	Tr	--	--	Tr	1	Tr	1	--	Tr
Epidote	--	--	--	Tr	Tr	--	Tr	Tr	1	--
Apatite	--	Tr	--	--	Tr	Tr	Tr	Tr	--	Tr
Zircon	--	Tr	--	--	Tr(?)	--	Tr(?)	--	--	--
Sphene	--	Tr	Tr	--	Tr	Tr	--	Tr	--	Tr
Opaque	Tr	Tr	Tr	Tr	Tr	Tr	--	Tr	Tr	Tr
Allanite	--	--	Tr	--	--	--	--	--	--	--

Table 13.--*Partial analyses of samples of granitic rocks from the gneiss of Shaib Hadhaq (gbh), including calculated total normative quartz and feldspar minerals, and quartz (qtz), alkali feldspar (A-fsp), and plagioclase (plag) in percent normalized to 100. See section on analyses in text for explanation of calculation*

RASS sample number	Field number	SiO_2 (percent)	CaO (percent)	Na_2O (percent)	K_2O (percent)	Calculated total Q + Ab + An + Or	Quartz (percent normalized to 100)	Alkali feldspar (percent normalized to 100)	Plagioclase (percent normalized to 100)
138,221	628	72.5	1.77	4.32	3.53	96.3	31.2	31.0	37.8
138,222	629-2	69.9	2.06	3.81	3.71	93.2	30.9	33.6	35.4
138,239	821	72.2	1.72	3.81	4.18	95.8	31.7	36.9	31.5
138,240	823	74.1	1.78	3.94	3.99	97.8	32.8	34.5	32.7
138,242	845-1	74.2	.79	3.27	5.68	96.9	32.8	49.5	17.7
138,243	846-1	68.9	2.53	4.00	3.16	93.2	30.2	28.7	41.2
138,244	847	65.8	3.73	4.60	1.15	90.9	29.3	10.7	60.0
138,246	861	73.6	1.20	3.98	4.33	96.5	32.4	37.9	29.7
138,247	863-1	71.9	.94	3.93	4.69	94.7	30.7	41.9	27.5
138,248	863-3	71.2	1.63	3.67	4.48	94.8	30.8	39.9	29.3
138,249	866	67.9	2.27	3.86	3.52	91.8	29.5	32.4	38.1
138,250	867	72.7	.92	3.34	5.34	95.3	32.4	47.4	20.2
138,251	871	74.3	1.88	4.20	3.65	98.3	32.4	31.4	36.2
138,254	934-1	70.6	2.49	4.13	3.22	95.2	30.4	28.6	41.1
138,255	934-2	69.7	2.60	3.94	3.35	94.4	30.1	30.0	40.0
138,256	937	70.5	1.34	2.85	6.62	95.6	26.9	58.5	14.6
138,257	938-1	71.5	2.02	3.46	4.75	96.2	30.0	41.7	28.3
138,258	940-1	67.7	2.90	4.93	1.89	92.8	27.5	17.2	55.3
138,259	947-1	76.1	.72	4.56	4.10	98.7	32.8	35.1	32.1
138,260	947-2	72.0	1.71	4.06	3.64	95.1	32.4	32.3	35.3
138,261	948-1	73.2	1.64	3.77	3.77	95.6	34.8	33.3	31.8
138,262	951	74.0	.23	3.76	4.41	93.8	37.1	39.8	23.2
138,263	952	74.8	.74	4.02	5.49	99.0	29.1	46.9	24.0

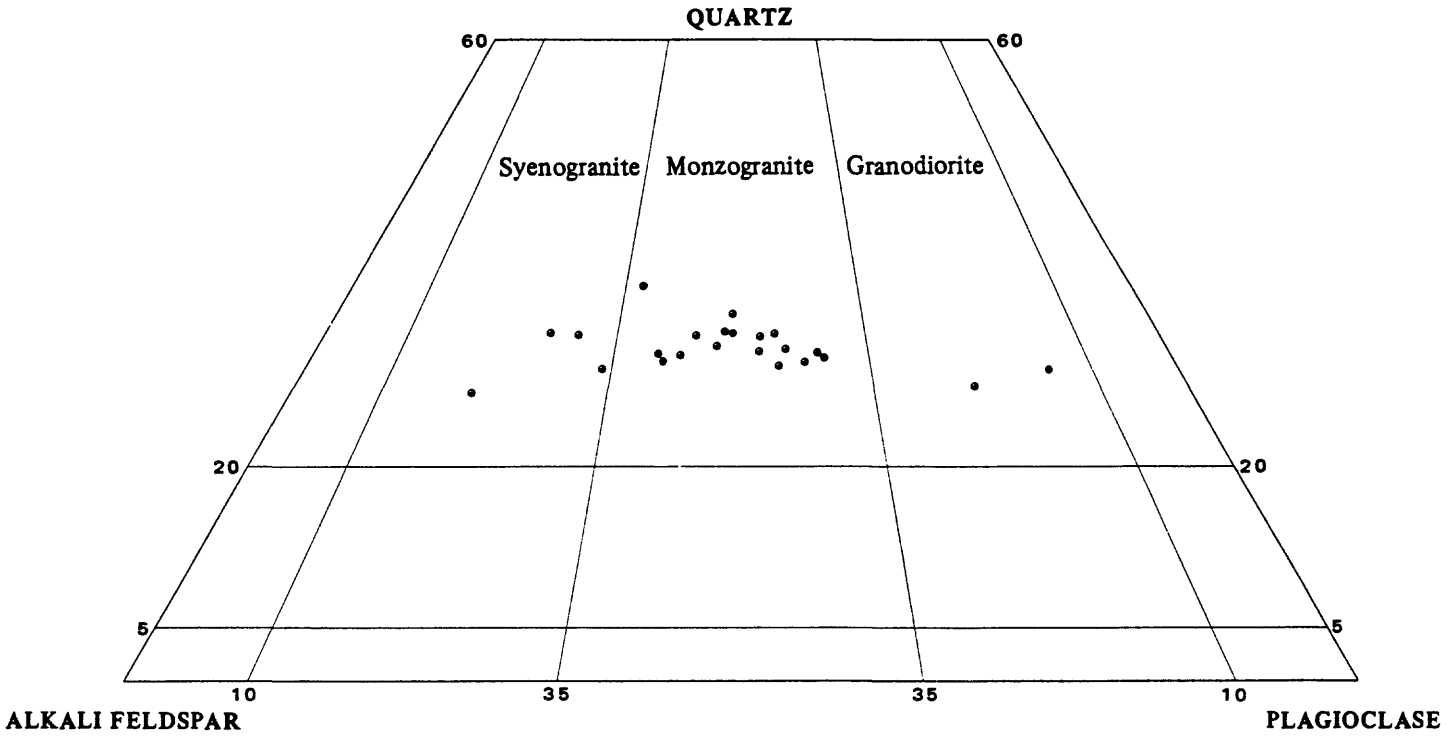


Figure 3.--Ternary diagram showing the calculated modal composition of granitic rocks from the gneiss of Shaib Hadhaq (gbh), • •

There is no consistent pattern between the alkali-feldspar or plagioclase content of analyzed samples and their position in the gneiss body. This fact and the irregular interlayering of the rocks suggest that the gneiss was intruded as a series of sills of diverse compositions rather than as a single zoned body.

Two-mica granite

A two-mica granite (bg) underlies a small flat pediment with sparse outcrop near the southeast corner of the quadrangle. The unit is continuous with granodiorite gneiss of Gonzalez (1975) in the adjacent Jabal Ishmas quadrangle.

The granite is very light gray to yellowish gray with black speckle, and is medium grained. It is composed of quartz, potassium feldspar, and plagioclase (table 14), and trace amounts of muscovite, biotite, chlorite, zircon, and opaque minerals.

Partial chemical analyses of two samples of two-mica granite are presented in table 15, and calculated modes derived from these analyses are plotted on a ternary diagram (fig. 4). The two rocks are monzogranites; presence of muscovite is not indicative of high potassium content in these rocks.

Tonalite, quartz diorite, and granodiorite

Rocks of this unit (toq) crop out in two small areas near the southeast corner of the quadrangle. Rocks underlying the southernmost area are continuous with gneissic tonalite, which underlies a prominent inselberg 2.5 km to the southeast in the Jabal Yafikh quadrangle (Schmidt, in press).

