DEPARTMENT OF THE INTERIOR
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Geology of the Wadi Ash Shu'bah Quadrangle, sheet 26E

Kingdom of Saudi Arabia

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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ABSTRACT

The Wadi Ash Shu'bah quadrangle, located in the north-central part of the Arabian Shield, is underlain by nine Precambrian volcano-sedimentary formations and a wide compositional range of Precambrian intrusive rocks. Late Proterozoic to early Paleozoic rocks of the Jibalah Group crop out in the southwestern part of the quadrangle. Paleozoic and younger units are limited to the early Paleozoic Siq Sandstone that crops out in the northwestern part of the quadrangle and small outcrops of Cenozoic basalt and unconsolidated Quaternary sediments.

The Hulayfah group, dated at older than 738 Ma, is the oldest volcano-sedimentary unit in the quadrangle and consists of metamorphosed basaltic to andesitic volcanic and subvolcanic rock, and interbedded limestone, sandstone, and silicic volcanic rock. The Maraghan formation is composed of strongly folded, fine-grained sedimentary rock that was deposited between 677 and 621 Ma. The Hadn and Hibshi formations are composed of rhyolitic to rhyodacitic volcanic rock and interbedded continental sedimentary rock that were deposited between 651 and 600 Ma, but are inferred to postdate the Maraghan formation because they are significantly less deformed. Andesitic flows and volcanic breccia in the southeast corner of the quadrangle are mapped as the Jurdhawiyah group; these rocks unconformably overlie the Maraghan formation. The Zarghat formation is a thick sequence of interbedded sedimentary rock and silicic volcanic rock, and unconformably overlies the Hadn formation. It is inferred to have been deposited between 600 and 580 Ma.

The Precambrian igneous rocks are organized into four tentative magmatic episodes. Greenstone of the Hulayfah group and dioritic intrusive rocks represent the oldest episode, and are believed to have formed in an ensimatic magmatic arc environment. These rocks were intruded during a second magmatic episode by post-Hulayfah monzogranite and granodiorite. A still younger, post-Hadn magmatic episode is represented by alkali-feldspar granite and syenogranite. The most recent magmatic episode is represented by small diabase and gabbro intrusions that are inferred to have been emplaced during a period of crustal rifting coincident with the deposition of the Jibalah group.

The magnesite deposit near the village of Zarghat is the most significant mineral deposit in the quadrangle. However, the Hulayfah group has the most potential for metallic deposits in the area as it contains numerous gossans and ancient mine workings.

INTRODUCTION

GEOGRAPHIC SETTING

The Wadi Ash Shu'bah quadrangle, sheet 26E, occupies an area of approximately 16,650 km^2 between lats 26°00' and 27°00' N. and longs 40°30' and 42°00' E. (fig. 1). The quadrangle is crossed by a major, northeastern-trending highway that connects Ha'il and Medina. New subsidiary paved roads, graded service roads, and desert tracks provide access to most points in the quadrangle.

Altitudes range from about 800 to nearly 1500 m. above sea level (a.s.l.) Extensive peneplains and pediments are developed in the southeastern and eastern parts of the area. More rugged terrain occurs in regions underlain by silicic volcanic rock and young granitic plutons in the northern and central parts of the quadrangle. Drainage is primarily to the southeast, by way of tributaries of Wadi Ash Shu'bah and Wadi Al Qahad which ultimately flow into Wadi ar Rumah near the southern boundary of the quadrangle.

The largest permanent settlements are near sources of groundwater. Ghazzalah, Mustajiddah, Al Awshaziyah, and As Sulaymi are on the flanks of high granite ranges. Zarghat is at a small oasis at the edge of Harrat Ithnayn, and Ar Rawdh is on the banks of Wadi al Qahad.

PREVIOUS INVESTIGATIONS

The Wadi Ash Shu'bah quadrangle forms part of the 1:500,000-scale Northeastern Hijaz quadrangle, I-205A, of Brown and others (1963). Broad regional geology has been discussed by Greenwood (1973), Chevremont (1982), Al-Shanti and Gass (1983), Schmidt and others (1979), Stacey and others (1984), and Stoeser and Camp (1984).

The 1:100,000-scale quadrangles that constitute the Wadi Ash Shu'bah quadrangle were prepared by Quick (1983, 1984, 1985), Leo (1984), O'Neill and Ferris (1985), and Williams and Simonds (1985) (fig. 2). Adjacent 1:100,000-scale quadrangles into which the 26E geology extends are also referenced in figure 2.

Adjacent 1:250,000-scale quadrangles were compiled by Delfour (1977), Dhellemes and Delfour (1980), Ekren (1985), Kellogg (1984a), Johnson and Williams (1984), Cole (1985b), and Fairer (1985a) (fig. 1).

Isotopic studies have been conducted by Stuckless and others (1984a), and Stacey and others (1984). Geochemical surveys have been carried out by Stuckless and others (1984b).

Mineral reconnaissance and assessment were carried out by Kahr (1962), Johnson and Trent (1965), and Hummel and others (1966). Brosset (1976) investigated the magnesite deposit near Zarghat. In addition, large parts of the sheet have been mapped in reconnaissance by Chevremont (1982) and Bowden (1982).

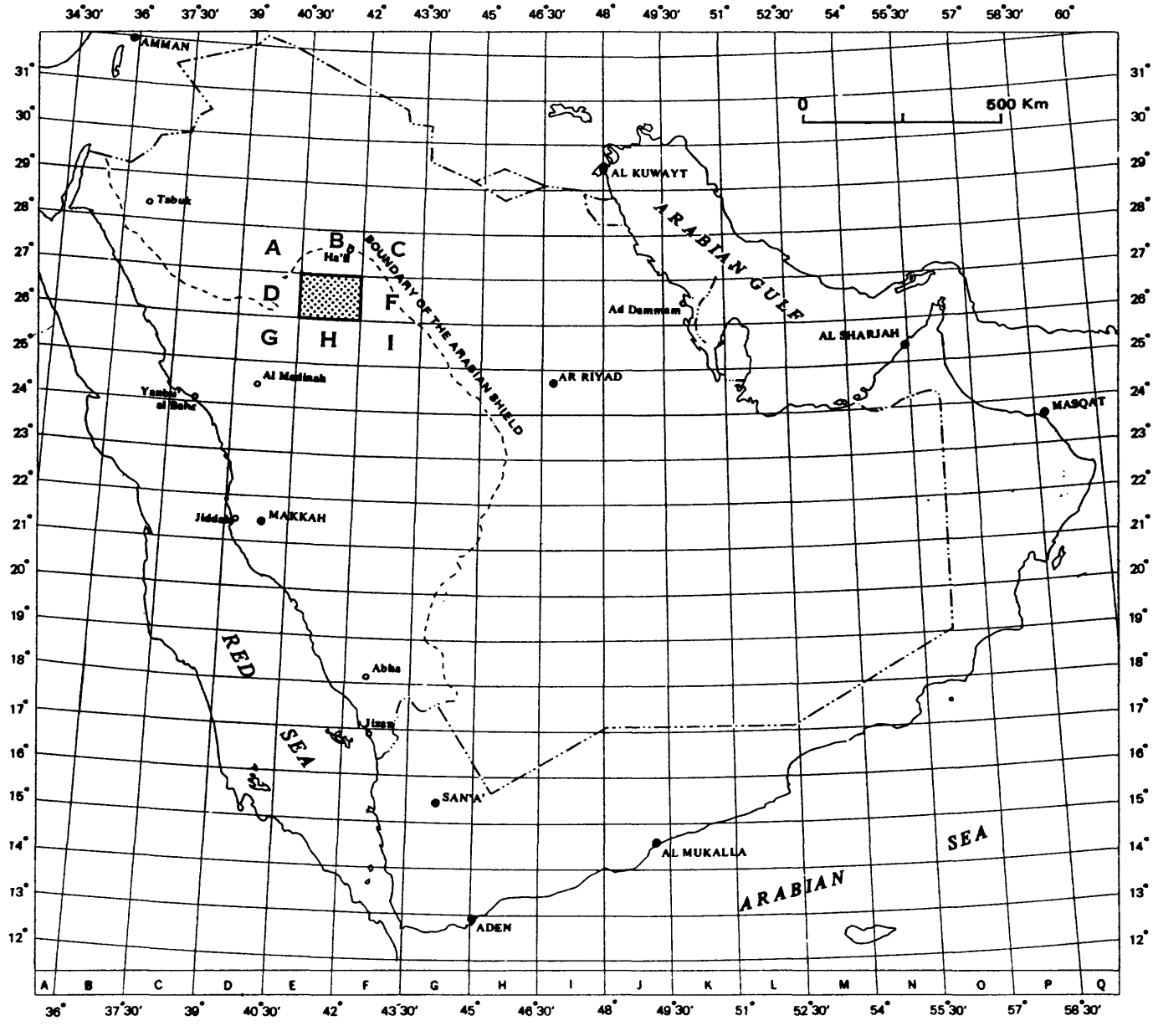

Figure 1.--*Index map of the Arabian Peninsula showing the location of the Wadi Ash Shu'bah quadrangle, sheet 26E, in stippled pattern. Adjacent quadrangles are: A, Jibal Al Misma; B, Ha'il (Ekren, 1985); C, Baq'a (Kellogg, 1984a); D, Harrat Ithnayn (Fairer, 1985a); F, Jabal Habashi (Williams and Johnson, 1984); G, Harrat Khaybar (Dhellemmes and Delfour, 1980); H, Nuqrah (Delfour, 1977); I, Aban Al Ahmar (Cole, 1985b).*

Table 1.--Correlation of map units used in this report with those used on 1:100,000-scale source maps.

1:250,000-scale	1:100,000-scale source maps					
Wadi Ash Shu'bah (this report)	Zarghat Quick (1984)	Ghazzalah Quick (1983)	Al Awshaziyah Leo (1984)	Ar Rawdh O'Neill and Ferris (1985)	As Sulaymi Quick (1985)	Al Ba'ayith Williams and Simonds (1985)
PRECAMBRIAN VOLCANIC AND SEDIMENTARY ROCKS						
bg	bg	bg	aqba*,aqv*,aqdr*	hab,hb,hbp	bg	bsv*
sv	--	hu*	aqv*,aqdr*	hsv*	svs	sv
ha	--	--	--	hab,hbp,hn,hs	--	--
asv	--	--	--	hsv*	--	--
lm	--	bm	--	hl	--	--
mu	--	--	--	--	--	ma,mam
hu	hu	hu,hcc,ha	awt,awts	sh	hu	hv,hvs
hc	--	--	aqc,cgl,awts*	--	--	--
jd	--	--	--	--	--	ju
hib	--	--	--	--	--	hi
zc	zc	--	--	sk,skr	--	--
zb	zb	--	--	--	--	--
zu	zu	--	--	sm,smr,jr	--	--
PRECAMBRIAN AND PALEOZOIC INTRUSIVE ROCKS						
um	--	--	--	--	--	mpr
qdd	hqd	hqd	--	qd	hd	qdd
gd	gd	gd,ton	gd	bgd,hgd	gd	qdd*,qm*
qmd	--	--	--	--	--	qmd
gns	--	--	--	--	--	gn
mg	mg	mga,mgb	mg1,mg2,sg*	mg	mg	mz,mg*,kmg
qp	--	--	--	qp	--	--
sga	gu*	sgm	--	--	--	--
agb	--	pgb	--	--	--	--
sgj	--	sgj	--	--	--	--
sg	--	--	mg2*	--	--	sg
sm	--	--	qlg,mg2*	--	sm	gr,mg*,mgy
afg	afg	afg	sg	afg	afg	--
afga	afga	pga	sgs	--	--	--
ag	--	pgr	pag	--	gas	--
gph	gph	gph,phf	--	sgh,afg*	gph	gph
gph1	--	--	--	--	gph1	--
gph2	--	--	--	--	gph2	--
ry	ry	ry	--	sr	ry	--
ap	ap	--	--	not labelled	--	ap
gb	gb	gb,gbm	gb,gp	--	gb	gb,mgb
di	di	dr	gb/d,qd	di	di	--
LATE PROTEROZOIC TO EARLY PALEOZOIC VOLCANIC AND SEDIMENTARY ROCKS						
js	zm,mag	--	--	jb,js	js	--
PALEOZOIC SEDIMENTARY ROCKS						
6s	O6s	--	--	--	--	--
CENOZOIC SEDIMENTARY AND VOLCANIC ROCKS						
QTb	Qb	Tv	--	QTby,QTbo	QTb	--
Qtg	--	--	Qes*	Jc	QTg	Qg*
Qg	--	--	Qg	--	--	Qg*,Qf
Qu	Qu	Qu	Qes*	Qao,Qf,Qsd	Qu	Qs
Qal	Qal	Qal	Qal	Qa,Qsa	Qal	Qa
Qp	Qp	Qp	Qs	Qs	Qp	Qsb

* In part

Note: Only preliminary maps were available for Ar Rawdh, As Sulaymi and Al Ba'ayith quadrangles and final symbolization of those maps may not correspond completely with this table.