Tonalite is light yellowish gray, medium grained, and strongly foliated. It consists of 65 to 75 percent plagioclase, 20 to 35 percent quartz, and 1 to 5 percent potassium feldspar, and includes trace amounts of biotite, zircon, opaque minerals, and secondary chlorite, muscovite, and calcite. Quartz diorite has light- and dark-gray splotches and is coarse grained. The sample studied contained about 75 percent plagioclase, 10 percent each chlorite and calcite, 5 percent quartz, and 1 percent actinolite. Granodiorite is uncommon in this unit.

Gabbro

Two bodies of gabbro (gab) of substantial size crop out in the quadrangle; one body of gabbro is in the central part of the quadrangle directly northwest of Jabal Dalfa; the other is in the southwest part of the quadrangle and overlaps

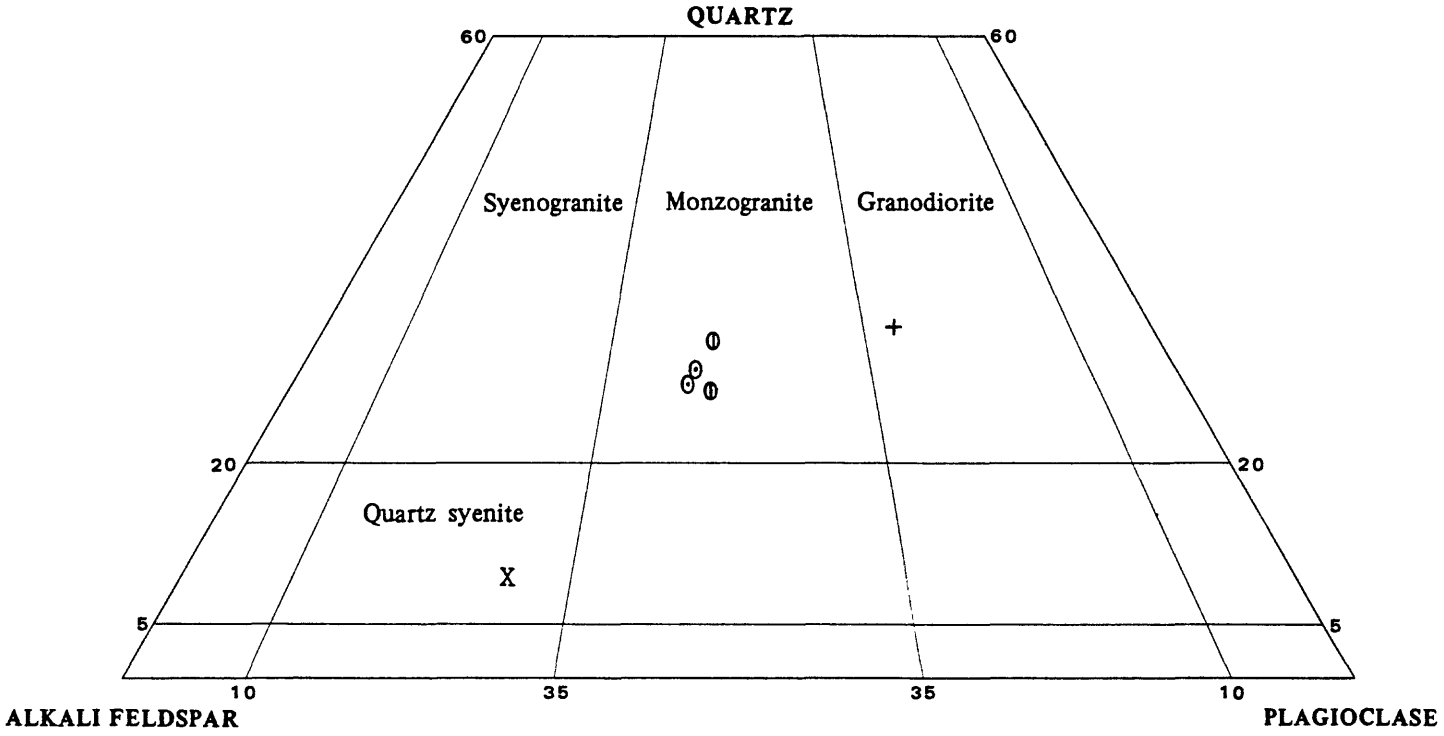
Table 14.--*Estimated modes of two-mica granite (bg)*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts]

	Granite	
Field sample number	781	782
Quartz	30	35
K-feldspar	30	20
Plagioclase	50	45
Muscovite	Tr	Tr
Chlorite	Tr	Tr
Biotite	1	1
Epidote	--	Tr
Calcite	--	Tr
Zircon	Tr	Tr
Opaque	Tr	--

Table 15.--*Partial analyses of samples of granitic rocks from granodiorite (gd), two-mica granite of Jabal Hadad (gh), two-mica granite (bg), and quartz syenite (sy), including calculated total normative quartz and feldspar minerals, and quartz (qtz), alkali feldspar (A-fsp), and plagioclase (plag) in percent normalized to 100. See section on analyses in text for explanation of calculation*

RASS sample number	Field number	Unit	SiO_2 (percent)	CaO (percent)	Na_2O (percent)	K_2O (percent)	Calculated total Q + Ab + An + Or	Quartz (percent normalized to 100)	Alkali feldspar (percent normalized to 100)	Plagioclase (percent normalized to 100)
138,224	638	gd	67.5	3.01	3.94	2.26	91.1	32.4	21.0	46.7
138,229	744	gh	71.2	.96	4.60	4.38	95.2	26.9	38.9	34.2
138,230	746	gh	74.3	1.02	4.41	4.19	97.6	31.2	36.3	32.5
138,231	781	bg	71.9	1.26	4.31	4.60	96.4	27.5	40.3	32.2
138,232	782	bg	69.8	1.94	3.80	4.34	94.4	28.5	38.9	32.6
138,245	856	sy	61.2	1.23	4.10	6.76	89.6	9.9	63.8	26.4



⊙ Two-mica granite (bg)
◐ Two-mica granite of Jabal Hadad (gh)
\+ Granodiorite (gd)
X Quartz syenite (sy)

Figure 4.--Ternary diagram showing the calculated modal composition of selected granitic rocks.

into the Ranyah quadrangle (Greene, in press). The gabbro in the central part underlies a flat pediment surface. Abundant, blocky to rounded outcrops 1 or 2 m higher than the flats are commonly wind polished and fluted. In aerial photographs, layering of the gabbro appears to form a dish-shaped structure in the center of the body.

The gabbro in the southwest part of the quadrangle underlies a series of prominent ridges, which reflect the layered nature of the rock. Outcrop is abundant, and the black bedrock and talus contrast sharply with the light-tan sand dunes, which partially engulf the ridges. In aerial photographs, layering of the gabbro in the southeast part of this body appears to form a partial funnel-shaped structure with northwest dip, and strike curving concave to the northwest. In the northwest part of the body, partly in the Ranyah quadrangle, the strike remains the same and the dip increases to vertical.

The gabbro is mostly medium to dark gray and light gray where especially rich in plagioclase. It is medium to coarse grained, commonly structureless in hand specimen, and locally includes alined plagioclase grains. The gabbro contains plagioclase, clinopyroxene, olivine, opaque minerals, hornblende, local biotite, and secondary chlorite (table 16). Hornblende commonly rims clinopyroxene or olivine, and biotite rims hornblende. More than half the rock has color indices below forty and therefore is leucogabbro.

The gabbro is largely fresh, layered, and undeformed, and thus bears considerable resemblance to the gabbro bodies studied by Coleman and others (1972) farther south.

Pyroxenite

A small lens of pyroxenite (px) crops out along the Najd faults near the northeast corner of the quadrangle. It is medium dark gray to slightly brownish, and medium grained. The sample studied is websterite, consisting of 65 percent orthopyroxene, 35 percent clinopyroxene, and a small amount of actinolite in seams.

Granite of Jabal ash Shayal

Jabal ash Shayal is a prominent rugged mountain about 3 km long south of Jabal Silli. It is underlain by cream to pink, medium- to coarse-grained granite (gs), in part distinctly foliated.