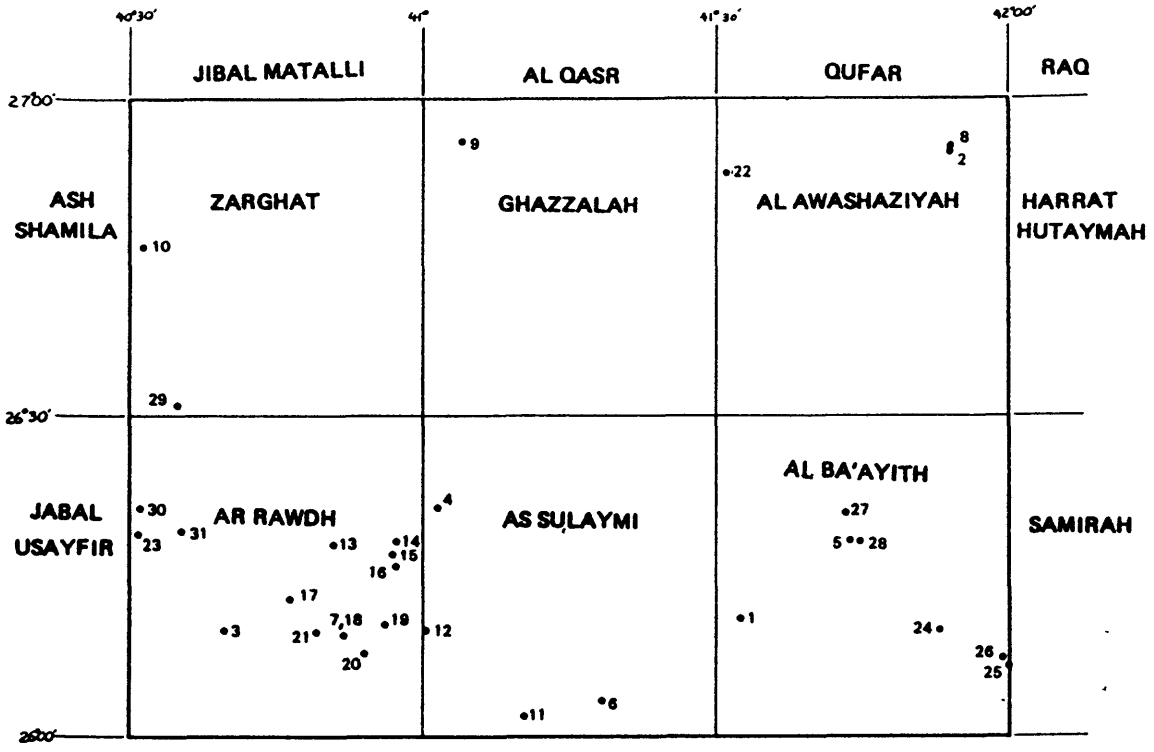

Figure 2.--*1:100,000-scale quadrangles in the Wadi Ash Shu'bah vicinity that are referred to in the text: Jibal Matalli (Ekren, 1984), Al Qasr (Stoeser and Elliot, 1985), Qufar (Kellogg, 1983), Rak (Kellogg, 1984b), Zarghat (Quick, 1984), Ghazzalah (Quick, 1983), Al Awshaziyah (Leo, 1984), Harrat Hutaymah (Pallister, 1984), Ar Rawdh (O'Neill and Ferris, 1985), As Sulaymi (Quick, 1985), Al Ba'ayith (Williams and Simonds, 1985), Samirah (Williams, 1983), Ash Shamila (Fairer, 1985b), J. Usayfir (Fairer, 1985c). Mineral occurrences are shown with numbers keyed to Table 2.*

PRESENT INVESTIGATION

The compilers carried out several days of field reconnaissance work to check correlations and age relations, after preparation of a preliminary report and map at a scale of 1:250,000.

Rocks described in this compilation are classified according to the guidelines of Streckeisen (1976, 1979), and Fisher (1961). Units are named for the most abundant lithology in cases where rock composition is variable. Fine-grained silicic volcanic rocks are provisionally named on the basis of phenocryst population, as follows: Rocks containing phenocrysts of quartz and potassium feldspar are termed rhyolite; those with phenocrysts of only potassium feldspar are termed rhyodacite; and those with phenocrysts of plagioclase with or without quartz are termed dacite.

Most of the rocks are discussed in terms of local informal formation- or group-rank units, defined within or near the Wadi Ash Shu'bah quadrangle. Map symbols used in this report are correlated with those used in the source quadrangles (table 1). Locally defined units are discussed relative to stratigraphic nomenclature of previous investigators, because presently there are no formally defined formation- or group-rank units in the Proterozoic of the northern Arabian shield, and many formation- or group-rank unit names previously have been applied within or adjacent to the quadrangle based on broad regional correlations unsupported by detailed stratigraphic evidence or isotopic age data.

ACKNOWLEDGMENTS

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This manuscript was reviewed by P. Rowley, K. A. Kellogg and H. M. Kluyver, D. Vaslet and T. A. Moore. Adoption of the Hulayfah group and assignment of intrusive rocks to named complexes and suites was performed to comply with requirements of the DMMR Stratigraphic Committee (T. A. Moore, written commun. 1984).

Table 2. -- *Mineral occurrences in the Wadi Ash Shu'bah quadrangle*

No.	MODS* No.	Name of Occurrence	Commodity
1	3903	Al Gharra	Quartz,Gossan,Cu
2	3899	Al Jayb	Cu
3	1588	Ar Rawdah(Raw6)	Cu,Fluorite
4	3898	Dulu Alasmarah	Au
5	3902	Humaymah	Gossan
6	4246	Jabal Alqunnawat(S)	Ag,Au
7	3108	Jabal Ar Rakha(W)	Au,Ag
8	3104	Jabal Aqab	Cu,Pb,Ag,Au,Gossan
9	3156	Jabal Ba'gham	Rare earths
10	2243	Jabal Bushrah	W,Fluorite
11	3897	Jabal Dibi	Au
12	4247	Jabal Idhkiri(W)	Gossan(Fe)
13	1596	Jabal Wasmah	Fluorite
14	4222	Jabal Wasmah(NE)	Fluorite,Cu,Fe
15	4220	Jabal Wasmah(S)	Magnesite
16	4221	Jabal Wasmah(SE)	Fluorite,Pb,Fe
17	1274	Jazabat Alufar(R1)	Cu,Pb,Au
18	3034	Jazabat Alufar(R2)	Cu,Pb,Zn
19	3035	Jazabat Alufar(R3)	Fluorite,Au
20	3036	Jazabat Alufar(R4)	Cu,Pb,Au(?)
21	3037	Jazabat Alufar(R5)	Cu
22	3298	Jibal Sabit(W)	Gravel
23	3900	Summer Saf	Cu
24	3901	Tulqah	Au
25	4235	Wadi Sha'bah(E)	Ag,Au
26	4234	Wadi Sha(NE)	Ag,Au
27	4250	Wadi Sha(NW)	Gossan(Fe)
28	4249	Wadi Sha(SW)	Gossan(Fe)
29	711	Zarghat(Dhis-Zar)	Magnesite
30	3038	Zarghat-S(R7)	Cu,Pb,Zn
31	3106	Zurayghat(S)	Au,Ag

*Mineral Occurrence Documentation System of the DMMR

GEOLOGIC OVERVIEW

The Wadi Ash Shu'bah quadrangle is located in the north-central part of the Precambrian shield of Saudi Arabia. The quadrangle is underlain by rocks that are late Proterozoic to Cenozoic age and composed of a wide compositional range of plutonic rock and nine distinct formations of volcanic rock and sedimentary rock.