Table 16.--*Modes of gabbro (gab)*

[Values in percent based on point count of thin section. Leaders (--) indicate not present; Tr, present in trace amounts]

	Gabbro						
Field sample number	809	811-1	812	852	851	855	930
Plagioclase	57.4	53.8	73.6	62.4	84.2	66.4	57.8
Hornblende	1.0	.6	Tr	1.2	2.2	3.8	8.8
Chlorite	.2	--	.2	1.0	--	2.0	--
Biotite	--	--	--	Tr	.4	.2	--
Clinopyroxene	33.0	31.6	16.0	28.4	11.2	8.0	28.0
Olivine	7.4	13.4	9.2	6.6	1.8	16.8	5.0
Calcite	--	--	--	--	--	.2	--
Opaque	1.0	.6	1.0	.4	.2	2.6	.4
Color index	43	46	26	38	16	33	42
Points counted	500	500	500	500	500	500	500

Some of the granite contains 40 to 50 percent nonperthitic potassium feldspar, 20 to 30 percent plagioclase, and 25 to 35 percent quartz. Other granite contains as much as 70 percent perthitic potassium feldspar, 1 to 5 percent plagioclase, and 25 to 35 percent quartz. The rocks contain 1 percent or less each hornblende, biotite, opaque minerals, and secondary chlorite. Sphene, zircon, and allanite locally are accessory minerals.

Partial chemical analyses and calculated modes of two samples of the granite of Jabal ash Shayal are presented in table 17; the modes are plotted on figure 5. The samples are nearly identical monzogranites containing about 33 percent quartz and an alkali-feldspar-plagioclase ratio close to the boundary with syenogranite.

Granite of Jabal Dalfa southwest

A prominent pinnacle 3 km west of Jabal Dalfa is composed of pale- to medium-pink, coarse-grained, structureless granite (gsw). A smaller jabal 12 km to the southwest and flats 10 km to the south are underlain by similar granite.

The granite is composed of 40 to 60 percent weakly perthitic potassium feldspar, 20 to 40 percent plagioclase, about 20 percent quartz, and less than 1 percent each hornblende, biotite, opaque minerals, zircon, sphene, and secondary chlorite.

Partial chemical analyses and calculated modes of five samples of this granite are presented in table 17; the modes are plotted on figure 5. All are monzogranites and four samples are nearly identical in composition. Granites of Jabal Dalfa southwest and Jabal ash Shayal taken together form a closely knit group (fig. 5). Their compositional range is nearly identical with that of the central part of the range for the gneiss of Shaib Hadhaq (fig. 3).

Two-mica granite of Jabal Hadad

Jabal Hadad is a group of rugged hills near the south boundary of the quadrangle, directly west of Umm Shat. The hills are underlain by pale- to medium-pink, coarse-grained, structureless granite (gh). The granite is composed of 35 to 40 percent potassium feldspar, 32 to 37 percent plagioclase, 25 to 32 percent quartz, and less than 1 percent each biotite, muscovite, opaque minerals, zircon, and secondary chlorite.

Partial chemical analyses and calculated modes of two samples from this unit are presented in table 15; the modes are plotted on figure 4. The samples are monzogranites with alkali feldspar to plagioclase ratios only slightly greater

Table 17.--*Partial analyses of samples of granitic rocks from granite of Jabal ash Shayal (gs) and granite of Jabal Dalfa southwest (gsw), including calculated total normative quartz and feldspar minerals, and quartz (qtz), alkali feldspar (A-fsp), and plagioclase (plag) in percent normalized to 100. See section on analyses in text for explanation of calculation*

RASS sample number	Field number	Unit	SiO_2 (percent)	CaO (percent)	Na_2O (percent)	K_2O (percent)	Calculated total Q + Ab + An + Or	Quartz (percent normalized to 100)	Alkali feldspar (percent normalized to 100)	Plagioclase (percent normalized to 100)
138,238	817-2	gs	75.2	.82	3.90	4.83	97.9	33.0	41.7	25.3
138,253	874	gs	75.7	1.15	3.91	4.79	99.3	32.4	40.8	26.8
138,227	738-1	gsw	71.6	1.37	4.07	4.42	95.4	29.4	39.2	31.4
138,228	739	gsw	71.5	1.14	4.27	4.41	95.2	28.7	39.2	32.1
138,252	873	gsw	75.0	2.14	3.73	3.73	98.7	34.9	32.0	33.1
138,264	975	gsw	73.4	1.35	4.21	4.69	98.1	28.6	40.4	31.0
138,265	976	gsw	74.3	1.01	4.24	4.53	97.8	30.8	39.2	30.0

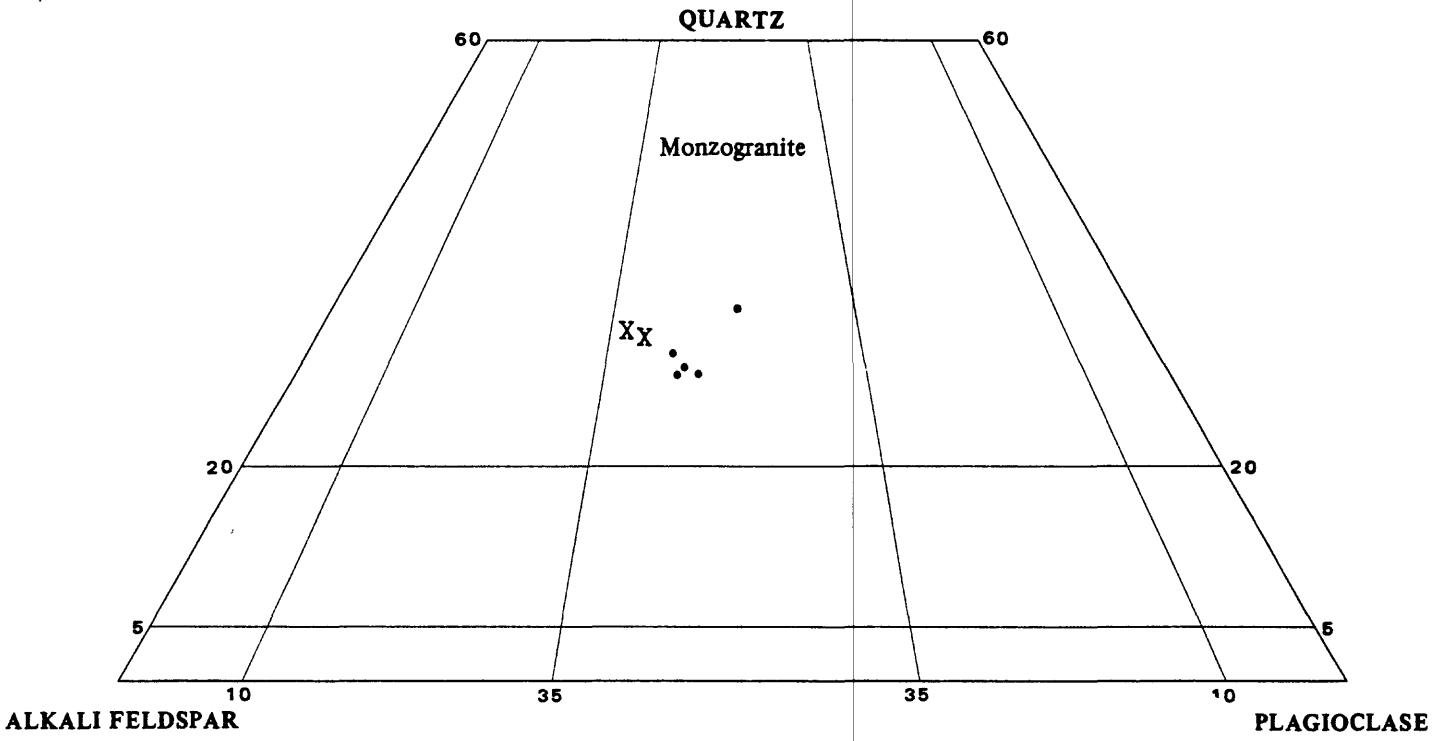


Figure 5.--Ternary diagram showing the calculated modal composition of granite of Jabal ash Shayal (gs), X, and granite of Jabal Dalfa southwest (gsw), • .

than 1; thus they are nearly identical to two samples of two-mica granite collected near the southeast corner of the quadrangle (fig. 4), despite the difference in color and texture between typical rocks from the two units.

Granodiorite

Granodiorite (gd) underlies three small jabals in an otherwise outcropless area in the north-central part of the quadrangle. The rock is medium to coarse grained, and light gray peppered with abundant black mafic mineral grains. It consists of about 45 percent plagioclase, 20 percent potassium feldspar, 30 to 35 percent quartz, and 1 to 2 percent each biotite and hornblende, and traces of zircon, sphene, and secondary chlorite.

A partial chemical analysis and calculated mode of a sample of granodiorite is presented in table 15; the mode is plotted on figure 4.

Alkali-feldspar granite

Alkali-feldspar granite (ag) underlies a small isolated jabal 13 km northeast of Jabal Silli. The granite is mottled very light gray and pale orange, and is medium grained and structureless. It consists of about 75 percent untwinned perthitic potassium feldspar, 20 percent quartz, 5 percent muscovite, and traces of opaque minerals and allanite. The potassium feldspar is peppered with secondary muscovite; some muscovite also occurs in primary grains.

Quartz syenite

A low rise 10 km north of Jabal Dalfa is underlain by quartz syenite (sy), which is uniformly dark grayish red, coarse grained, and structureless. It consists mostly of perthitic potassium feldspar, hematite, and interstitial quartz. Most of the feldspar grains have been broken into fragments along cleavage planes or perthite lamellae and recemented with hematite. A partial chemical analysis and calculated mode of a sample of quartz syenite is presented in table 15; the mode is plotted on figure 4.

Andesite dikes

Andesite dikes commonly intrude the gneiss of Shaib Hadhaq and locally penetrate other units. A swarm of these dikes is parallel to the foliation in the west part of the main belt of the gneiss of Shaib Hadhaq, and both concordant and discordant swarms occur elsewhere (pl. 1).

Most of the dikes are 0.5 to 3 m wide and apparently vertical. Some are grayish red to dark reddish brown; others

are medium dark to dark gray. Most are aphanitic to fine grained with sparse microphenocrysts of plagioclase.

The brown dike rocks consist almost entirely of plagioclase and opaque oxides (table 18, 940-2, 948-3). The gray dike rocks contain also quartz, hornblende, and biotite or chlorite (table 18, 939-1, 950).

SURFICIAL DEPOSITS

Sand and gravel

Much of the Jabal Dalfa quadrangle is covered by coarse sand and gravel (Qs), thick enough to completely conceal bedrock except where pediments or inselbergs are mapped. The sand and gravel are poorly sorted but well stratified, and are composed mainly of quartz, feldspars, and pebbles of granitic rocks. Pebbles of other rocks are locally present. The sand and gravel were probably deposited by Wadi Ranyah and Wadi Bishah as they shifted their courses across the plain. Most of the deposition probably took place during a more humid climatic cycle in the Pleistocene.

Alluvial fans

Alluvial fans (Qf) are separately mapped adjacent to Jabal ash Shayal, Jabal Silli, and Jabal Dalfa. Many of the fans coalesce to form aprons. The deposits consist of boulders and slabs interlayered with sand and gravel derived from the bedrock of the adjacent jabal.

Alluvium

Alluvium (Qa) is present along major wadis in the quadrangle. It is separately mapped where intermittently active stream channels are well defined. It consists of sand and gravel similar to that covering most of the quadrangle.

Uruq dunes

Uruq-type sand dune fields (Qdu) (Jackson and others, 1979) cover large portions of the quadrangle. They are most typically developed in broad bands adjacent to Wadi Bishah and Wadi Ranyah in the west half of the quadrangle. The bands consist of transverse dune ridges, generally 1 to 3 m high, separated by bare flat areas. The ridges are commonly joined in an anastomotic or braided pattern. The dunes trend N. 45° to 75° E., locally east, and generally parallel the adjacent wadi channel. Their asymmetry indicates that the wind is predominantly from the southeast.

Elsewhere in the quadrangle uruq dunes are more irregular. Dune areas between and immediately northwest of the

Table 18.--*Estimated modes of andesite dikes*

[Values in percent based on visual estimate of thin sections. Leaders (--) indicate not present; Tr, present in trace amounts; p, phenocryst; g, groundmass]

Name and color	Andesite Dark gray	Andesite Medium dark gray	Andesite Grayish red	Andesite Dark reddish brown	Andesite Medium dark gray
Field sample number	820	939-1	940-2	948-3	950
Quartz	--	10	2	Tr	7
Plagioclase	p-Tr g-80	70	p-2 g-90	p-1 g-99	p-2 g-70
Hornblende	--	10	1	--	p-Tr g-10
Chlorite	--	10	--	--	--
Biotite	20	--	--	p-Tr g-Tr	10
Epidote	--	1	--	--	--
Calcite	Tr	--	--	Tr	--
Sphene	--	1	--	--	1
Opaque	1	Tr	5	Tr	Tr

Wadi Ranyah distributaries generally consist of sand sheets in their southeast, or windward, parts and transverse dunes in their leeward parts. The orientation of the dune fields controls the location of the wadis that lie between. Transverse dunes with intervening outcrop encroach on the south part of the largest pediment of metabasalt. Sand sheets and transverse dunes alternate in patchy fashion in the large dune field in the northwest part of the quadrangle. Dune alinement appears to be somewhat bimodal, either about N. 45° E. or due east. The principal source of sand for both the uruq and giant dune fields in the northwest quadrant appears to be Wadi Ranyah. Traces of a distributary system can be seen through the dunes in the area north of the wadi and west of the largest metabasalt pediment.

At the east boundary of the quadrangle south of the main Wadi Bishah distributaries, a small area of uruq dunes is part of a belt of eastward-oriented transverse dunes, which mostly lie in the adjacent Bir Juqjuq quadrangle. These dunes, and east-trending dunes elsewhere in the quadrangle, suggest that winds from the south are locally important for dune formation.

Giant dunes

The giant dune fields (Qdg) are one of the most beautiful features of the Jabal Dalfa quadrangle. The dunes are mostly sharply crested sinuous ridges; some have a branch to windward and form star dunes. The dune ridges are 0.5 to 1 km long and as much as 50 m higher than the adjacent flats. The dunes are transverse and mostly oriented N. 30° E. to north. Smaller transverse dunes, oriented N. 45° E. to east, lie between the rows. The highest dunes are found in the area 8 to 15 km southwest of Jabal Dalfa. Blowouts between giant dunes reveal a gravel plain surface; some reveal bedrock (pl. 1). Many jabals of gabbro near the southwest corner of the quadrangle are partially engulfed by dunes. Wadi Ranyah and Wadi Bishah form the most likely sources of sand for the giant dunes.

STRUCTURE AND STRATIGRAPHY

The Jabal Dalfa quadrangle contains parts of several north-trending belts of metamorphic and plutonic rocks, locally modified by the Najd fault system to be northwest trending. Most of the metavolcanic and metasedimentary rocks are either massive or have steeply dipping to vertical foliation and bedding. Minor folds are rare, and the role played by isoclinal folding versus fault stacking in producing thick sequences of layered rocks is generally obscure.

The stratigraphic order of the layered rocks in the quadrangle is uncertain and the correlation of map units (pl. 1)

is tentative. A few clues are available from adjacent quadrangles, but there are no clearly conformable sequences or radiometric dates of rocks from within the Jabal Dalfa quadrangle.