The volcanic and sedimentary rocks were previously mapped by Brown and others (1963) as Shammar rhyolite and Halaban, Hibshi, and Murdama formations. Subsequent work in the adjacent Nuqrah quadrangle (Delfour, 1977) elevated the Shammar and Murdama to group status. Delfour subdivided the Murdama group into the Hibshi and Hadiyah formations, and the Shammar group into the Kuara and Malha formations. He also substituted the Hulayfah group for rocks previously classified as Halaban by Brown and others (1963), and recognized an additional unit, the Jibalah group. Most of the previously mentioned units have been applied to rocks over wide regions of the Arabian Shield without adequate stratigraphic control or isotopic age data. Recent geologic thought has emphasized interpretation of the Proterozoic Arabian Shield in terms of petrogenesis in one or more oceanic volcanic arc environments followed by development of an intracratonic volcanic arc on the foundation of the older arc(s) (Schmidt and others, 1979; Al-Shanti and Gass, 1983; Stacey and others, 1984; Stoeser and Camp, 1984). Analogy to well-documented volcanic arc systems (e.g. Hamilton, 1979) suggests that the Proterozoic history of the Arabian Shield was complex and that similar sequences of volcanic and sedimentary rocks may have been produced at radically different times in different parts of the shield. Primarily for this reason, the preexisting regional stratigraphic nomenclature has mostly been avoided in this compilation in favor of locally defined units.

The stratigraphy of layered rocks in the Wadi Ash Shu'bah quadrangle is organized in this report as follows: (1) The oldest volcano-sedimentary sequence is an association of basaltic- and intermediate-composition volcanic and volcaniclastic rocks that are metamorphosed to greenschist and, locally, to amphibolite facies. These rocks are mapped as subdivisions of the Hulayfah group. (2 - 4) Small areas in the southeastern part of the quadrangle are underlain by sedimentary and volcanic rocks of the Maraghan and Hibshi formations, and the Jurdhawiyah group. (5) The Hadn formation, which may be approximately contemporaneous with the Hibshi formation and Jurdhawiyah group, is composed of mostly massive ash-flow tuff and minor continental sedimentary rocks. (6) The Zarghat formation unconformably overlies the Hadn formation and is composed of silicic volcanic rock, volcaniclastic rock, sandstone and massive conglomerate. (7) The Late Proterozoic- to Early Paleozoic-age Jibalah group is composed of conglomerate, basalt, sandstone, and limestone deposited in a northwest-trending graben. (8) Small exposures of Cambrian-age Siq sandstone crop out as flat-lying, quartz-rich sandstone in the northwestern part of the quadrangle. (9) Tertiary and Quaternary rocks include lobes of flood basalt contiguous with Harrats Ithnayn and Khaybar, isolated basaltic plugs and flows, and an extensive cover of unconsolidated sediments.

The plutonic rocks in the quadrangle are divisible into four principal magmatic episodes based on their ages relative to the Hulayfah group and Hadn formation. The earliest episode is represented by quartz diorite and diorite, which intrude but are thought to be coeval with the Hulayfah group. Granodiorite, tonalite, monzogranite, and lesser amounts of more evolved granitic rocks intruded the Hulayfah group during a second magmatic episode that predated the Hadn formation; these rocks may be thought of as roughly equivalent to the "syntectonic granites" of Schmidt and others

(1979). A third magmatic episode is marked by bodies of granite, syenogranite, alkali-feldspar granite, and alkali granite that intrude the Hadn formation. The post-Hadn intrusions are collectively equivalent to the "post-tectonic granites" of Schmidt and others (1979). The last magmatic episode is represented by diabase and gabbro that are interpreted to be plutonic equivalents of the Jibalah basalts.

PRECAMBRIAN VOLCANIC AND SEDIMENTARY ROCKS

HULAYFAH GROUP

Exposures of moderately metamorphosed basalt, andesite and sedimentary and silicic volcanic rock are tentatively assigned to the Hulayfah group (Delfour, 1977). This assignment is made with reservations that must be detailed before the units are described.

Delfour (1977) originally described the Hulayfah group in terms of two units that have type localities in different parts of the Nuqrah quadrangle. The Afna formation was named for interbedded mafic to intermediate volcanic rock and lesser amounts of sedimentary and silicic volcanic rocks that crop out south of the village of Hulayfah, and which were estimated to be 740 Ma based on potassium-argon dating (Delfour, 1977). The Nuqrah formation was named for exposures near the village of Nuqrah that consist of mostly silicic volcanic rock and lesser amounts of sedimentary rock and basalt. Calvez and others (1983) measured ages for rhyolites from the Nuqrah formation of 839 $\pm$ 23 Ma by uranium-lead method and 821 $\pm$ 48 Ma by rubidium-strontium method. Although it is possible that the age on the Afna formation has been reset, it is also possible that the rocks of the Nuqrah type locality could actually be much older than those of the Afna type locality. In any case, the two type localities are separated by a tectonically emplaced ophiolitic complex and analogy to similar geologic environments in the Western United States (e.g. Irwin, 1977) suggests that the two type localities are probably unrelated terranes separated by a major tectonic suture zone. Therefore, this report uses Hulayfah group to refer to metamorphosed volcanic and sedimentary rocks that predate the plutonic rocks of the Wadi Ash Shu'bah quadrangle, but which may represent a wide range of ages. Rocks assigned to the Hulayfah group in the Wadi Ash Shu'bah quadrangle crop out both north and south of the Wadi al Qahad faults, which collectively display at least 50-75 km of left-lateral offset of post-Hulayfah units (see Structure section). Exposures south of the Wadi al Qahad faults are mapped as subdivisions of the Afna formation (Delfour, 1977). Exposures north of the Wadi al Qahad faults are mapped as the Banana formation (Quick, 1983), and the Sufran formation (Williams and Simonds, 1985).

Banana formation

Metamorphosed basaltic to andesitic volcanic rocks that crop out north of Wadi al Qahad are mapped as the Banana formation (bg) of the Hulayfah group. Representative exposures are located near the village of al Banana in the Ghazzalah quadrangle (Quick, 1983). This unit contains minor amounts of marble, graywacke, dacite and rhyolite extrusive rocks. The volcanic and subvolcanic rocks form dark-gray hills and pediments. The regolith is typically blue-green, reflecting the presence of abundant chlorite and epidote. The terrain is dotted with small patches of white detritus from underlying quartz veins. The topography is gentle and, although some hills are as much as 100 m high, cliffs are not present. Boulders are generally less than 0.5 m in diameter, subrounded, and weather to medium-gray to ruddy-brown.

Volcanic flows and flow breccia dominate the greenstone sequence. The more mafic rocks are commonly vesicular and, immediately north of Al Birkah, have locally developed pillow structures. In hand specimen, the rocks are aphanitic to plagioclase- and(or) pyroxene-phyric. Rare interbeds of volcanic wacke contain clasts of flow-banded volcanic rock, plagioclase-phyric volcanic rock, felsite, mafic aphanite, and diorite. Bedding is undiscernable except where thin beds of marble or wacke crop out.

The rocks have recrystallized at lower to middle greenschist facies in most places. Primary hornblende and pyroxene are partly to completely replaced by chlorite and actinolite. Plagioclase is partially saussuritized and locally replaced by epidote.

The volcanic rocks are locally intruded by dikes and sills of diabase and microdiorite too small to record as separate units. These intrusive rocks are postulated to have formed as shallow intrusions that may have been comagmatic with the greenstone because they are compositionally similar and display the same degree of metamorphism and deformation.