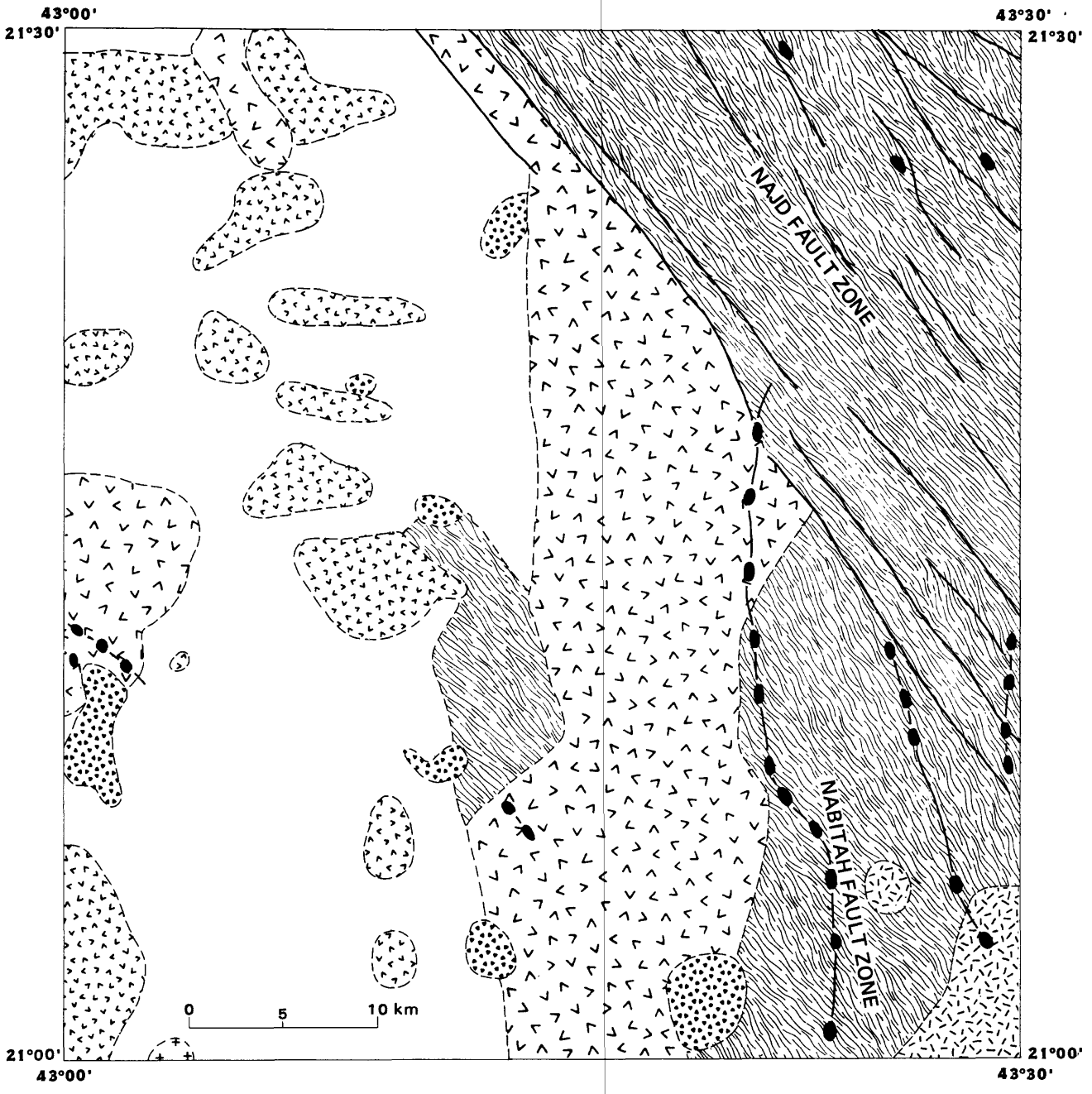
In the southeast part of the quadrangle, a north-trending belt of metavolcanic rocks, Umm Shat, is bounded on the east by the Nabitah fault. This belt of rocks extends at least 70 km to the south as a distinct feature (Gonzalez, 1975, Schmidt, in press) and ends in the Jabal Dalfa quadrangle, apparently cut off by the Nabitah fault (fig. 6). Units containing serpentinite are along the extension of the Nabitah fault as interpreted on figure 6 and along two parallel faults to the east. These units have been variously described as ophiolite or primitive oceanic crust, parts of a belt extending across the entire Arabian Shield, though displaced by the Najd faults (Schmidt and others, 1979; Frisch and Al-Shanti, 1977). However, the author believes that these serpentinites resulted from relatively cold intrusions along faults (Worl, 1980); therefore, they or their enclosing rocks are not ophiolite.

Metavolcanic and metasedimentary rocks of the Arfan formation in the northeast part of the quadrangle, and gneiss immediately to the northeast, trend northwest and are separated by faults of the Najd system. Because the Najd faults are generally left lateral, these slices have been moved various distances from the southeast toward the northwest. However, the layered rocks are continuous with those lying on the southwest flank of the Arfan syncline (Hadley, 1976); therefore, they are probably in stratigraphic order, youngest to the northeast, even though separated by faults (fig. 7). Figure 7 shows a reinterpretation of structure in the northwesternmost part of the Bir Juqjuq quadrangle. Faults have been added to separate the gneiss from the rocks of the Arfan formation.

The aeromagnetic map (pl. 2) suggests that the broad outcropless area southwest of the Arfan formation is underlain by belts of layered rocks of differing magnetic susceptibilities. These belts are interpreted on figure 6 as separated by additional faults, which are part of the Najd system.

The metabasalt and meta-andesite of the central belt is massive; hence its internal structure is unknown. It is assigned a position high in the stratigraphic order because it, like the metabasalt and meta-andesite of Rawdah in the Ranyah quadrangle (Greene, in press), is intruded only by the youngest granites.

The western third of the quadrangle is mostly underlain by the gneiss of Shaib Hadhaq and related volcanic and granitic rocks of Urayyiq, generously intruded by gabbro. As in



Younger granite (gs, gsw, gh, gd, ag, sy)

Older intrusive rocks (bg, toq)

Gabbro

Gneiss of Shaib Hadhaq and equivalent rocks (gbh, vgu)

Serpentinite

Fault, mostly inferred

Younger metavolcanic rocks (mbac, cc, am, sbc)

Older metavolcanic and metasedimentary rocks and gneiss (adm, cgg, mda, mba, sss, ma, scg, bcas, ds, mbas, sis, umc, smb, q, msc, mdb, gn, qdg, gnt, gnh)

Contact, mostly concealed or inferred

Figure 6.--Tectonic map of the Jabal Dalfa quadrangle, interpreted from geologic and aeromagnetic maps. Unit symbols explained on plate 1.

the Ranyah quadrangle (Greene, *in press*), the aeromagnetic map shows anomalies suggesting considerably more gabbro, beneath surficial deposits or a thin cover of gneiss, than appears at the surface (fig. 6). The main outcrop of gneiss of Shaib Hadhaq has a strongly alined fabric with northwest trend, as does the gneiss in the northeast corner of the quadrangle; however, Najd faults are not a dominant feature in the western belt.

The Jabal Dalfa block is enigmatic. The metabasalt of Jabal Dalfa is mostly separated from adjacent rocks by northwest-trending faults along which there has been considerable tectonic mixing. The layered rocks are intruded by the gneiss of Shaib Hadhaq; therefore they belong relatively low in the stratigraphic sequence.

Layered rocks underlying Jabal Silli strike northeast nearly at right angles to the strike of the adjacent gneiss. These rocks are not intruded by the gneiss, and are believed to be of comparable stratigraphic position to the metabasalt and andesite of the central belt.

METAMORPHISM

The metamorphic grade of the rocks in the Jabal Dalfa quadrangle varies irregularly. The metasedimentary and metavolcanic rocks generally are in greenschist facies. Locally, the rocks have been raised to transition or amphibolite facies. The single occurrence of quarzite containing sillimanite in the west-central part of the quadrangle is probably a result of the high temperature of emplacement of the adjacent gneiss.

GEOCHRONOLOGY

No radiometric dates have been obtained for rocks from the Jabal Dalfa quadrangle. Correlations with dated rocks from adjacent areas provide reasonable estimates of the ages of the plutonic rocks. The ages of the layered rocks are uncertain.

Gneiss from the Bir Juqjuq quadrangle 18 km N. 72° E. of the southeast corner of the Jabal Dalfa quadrangle has yielded a 6-point isochron age of 782 $\pm$ 26 Ma (Kroner and others, 1979). The gneiss is probably equivalent to augen gneiss and quartz diorite gneiss in the southeast part of the Jabal Dalfa quadrangle, and possibly equivalent to hornblende and plagioclase gneiss and tonalite gneiss in the northeast part. Because the gneiss is in fault contact with surrounding units in both quadrangles, it is uncertain whether the isochron age is the age of intrusion or the age of cataclasis. Nevertheless, the aforementioned date is the oldest from adjacent

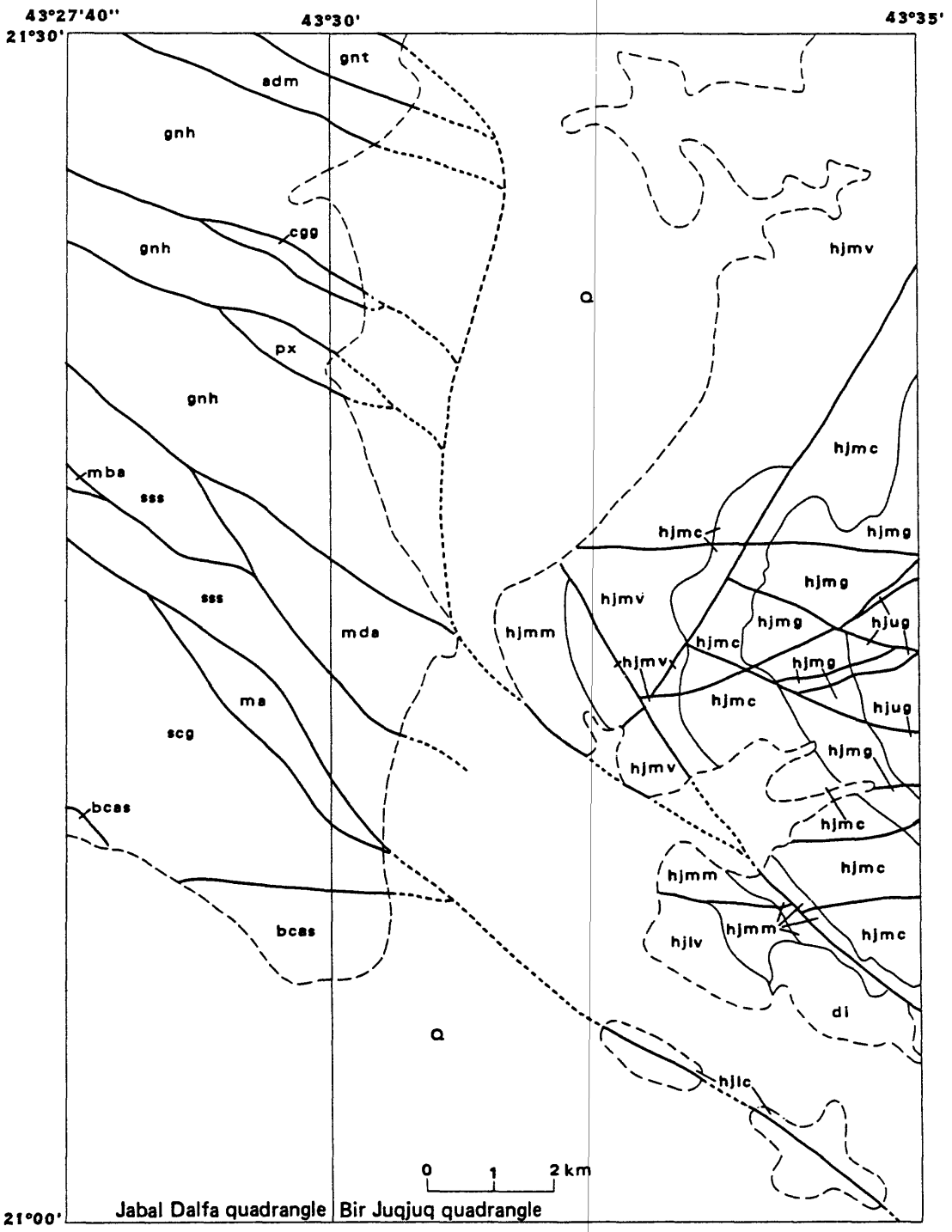


Figure 7.--Sketch map showing the northeasternmost part of the Jabal Dalfa quadrangle and a reinterpretation of the adjacent part of the Bir Juqjuq quadrangle (originally mapped by Hadley, 1976). Same scale as plate 1. Geology of Jabal Dalfa quadrangle taken from plate 1. Geology of the part of Bir Juqjuq quadrangle west of belt of Quaternary cover from fieldwork by author. Extent of Quaternary cover from interpretation by author of aerial photographs. Geology of the part of Bir Juqjuq quadrangle with bedrock exposure east of belt of Quaternary cover by Hadley (1976). Concealed faults interpreted by author, except for southernmost one, which is by Hadley (1976).

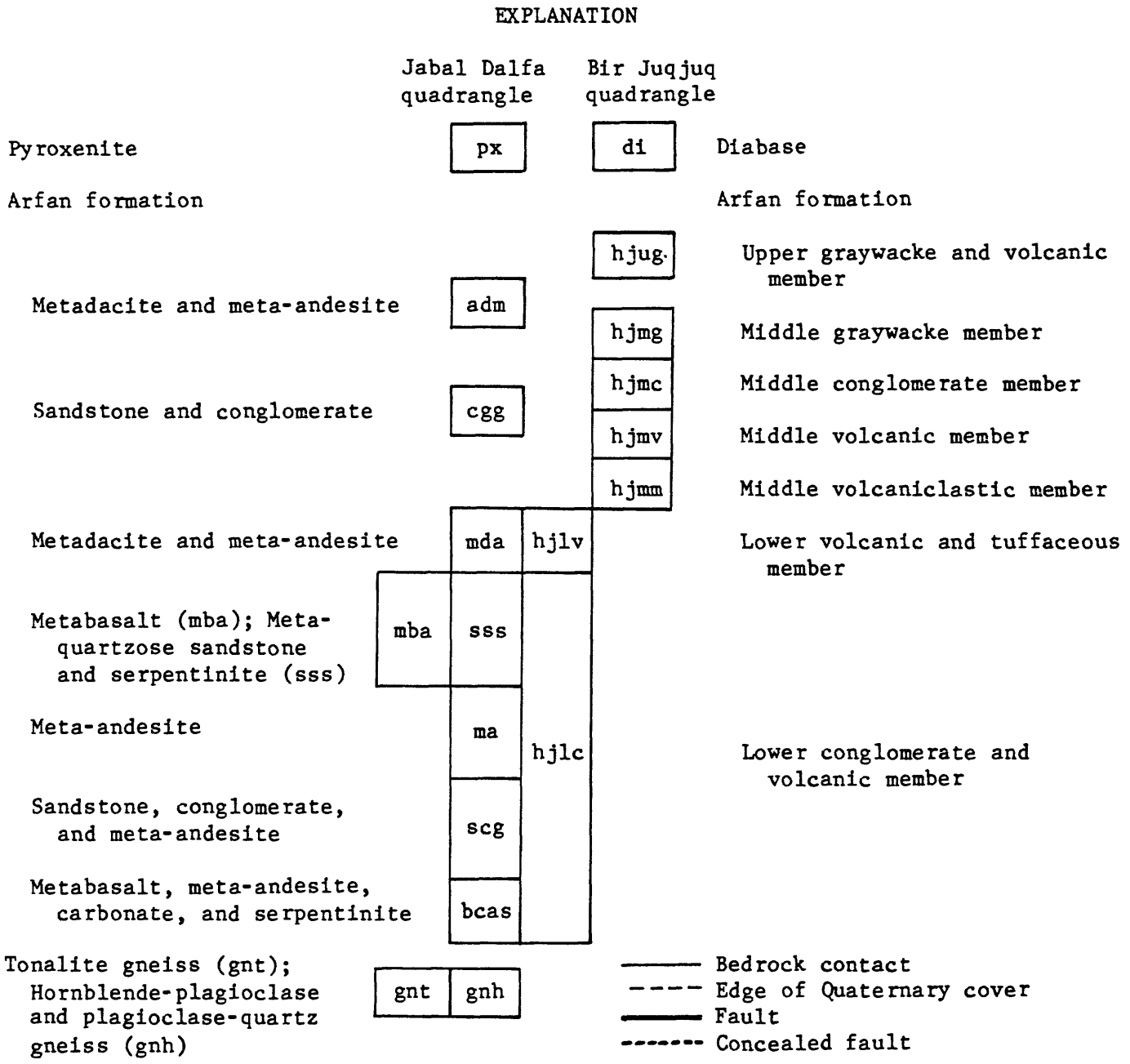


Figure 7.--Continued.

quadrangles and suggests that this gneiss in the Jabal Dalfa quadrangle is the oldest intrusive rock and is probably older than most of the layered rocks.