Sufran formation

The Sufran formation (sv) is named for sedimentary and silicic volcanic rocks that crop out at Jibal Sufran al Ballaziyah (Williams and Simonds, 1985). The formation has been extended in this report to include extensive outcrops at Jibal Musamma and north of Jibal Ghatat, and smaller outcrops at Dulu al Asmarah. This unit includes rocks previously assigned to the Hadn formation (Quick, 1983), and the Aqab formation (Leo, 1984).

The Sufran formation crops out in close association with the Banana formation but is distinguished by a greater abundance of sedimentary and silicic volcanic rocks. The Sufran formation is composed of mostly silicic volcanic lava flows and ash-flow tuffs that are interbedded with lesser amounts of graywacke, conglomerate, breccia, basalt and andesite. The silicic volcanic rocks weather purple to red-brown, typically contain phenocrysts of white to salmon-colored feldspar, and range in composition from dacite to rhyolite. The silicic volcanic rocks are clearly recrystallized although the effects of metamorphism are more subtle than in the Banana formation. The matrices of these rocks consist of a felty-textured mosaic of quartz and feldspar. Epidote and chlorite are locally abundant.

The Sufran formation is assigned to the Hulayfah group on the basis of apparent conformity and possible local interfingering with the Banana formation. The Sufran formation conformably overlies the Banana formation at Jibal Musamma and near Jibal Ghatat and there is no evidence of a major hiatus between the two formations such as a basal conglomerate in the Sufran formation. At Dulu al Asmarah, the outcrop pattern of rocks assigned to the Sufran formation suggests that they constitute lenses within the Banana formation.

Afna formation

The Afna formation (ha) is mapped south of Wadi al Qahad and consists of basalt, andesite, volcaniclastic rock and sedimentary rock. Interbedded sedimentary and volcanic rock (sv) and marble (lm) are mapped as separate, lithologic members where those rocks are abundant.

The Afna formation is named for exposures of volcanic and sedimentary rock at Jabal 'Afinah, Jabal at Tuwayn and Jabal at Tin in the adjacent Nuqrah quadrangle (Delfour, 1977). With the exception of a narrow interval covered by a flow of harrat basalt, the Afna formation is traceable without major break from the type area into the Ash Shu'bah quadrangle. However, the Afna formation has been extended in the Ash Shu'bah quadrangle to include rocks assigned previously to the Nuqrah formation by Delfour (1977).

Within the Wadi Ash Shu'bah quadrangle, most of the Afna formation is composed of basaltic to andesitic volcanic rock and breccia. These rocks underlie extensive areas between Wadi al Qahad and Wadi ar Rumah, however, exposure in this region is poor and, consequently, relationships are poorly understood. The basaltic rocks are dark green to black and locally amygdaloidal. Layering is poorly defined and pillow structures are scarce. Primary mineral assemblages are replaced by fine-grained intergrowths of chlorite, albite and quartz. The andesitic rocks are medium- to dark-green, better layered than the basalts, and are associated with volcanic breccia and polymict conglomerate. Andesite contains plagioclase phenocrysts and some flows are weakly vesicular. The conglomerate contains angular to subrounded clasts of diorite, granodiorite and basalt.

Limestone and marble member:

Lenses of limestone and marble (lm) are interbedded with the volcanic rocks south of Wadi al Qahad where they are mapped as the marble member of the Afna formation. These rocks form buff- to blue-gray-weathering ridges that stand above the surrounding metavolcanic rock.

Sedimentary member:

Interbedded sedimentary and volcanic rocks are mapped as a separate member (asv) of the Afna formation where they crop out over significant areas. The rocks are typically well-layered andesitic tuff, andesitic flow rock, siltite, argillite, fine-grained sandstone, and tan to gray limestone. The andesitic and clastic rocks are green weathering. The limestone contains abundant black chert nodules.

Medium-grade metamorphic rock

Epidote-amphibolite-grade assemblages are developed locally in aureoles around monzogranite and granodiorite plutons and in broad areas in the southern part of the Wadi Ash Shu'bah quadrangle. These rocks, which are depicted with a stippled pattern, are typically foliated or gneissic and contain abundant epidote and green metamorphic hornblende. Examples of these rocks are well exposed south of Jibal Awbariyat along the southern border of the quadrangle, and 2 km northwest of Al Qahsiyah in the central part of the quadrangle.

Age and thickness

The Hulayfah group is interpreted to be the oldest volcano-sedimentary unit in the quadrangle. Wherever it is in contact with plutonic rocks it is intruded by them; there is no evidence for a pre-Hulayfah basement in the Wadi Ash Shu'bah quadrangle as postulated by Delfour (1977) in the Nuqrah quadrangle to the south. The stratigraphic thickness of the Hulayfah group is unknown in the Wadi Ash Shu'bah quadrangle because its internal structure and stratigraphy are poorly documented and because of the absence of a basal contact.

MARAGHAN FORMATION

Sedimentary rocks of the Maraghan formation (mu)(du Bray, 1983; Johnson and Williams, 1984) crop out in the extreme southeastern part of the quadrangle. These rocks are equivalent to and contiguous with rocks mapped in the Nuqrah quadrangle as

the Hadiyah formation of the Murdama group (Delfour, 1977). The name, Hadiyah, for these rocks, however, is inappropriate because the type locality for the Hadiyah formation (Johnson and Trent, 1965) is over 200 km to the southwest.

The Maraghan formation consists of light-olive-green, locally calcareous, fine-grained sandstone, siltstone, and shale. Marble occurs as boudin-like masses as much as 100 m thick, and thin limestone lenses occur throughout the section.

The total thickness of the Maraghan formation is unknown because of intense folding, an absence of basal exposures, and a general absence of internal stratigraphic markers. Stratigraphic relationships between the Maraghan formation and all other units except the Jurdhawiyah group cannot be determined in the Wadi Ash Shu'bah quadrangle.

HADN FORMATION

Outcrops of predominantly silicic volcanic rocks and arkosic sandstone and conglomerate are mapped as the Hadn formation (hu, hc), which was named and described by Chevremont (1982) for exposures of rhyolitic to rhyodacitic volcanic rocks and interbedded sedimentary rocks that underlie Jabal Hadn in the southern part of the Al Qasr quadrangle. Chevremont (1982) extended the Hadn formation from its type locality into the Al Awshaziyah quadrangle where he measured several stratigraphic sections at Jibal Rumman as Sumr. In this report, the Hadn formation has been extended to include outcrops at Jibal al Furs, Jibal Umm al Amar, Jibal ash Shu'bah, and east of As Sulaymi based on striking similarities in lithology and similar relative ages to plutonic rocks and the Hulayfah group. The Hadn formation comprises rocks previously mapped as the Awshaziyah formation (Leo, 1984) and some of the rocks previously mapped as Shammar rhyolite (Brown and others, 1963). The Hadn formation may be equivalent to parts of the Malha formation of the Shammar group mapped in the Nuqrah quadrangle. (Delfour, 1977).

The Hadn formation (hu) is composed predominantly of rhyolitic to rhyodacitic ash-flow tuff, lesser amounts of massive rhyolitic and rhyodacitic lava flows, and minor amounts of arkosic sandstone and conglomerate. Dacitic, andesitic and basaltic lava flows are scarce. The rocks are more resistant to erosion than the Hulayfah group rocks and form steep-sided hills, precipitous cliffs, and steep talus slopes. Exposures typically weather rusty red brown to black, and the regolith ranges in color from red brown to tan to olive green.

Silicic volcanic rocks of the Hadn formation (hu) are composed mostly of crystal-rich, ash-flow tuff. The phenocryst populations of the volcanic rocks show considerable variation. The following phenocryst assemblages were observed in the Ghazzalah quadrangle (Quick, 1983): plagioclase in about 35 percent of the rocks; potassium feldspar in about 25 percent; quartz, potassium feldspar, and plagioclase in about 10 percent; potassium feldspar and plagioclase in about 10 percent. Blue alkali-amphibole is present locally. The phenocryst populations suggest that the rocks span a range in composition from rhyolite to dacite, and the presence of blue amphibole suggests that some rocks may be peralkaline in composition. Major-element chemistry for rocks from the Hadn type locality suggest that most of the volcanic rocks are rhyolite (D. B. Stoeser, written commun., 1984).

Some pyroclastic rocks contain lithic fragments that range in size from less than 5 mm to 1 m, that are relatively equant, and that are angular to rounded in shape. Most lithic fragments are composed of rhyolitic to rhyodacitic volcanic rock. Fragments of plutonic rock are rare and mostly occur near the base of the Hadn formation. Angular

clasts of granodiorite and medium-grained monzogranite and syenogranite are incorporated in ash-flow tuff at Jabal Ma'a. In general, fragments of fine-grained, red, alkali-feldspar granite constitute less than 1 percent of the clasts but do not seem to be confined to any stratigraphic horizon.

Lithic fragments and phenocrysts are typically set in an extremely fine-grained (0.01-0.1 mm) mosaic of quartz, alkali-feldspar, chlorite, and opaque minerals, with or without amphibole, fayalite, and diopside. Fiamme structures and flow bands have devitrified to a slightly coarser grain size (0.05-0.1 mm) and commonly contain spherulitic aggregates of quartz and feldspar. The matrix in some rocks contains acicular microlites (0.05-0.15 mm) of albite, which define a pilotaxitic-like fabric that wraps around phenocrysts. Microphenocrysts of sanidine are abundant in other rocks.

Locally, arkosic sandstone and conglomerate beds are present at the base of and within the silicic volcanic unit but are too thin to depict separately on the map. Interbedded sedimentary rocks are well exposed at Jabal Ma'a, Jibal Umm al Amar, and Jibal Al Jabiriyah.

Sandstone and conglomerate member

Sandstone and conglomerate of the Hadn formation is mapped as a separate member (hc) where exposures of these rocks are large. Sandstone and conglomerate of the Hadn formation is mapped at Jibal Musamma, along the southern side of Jibal Rumman as Sumr and at the summit of Jabal Dharaf. The conglomerate at Jibal Musamma and Jibal Rumman as Sumr contains rounded to subangular clasts of monzogranite, dioritic rock, and silicic volcanic rock in an arkosic matrix. Medium- to fine-grained arkosic sandstone is interbedded with the conglomerate.

The Hadn volcanic rocks have been only incipiently recrystallized. Some amphibole and pyroxene grains are partially replaced by chlorite. Potassium-feldspar phenocrysts and, to a lesser extent, plagioclase phenocrysts are partially altered to a cryptocrystalline intergrowth of hematite, albite, and clay(?) minerals. Vugs are commonly filled by chlorite, epidote and stilbite. Primary igneous textures are widely preserved, including fiamme, fine (0.2 mm) flow banding, lithophysae, and spherulites. Locally, original shapes of glass shards appear to be preserved, and there are possible relics of perlitic fractures. The extent to which these primary igneous features are preserved is in striking contrast to the metamorphism in the Hulayfah group.

Age and thickness

The internal stratigraphy of the Hadn formation is poorly understood. It is possible that the formation is composed of one deeply eroded but originally continuous sheet of pyroclastic and sedimentary rocks but it is also possible that the Hadn formation formed as several, coeval and interfingering volcanic piles that developed near different eruptive centers. The presence of interbedded continental sedimentary rock suggests that the rocks were deposited in a subaerial environment. The thickness of the formation is estimated to be 3 to 5 km at Jibal Rumman as Sumr where a particularly well bedded section is exposed (Chevremont, 1982). Elsewhere, bedding is indistinct and irregular in orientation, making determination of stratigraphic thickness difficult.

All of the rocks mapped as Hadn formation unconformably overlie both the Hulayfah group and bodies of hornblende quartz diorite and granodiorite that intrude the Hulayfah group. Basal sedimentary rocks of the Hadn formation are also deposited on silicic volcanic rocks of the Sufran formation at Jibal Musamma, Jabal Dharaf, and Jibal Al Jabiriyah.

JURDHAWIYAH GROUP

Interbedded andesite flows and volcanic breccia in the southeastern corner of the quadrangle are mapped as undivided rocks of the Jurdhawiyah group (jd) after contiguous rocks in the adjacent Aban al Ahmar quadrangle to the southeast that were described and named by Cole (1985a, b). The rocks weather dark green to black, and contain minor intercalations of green conglomerate and sandstone.

The Jurdhawiyah group is interpreted to be unconformably deposited on the Maraghan formation (Williams and Simonds, 1985). Although there are no contact relationships in the Wadi Ash Shu'bah quadrangle that constrain the thickness or lower age limit of the Jurdhawiyah, the outcrop pattern suggests that the Jurdhawiyah rests unconformably on folded Maraghan formation. A clearly exposed unconformity with Jurdhawiyah rocks overlying the Maragham formation is described by Cole (1985b) in the Aban al Ahmar quadrangle. The Jurdhawiyah group is tentatively inferred to be approximately the same age as the Hadn formation, in the absence of additional contact relations and isotopic ages.

HIBSHI FORMATION

A narrow belt of sedimentary rocks in the southeastern corner of the Wadi Ash Shu'bah quadrangle is mapped as the Hibshi formation (hib) after contiguous outcrops to the northeast at Jabal Habashi (Brown and others, 1963). The Hibshi formation in the Wadi Ash Shu'bah quadrangle consists of a basal cobble and pebble conglomerate, which contains fragments of mostly dioritic rocks, and overlying, poorly consolidated, dark green to black, coarse pebbly to fine-grained sandstone, green siltstone, and minor dark green fine-grained greenstone. The outcrops define a low (less than 5 m) ridge that rises above a pediment of dioritic/ granodioritic rocks to the north.

The rocks at Jabal Habashi, the type locality of the Hibshi formation, (Williams, 1983) consist of a basal boulder conglomerate overlain by interbedded arkosic sandstone, siltstone, conglomerate, and rhyolitic to rhyodacitic ash-flow tuff and lava flows (Williams, 1983). The volcanic rocks, which are concentrated at the top of the section, are not present in the Wadi Ash Shu'bah quadrangle.