Rocks from the Arfan formation in the Bir Juqjuq quadrangle give a 2-point isochron age of 775 Ma and a 3-point isochron age of 761 ± 23 Ma (Fleck and others, 1980). The 775 Ma date is from a sample near the middle of the Arfan syncline, only 18 km S. 50° E. of the northeast corner of the Jabal Dalfa quadrangle. The sequence of layered rocks in the northeast part of the Jabal Dalfa quadrangle has been assigned to the Arfan formation, is continuous with several units on the west limb of the syncline, and is thus likely to be only slightly older.

Plutonic rocks in the gneiss of Shaib Hadhaq and the metavolcanic and granitic rocks of Urayyiq are probably the equivalent of granites and gneisses in the Al Junaynah, Wadi al Miyah, and Jabal al Qarah quadrangles (Schmidt, 1981a; in press; in press), which were involved in gneiss doming. Samples from these quadrangles give 4-point isochrons of 724 ± 93 Ma, and 723 ± 107 Ma (Fleck and others, 1980). About 723 Ma is a reasonable age for the gneiss of Shaib Hadhaq; however, the large statistical uncertainties render the dates of limited value.

Several concordant biotite and hornblende ages of layered, commonly synformal gabbros in the southern Arabian Shield suggest that the age of intrusion of most of the gabbro is from 625 to 640 Ma (Coleman and others, 1972; Fleck and others, 1976, p. 19). The gabbro sampled is unaltered and has primary igneous textures. The structural and textural similarity of the gabbro of the Jabal Dalfa quadrangle to those dated suggests that their ages may be the same.

The granites of Jabal ash Shayal and Jabal Hadad appear to be late intrusive rocks and have four to five times the background level of radioactivity (pl. 2). In this way, they resemble the perthite granites of Kwar Barahah and Jabal Suily in the Ranyah quadrangle (Greene, in press), which in turn are equivalent to the "red" syenogranites of the Al Junaynah and Wadi al Miyah quadrangles (Schmidt, 1981a; in press). The best ages for these rocks are the K-Ar dates reported by Fleck and others (1976) on samples of syenogranite from Jabal al Najiah in the Al Junaynah quadrangle. Biotite from two samples gave dates of 602.1 ± 7.6 Ma, and 596.3 ± 7.4 Ma. These ages fall in the early phase (610 to 560 Ma ago) of the Pan African Event (610 to 510 Ma ago)(Fleck and others, 1976).

AIRBORNE MAGNETOMETER SURVEY

An airborne magnetometer survey of the Jabal Dalfa quadrangle and adjacent areas was made under the supervision of the Bureau de Recherches Geologiques et Minieres (sheet 145, 1966-67; pl. 2). Magnetic contours at 500, 100, and, locally, 20 gammas relative to arbitrary datum are shown.

At the latitude of Saudi Arabia, a relatively magnetic rock body ideally is expressed by a magnetic high in the south part of the body paired with a magnetic low in the north part. Many such anomalies are in the Jabal Dalfa quadrangle; some match known magnetic rock bodies well and some less well. The presence of magnetic rock bodies may be inferred by still other anomalies. Several important linear magnetic gradients are in the quadrangle. A linear magnetic gradient on an aeromagnetic map is where magnetic contours crowded close together extend for some distance in a straight line to show a steep gradient. Most of the linear gradients parallel the trends of Najd faults (pl. 1; also U.S. Geological Survey and Arabian-American Oil Company, 1963; Hadley, 1976). A detailed discussion of these features follows, starting in the southwest quadrant of the quadrangle and proceeding counterclockwise.

Several large paired anomalies are in the southwest quadrant, particularly near the west and north edges. Two of the anomalies correspond to large outcrops of gabbro (pl. 1). East of Jabal ash Shayal the magnetic high is separated from its corresponding low, and a large body of gabbro at shallow depth is strongly indicated. North of Jabal ash Shayal, a paired anomaly corresponds to serpentinite outcrop.

An outcropless area in the middle of the southwest quadrant contains a north-trending chain of paired anomalies; two very distinct pairs of anomalies are a little farther east. The first anomalies probably represent additional gabbro because they lie in the belt of gneiss of Shaib Hadhaq, with which the gabbro is associated in the Ranyah and Jabal Dalfa quadrangles. The second pair of anomalies may represent serpentinite, although none is exposed.

Metabasalt and meta-andesite of the central belt and Umm Shat in the southeast quadrant have little magnetic expression. However, a distinct, north-trending chain of paired anomalies extends from the serpentinite directly east of Umm Shat, through the inselbergs of serpentinite, the pediment underlain by serpentinite, marble, and metabasalt, and north into the metabasalt and meta-andesite of the central belt (fig. 6). These anomalies indicate additional bodies of serpentinite along what appears to be an extension of the Nabitah fault zone (Gonzalez, 1975).

Another north-trending chain of paired anomalies extends from the serpentinite in the metagabbro, granite, metavolcanic, and ultramafic unit through additional serpentinite and into an outcropless area, suggesting a fault parallel to the Nabitah fault zone. A third chain of north-trending anomalies crosses the linear gradients of the Najd fault at the quadrangle boundary.

A distinct belt of magnetic lows crosses the Nabitah fault zone north of Umm Shat and extends westerly and then northwesterly parallel to the Najd faults. A deep low on this belt coincides with the syenite north of Jabal Dalfa, and continues across the outcropless northwest quadrant.

In the northeast quadrant, many elongate anomalies and linear gradients have northwest trends parallel to Najd faults. A magnetically flat band about 5 km wide runs through the outcropless area in the middle of the quadrant. Several elongate paired anomalies are on the southwest side of this band. A magnetically noisy zone, with one distinct paired anomaly lies northeast of the flat zone. Further to the northeast, another flat band and a distinct series of elongate anomalies parallel the bands of layered and gneissic rocks. The belt of sandstone and conglomerate and the belt of hornblende and plagioclase gneiss contain distinct paired anomalies; thus they are relatively magnetic rocks. The two serpentinite outcrops in this area do not correlate directly with anomalies; however, a relationship between serpentinite and nearby anomalies cannot be ruled out.

The outcropless flat in the northwest quadrant is magnetically noisy. In addition to the belt of magnetic lows, the quadrant contains a number of distinct paired anomalies. The belt of gneiss of Shaib Hadhaq apparently continues through this area, and the anomalies probably represent gabbro intrusions. A rather weak paired anomaly was recorded at Jabal Silli, confirming the presence of limited quantities of mafic intrusive rocks.

ECONOMIC GEOLOGY

Metallic deposits

Gold-quartz veins

The Jabal Dalfa quadrangle includes the northernmost part of the Jabal Ishmas-Wadi Tathlith gold belt (Worl, 1979; 1980). The gold deposits are within or next to quartz veins or quartz-rich breccia zones and are closely associated with greenschist-facies metavolcanic and volcaniclastic rocks (Worl, 1980). The regional controlling structure for the

deposits, except Jabal Umm Matirah, is the Jabal Ishmas-Wadi Tathlith fault zone (Nabitah zone of Gonzalez, 1970). Along this fault zone, Worl (1980) has recognized five groups of ancient gold mines. Four mines of the northernmost group are in the Jabal Dalfa quadrangle; two others are within 5 km of the south boundary. Descriptions and potential resource estimates of these ancient mines and their Mineral Occurrence Documentation System (MODS) data bank numbers are presented in table 19.

Worl (1979) concluded that the Jabal Umm Matirah and Jabal Dalfa prospects are worthy of further investigation. A drillng project under the direction of the DGMR has been completed at the Jabal Umm Matirah locality (D. Hackett, written commun., in Fenton, 1982) and the prospect was found to be uneconomic. Worl (1979, fig. 2) includes a plane table map of the Jabal Umm Matirah ancient mine. Further description of the locality is given by Hadley (1976, p. 28).

Nickel-copper prospect

Low, dark hills underlain by serpentinite and metagabbro (ggvu) in the southeast part of the Jabal Dalfa quadrangle are locally referred to as Jabal Judayr (Hadley, 1976). Abundant outcrops of limonitic gossan and several test pits are in this area. Gonzalez (1970) described material from this locality as laterite enriched in nickel and cobalt. Further investigations, including surface sampling, and gravity, self-potential, and electromagnetic studies, were completed in this area in 1974 (Hadley, 1976). Two holes were drilled, revealing a pyrrhotite and pyrite zone. Analyses showed significant amounts of nickel, copper, and chromium, but the deposit was not considered large enough or of sufficiently high grade to warrant further investigation.