Delfour (1977) interpreted the Hibshi formation to be the basal member of the Murdama group; this interpretation would make the Hibshi formation older than the Maraghan formation. Based on mapping and stratigraphic studies in the Samirah quadrangle, Williams (1983) interpreted the Hibshi formation to be a near-shore facies of the Murdama group, which would make the Hibshi and Maraghan formation approximately coeval. Williams (1983) reported clasts of Maraghan (his Hadiyah) in the Hibshi formation as evidence -- an observation that would also be consistent with a post-Maraghan age for the Hibshi formation. Cole (1985a) emphasized the intense folding of the Maraghan formation relative to the minor deformation in the Hibshi formation, and concluded that the Hibshi formation was younger than the Maraghan formation. This interpretation is adopted in this report, although it is emphasized that there is no definitive evidence and that the stratigraphic relationship between the Hibshi and the Maraghan formation is obscured by poor exposure and thrust faulting (see Structure Section).

Isotopic age dating of the Hibshi and Hadn formations suggests that they are approximately the same age (see Geochronology section).

ZARGHAT FORMATION

Interbedded volcanic and sedimentary rocks that crop out along the western edge of the quadrangle are mapped as the Zarghat formation after rocks exposed near the village of Zarghat (Quick, 1984). These rocks appear to be separated from the Hadn formation by a major unconformity. Outcrops that previously were mapped as Kuara and Malha formations and as rhyolite of the Jibalah group by O'Neill and Ferris (1985) are included within this unit because reconnaissance of the Ar Rawdh quadrangle by the compilers demonstrated that these rocks are identical in outcrop to rocks mapped as Zarghat formation farther to the north. Rhyolitic volcanic rocks are not described in the Jibalah group in the adjacent Nuqrah quadrangle (Delfour, 1977). The Kuara and Malha formations were originally named by Delfour (1977) for exposures of silicic volcanic rock and sedimentary rock in the Nuqrah quadrangle. Zarghat formation is preferred in the Wadi Ash Shu'bah quadrangle because Delfour's (1977) descriptions suggest that the Malha formation in the Nuqrah quadrangle includes rocks equivalent to both the Hadn formation and this report's younger Zarghat formation .

The Zarghat formation is divided into a basal conglomerate member, a basalt member and a mixed volcanic and sedimentary rock member.

Basal conglomerate member

The basal conglomerate member (zc) is a poorly sorted mixture of well- rounded pebble- to boulder-sized clasts and more angular sand-sized fragments. Measured clast sizes range from less than 1 mm to 4 m in diameter. The matrix is variable in composition; locally it is composed of friable arkosic sandstone and in other places it is tuffaceous sandstone. Induration is poor and as a result, the matrix is not preserved at the surface in most places and outcrops are littered with unconsolidated cobbles and boulders.

Most clasts in the conglomerate are composed of red- and dark-gray-weathering volcanic rock that resemble lithologies in the Hadn formation. Lithologic varieties are vitrophyre, aphanite, basalt, volcanic breccia, and volcanogenic sandstone. The vitrophyric rocks are the most abundant and typically contain phenocrysts of euhedral quartz, pink or white potassium feldspar, and white laths of plagioclase in a red to dark-gray matrix that is divitrified to an aphanitic felsite. Plutonic rocks are less abundant, comprising only 10-20 percent of the clasts. Clasts of fine- to medium-grained alkali-feldspar granite, arfvedsonite- bearing alkali granite, syenogranite, granodiorite, tonalite and diorite are present in minor amounts throughout the conglomerate. Locally, boulders as much as 3 m in diameter are present, and the large size of these clasts suggests that much of the conglomerate was deposited near its source.

Basalt member

Basalt (zb) is locally interbedded with and, in some places, overlies the basal conglomerate of the Zarghat formation. The largest exposures of basalt are along the eastern flank of Jabal Ham where flows reach an aggregate thickness of about 100 m. In contrast to the greenstone of the Hulayfah group, the Zarghat basalt is resistant to erosion and weathers dark gray to black without the green hues indicative of abundant chlorite and epidote. Individual flows are discernable in many places and range from 1-3 m to tens of meters thick. Some flows have well-developed columnar jointing; elongated, quartz-filled vesicles as much as 2 cm long are locally abundant.

Mixed volcanic and sedimentary rock member

Most of the Zarghat formation is mapped as mixed volcanic and sedimentary rocks (zu). The volcanic rocks consist of rhyodacite to dacite ash-flow tuff, lapilli air-fall and(or) water-laid tuff, and volcanic breccia. The rocks are characterized by white or salmon-colored feldspar phenocrysts and an aphanitic, red-brown to gray matrix. Lapilli are composed of volcanic rock similar to the host rock. Bedding ranges from less than one meter to tens of meters in thickness. Fiamme are rare and many of the rocks appear to grade from lapilli-rich tuff into volcanic sandstone. Columnar-jointed rhyolite flows, composed of pink feldspar and quartz phenocrysts in a pink aphanitic matrix, form prominent, red-brown hogbacks south of Jibal Ham. North of Zarghat, dacite flows, composed of white feldspar phenocrysts in a gray matrix, form another set of prominent hogbacks.

The volcanic rocks are interbedded with fine- to coarse-grained volcanogenic wacke, arenite, conglomerate, and breccia. Most rocks weather red brown to medium or dark gray. Particularly well-bedded wacke and conglomerate crop out with a total stratigraphic thickness of 400-500 m about 10 km southwest of Jabal Ham. Beds range in thickness from 5 cm to 1 m; individual beds are remarkably uniform in thickness and continuous for hundreds of meters. All of the sedimentary rocks are poorly sorted and immature. Most clasts consist of fine-grained to aphanitic volcanic rocks that are texturally and mineralogically similar to the volcanic rocks in the Zarghat and Hadn formations. Fragments of quartz, potassium feldspar, plagioclase and opaque minerals are less abundant. Individual beds may be composed of a matrix that ranges from less than 5 to as much as 50 percent of the rock. The matrix consists of clastic material, clay, and devitrified glass that is finer grained than 0.1 mm. The matrix/clast ratio ranges considerably as does the abundance of devitrified glass shards. The sedimentary rocks appear to grade into clast-rich airfall or water-laid tuffs that may have been reworked.

Age and thickness

The presence of clasts of granite from the Ash Shu'bah complex in the Zarghat conglomerate suggests that the Zarghat formation unconformably overlies the Hadn formation, which is intruded by the Ash Shu'bah complex at Jibal Ba'gham and Jibal Umm al Amar. The thickness of the Zarghat formation is estimated to be about 3 km in the vicinity of the village of Zarghat (Quick, 1984).