Geochemical survey

A geochemical survey of the mineral potential of the Jabal Dalfa quadrangle has been completed (Fenton, 1983). Plutonic rocks were analyzed for gold, silver, copper, lead, and zinc by the atomic absorption method using nitric acid extraction. Volcanic rocks were analyzed for the same elements plus cobalt, nickel, and chromium. All rocks were analyzed on the Kevex X-ray fluorescence spectrometer for zirconium, yttrium, niobium, arsenic, molybdenum, rubidium, strontium, and potassium.

Nonmetallic deposits

Marble

Marble crops out at several localities in the Jabal Dalfa quadrangle and in substantial quantities near the southeast corner where three bands of outcrop range from 1 to 2.5 km long. The marble is medium to dark gray with light-gray

Table 19.--*Descriptions and potential resource estimates of ancient gold mines in the northernmost part of the Jabal Ishmas - Wadi Tathlith gold belt*[1/]

[Each ancient mine is given the status of prospect or occurrence based upon size of the deposit and the amount of geologic exploration.]

MODS[2/]	Name and location	Status (Size in meters)	Exploration (Du-dump, Gr-grab and Ch-channel samples; RASS sample numbers)	Workings (length, width in meters)	Geologic descriptions	Analytical data (gold in grams per ton)	Potential resource (Metric tons)	(Grams per ton)
01172	Jabal Umm Matirah 21°23'30"N. 43°29'30"E.	Prospect (2000x1000)	Detailed mapping 1:1000 scale Sampling Du, Ch 115018-021 115129-154	Shallow open pits along veins, 1-3 m deep, now sand filled. Minor slag; village with tailings. Small placer mines in same general area. (110,4) (60,5)(30,2) 60,5)(numerous small)	Series of en echelon quartz veins cutting metagraywacke of the Halaban formation. Veins are composed entirely of milky, vuggy, hematite-stained quartz. Visible gold, but no sulfides. Attitude of veins: strike 20° dip 90°	12 dump samples .05 to 22, avg. 3.54 g/t 3 channel samples, 4.2 to 16, avg. 11 g/t 8 grab samples, .6 to 16.0, avg. 6.64 g/t	164,025 91,125	10-14 11-16
01451	Jabal Silli 21°12'56"N. 43°08'02"E.	Occurrence (100x10)	Visited Sampling Gr 115052-053	Small, widely scattered open pits on poorly exposed quartz veins. All less than 20 m in length.	Small, widely scattered quartz veins.	2 grab samples, no gold detected.		

Table 19.--*Descriptions and potential resource estimates of ancient gold mines in the northernmost part of the Jabal Ishmas-Wadi Tathlith gold belt*--Continued

MODS	Name and location	Status (Size in meters)	Exploration (Du-dump, Gr-grab and Ch-channel samples; RASS sample numbers)	Workings (length, width in meters)	Geologic descriptions	Analytical data (gold in grams per ton)	Potential resource (Metric tons)	(Grams per ton)
01153	Jabal Dalfa Group 21°09'00"N. 41°13'30"E.	Prospect (6000x5000)	Sampling Du, Gr 115023-032 115058-061 115106-111	Numerous small open pits along quartz veins, most 100 m or less in length.	Numerous quartz veins related to monzogranite intrusive rocks. All veins are in or next to felsic dikes or plugs. Country rocks include gabbro, biotite schist and chlorite schist. Red carbonate alteration is common along the edges of the veins. Veins composed of quartz breccia and calcite with locally abundant hematite- and jarosite-staining. Local visible gold, but few sulfides. Attitude of veins: strike 45° to 80°	12 dump samples .16 to 26, avg. 5.3 g/t	303,750 22,275 44,550	15-21 15-21 15-21
01440	Chaim 21°04'15"N. 43°14'00"E.	Prospect (750x100)	Visited Sampling Du, Gr, Ch Sample trench across ancient working to depth of 3 m 115048-051	Scattered open cuts and one vertical shaft along a 1 km long zone, now sand filled (100,7)(80,5)	Quartz veins, veinlets and breccia cement in 5 m wide breccia zone; attitude: strike 35° dip 50"W. Vein composed of milky quartz with pyrite, galena, hematite, and malachite. Country rock calcareous metatuff.	3 dump samples 1.52, 1.52, and 7.90 g/t 2 dump samples 2.2 and 2.2 g/t 2 channel samples 23 and .9 g/t	120,000 8,000 (ancient dump)	9-12 3.07

Table 19.--*Descriptions and potential resource estimates of ancient gold mines in the northernmost part of the Jabal Ishmas-Wadi Tathlith gold belt*--Continued

MODS	Name and location	Status (Size in meters)	Exploration (Du-dump, Gr-grab and Ch-channel samples; RASS sample numbers)	Workings (length, width in meters)	Geologic descriptions	Analytical data (gold in grams per ton)	Potential resource (Metric tons)	(Grams per ton)
	Umm Shat Group	(5500x1200)						
01459	Gharb 20°57'40"N. 43°17'15"E.	Prospect (600x25)	Detailed mapping 1:1000 scale Sampling Du,Gr,Ch Five sample trenches across ancient workings. 115008 115033-047	Numerous small sand-filled pits, shafts, and inclines along several small veins. Judging from the amount of dump material some of the pits, shafts, and inclines must be deep.	Several quartz veins and quartz-healed breccia zones; attitude: strike 335°, dip 85°SW. The major zones are approximately 1 m wide with 50 cm to 1 m alteration on each side. Parallel felsic dikes. Country rocks are siltstones, sandstones, and calcareous metatuff of the Halaban group. Veins composed mainly of milky quartz with hematite stain and local malachite and limonite. Pyrite, chalcopyrite, sphalerite, and visible gold within limonite occur in minor amounts.	7 dump samples 3.0 to 3.8, avg. 3.48 g/t 5 channel samples .1 to 1.0, avg. .5 g/t Several dump samples avg. 2.6 g/t Several channel samples avg. 3.0 g/t	45,560 91,125 (inferred under alluvial cover)	10-14 ?

Table 19.--*Descriptions and potential resource estimates of ancient gold mines in the northernmost part of the Jabal Ishmas-Wadi Tathlith gold belt*--Continued

MODS	Name and location	Status (Size in meters)	Exploration (Du-dump, Gr-grab and Ch-channel samples; RASS sample numbers)	Workings (length, width in meters)	Geologic descriptions	Analytical data (gold in grams per ton)	Potential resource (Metric tons)	(Grams per ton)
01460	Sharg 20°57'50"N. 43°20'10"E.	Prospect (270x70)	Detailed mapping 1:1000 scale Sampling Du,Gr,Ch Three sample trenches across ancient workings.	Numerous small sand-filled pits, shafts, and inclines along vein zone.	Quartz stringers along shear zone in quartz monzonite. Attitude: strike 50°, dip 35°SE. Parallel felsic dikes. Zone of shearing, quartz veinlets, disseminated pyrite, and alteration is extensive, but gold metallization is confined to narrow zone.	3 dump samples .04 to 6.2, avg. 2.8 g/t 2 channel samples .6 and .4 g/t 20 channel samples one contained Au 6.8 g/t Several dump samples avg. 2.6 g/t	52,650	8-11

1/ Adapted from Worl, 1979, Appendix A. Approximate latitude and longitude corrected for some localities.
2/ Mineral Occurrence Documentation System numbers.

streak and mottle and is medium to fine grained. The marble may be suitable for building stone if material with widely spaced joint or bedding planes can be found.

Granite

Granite from Jabal ash Shayal and Jabal Hadad is attractive and may be suitable for dimension stone.

Sand and gravel

Sand and gravel are plentiful in the quadrangle; however, sparse population and distance from markets prevent their greater utilization.

Ground water

Ground water is not abundant. The wells farthest downstream on Wadi Ranyah and Wadi Bishah are on the north side of Jabal Silli and the south side of Jabal Dalfa, respectively. These may be the only wells in the quadrangle.

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