PRECAMBRIAN INTRUSIVE ROCKS

PERIDOTITIC AND GABBROIC ROCKS

Altered peridotitic and gabbroic rocks (um) crop out in small areas in the southeastern corner of the quadrangle near Wadi ar Rumah and in the southwestern corner of the quadrangle near Jabal Mahajarah. The ultramafic rocks are completely altered to serpentinite, and listwanite, a carbonate rock produced by CO_2-metasomatism of peridotite during serpentinization. Similar lithologies are exposed to the east of the Wadi Ash Shu'bah quadrangle along the Raha thrust fault (du Bray, 1983) and their presence near Wadi ar Rumah has been used by Williams and Simonds (1985) as an argument for the presence of a thrust fault in the southeastern corner of the Wadi Ash Shu'bah quadrangle. All contacts of the ultramafic and gabbroic rocks appear to be tectonic, and therefore, the relative ages of these rocks are not determinable in the field. This unit is tentatively correlated with the ultramafic and gabbroic rocks of the Urd group that are exposed in the Nuqrah quadrangle and interpreted to be components of an ophiolite underlying the Hulayfah group (Delfour, 1977).

JUWAYY RASHIB COMPLEX

The Juwayy Rashib complex (qdd) is composed of quartz diorite and diorite that crop out in close association with greenstone of the Hulayfah group. The unit name is introduced in this report for outcrops along the west bank of Wadi Juwayy Rashib about 20 km west of Ghazzalah. The Juwayy Rashib complex also crops out over large areas in the southeastern corner of the Wadi Ash Shu'bah quadrangle and over smaller areas near Jibal al Furs, Dil Akbad, and south of Wadi al Qahad. The rock appears similar to the greenstone from a distance, forming outcrops of low-lying hills covered with gray-green regolith and small (less than 1 m) rounded to subangular, dark-gray boulders.

The rocks show a complete gradation between diorite and quartz diorite. Textures range from hypidiomorphic-granular to intersertal. Color indices range from 15 to 30, and brown, magmatic hornblende is the dominant ferromagnesian mineral although minor amounts of biotite are present locally. Plagioclase ranges in composition from An_{30} to An_{50}. Alteration has resulted in saussuritization of plagioclase and chloritization of amphibole and biotite. Calcite and epidote veins are locally abundant.

Outcrops of Juwayy Rashib complex near the village of Saqf are intruded by granodiorite and tonalite that are, in turn, unconformably overlain by the Hadn formation. Clasts of quartz diorite and diorite occur in the basal conglomerates of the Hadn and Zarghat formations. The Juwayy Rashib complex is interpreted to be the plutonic equivalent of the mafic and intermediate volcanic rocks of the Hulayfah group because of their spatial association and mineralogic similarity to small bodies of dioritic rocks that pervade the Banana formation.

POST-HULAYFAH INTRUSIVE ROCKS

Murran Suite

The Murran suite is introduced in this report for exposures of post-Hulayfah granodioritic, tonalitic and monzodioritic rocks exposed along and near Sha'ib Murran in the southeastern corner of the quadrangle. The suite includes the Ma'a complex, the Samirah quartz monzodiorite and the Ba'ayith complex.

(p. 19 follows)

Ba'ayith complex

Large areas in the southeastern part of the Wadi Ash Shu'bah quadrangle are underlain by gneissic and schistose granodioritic rock (gns), which is mapped as the Ba'ayith complex. The Ba'ayith complex is introduced in this report for exposures north of the village of al Ba'ayith. The unit is poorly exposed and, in most places, the only evidence of the bed rock is a coarse grus developed between more resistant-weathering dikes. The outcrop style and appearance, where exposed, are similar to those of the Samirah quartz monzodiorite and Ma'a complex except that the rocks have a poorly developed gneissic to schistose fabric.

The rocks consist of plagioclase, quartz, and lesser amounts of potassium feldspar, hornblende, biotite, and sphene. Hornblende is the dominant ferromagnesian mineral. The primary igneous texture has been overprinted by a weak protoclastic fabric and the mafic minerals have undergone considerable alteration to chlorite and epidote. Nevertheless, relics of primary hypidiomorphic-inequigranular texture are abundant.

These gneissic and schistose rocks are considered to be slightly to moderately deformed equivalents of either the Ma'a complex or the Samirah quartz monzodiorite, based on similarities in mineralogy and relict primary texture, and as such are considered to be younger than the Hulayfah group. The greater deformation in the Ba'ayith complex may simply reflect erosion to a deeper crustal level than in the rest of the Wadi Ash Shu'bah quadrangle. This interpretation is supported by the generally higher grade of metamorphism displayed by nearby exposures of the Hulayfah group. Similar rocks were mapped by Delfour (1977) in the Nuqrah quadrangle as pre-Hulayfah basement, an interpretation that would reverse the above age assignments.

Shuwayman suite

The Shuwayman suite is named for exposures of monzogranite that crop out in the Jabal Habashi quadrangle (Johnson and Williams, 1984). Within the Wadi Ash Shu'bah quadrangle the Shuwayman suite is mapped as mostly Klob monzogranite and as small exposures of quartz-rich pegmatite.

Klob Monzogranite

The Klob monzogranite (mg) underlies extensive areas in the Wadi Ash Shu'bah quadrangle. The monzogranite forms a virtually continuous terrain of batholithic-scale in the northeastern part of the quadrangle. This unit is continuous with rocks to the east of the Wadi Ash Shu'bah quadrangle that were collectively mapped as Klob monzogranite in the Harrat Hutaymah quadrangle (Pallister, 1984) and later compiled as the Shuwayman suite in the Jabal Habashi quadrangle (Johnson and Williams, 1984). This large body ranges in composition from granodiorite to syenogranite and probably represents a composite of many smaller plutons. Isolated, rounded to irregular monzogranite plutons farther to the south and west are mapped as Klob monzogranite (mg) on the basis of petrologic similarity although they are not unequivocally related.

The Klob monzogranite forms low lying, cavernous-weathering outcrops that are covered with a distinctive white grus. The rock is composed mostly of quartz, plagioclase (An_{20-30}), and microcline, that form a medium- to coarse-grained hypidiomorphic-granular intergrowth. Rapikivi texture is developed locally. Biotite typically forms interstitial clusters (less than 1.5 mm) of tiny grains associated with opaque minerals, albite, quartz, and zircon. Green hornblende is present in about 10 to 20 percent of the rocks and is most common in the isolated intrusions mapped as

(p. 21 follows)

commonly replaced by chlorite. Calcite veins in some rocks are abundant and plagioclase is pervasively sericitized.

The granite intrudes and contains roof pendants of granodiorite, presumably derived from the Ma'a complex, and Hadn volcanic rocks near Jibal Ash Shu'bah. The syenogranite is unconformably overlain by the Zarghat formation on the eastern flank of Jibal Ham. The Ash Shu'bah complex, therefore, provides critical information on the relative ages of the Hadn and Zarghat formations.

Ba'gham granite

Coarse-grained, dark-gray peralkaline granite mapped as the Ba'gham granite (agb) crops out along the northeastern margin of the Ash Shu'bah syenogranite, and appears to grade from it. The peralkaline granite outcrop is rugged and typified by high hills with steep walls and cliffs, and talus slopes with large (1-5 m) angular boulders. The rocks are distinguished from all others in the quadrangle by their high level of radioactivity.

The Ba'gham granite is composed of a coarse-grained (2-15 mm), hypidiomorphic- to xenomorphic-granular intergrowth of 50 to 70 percent microcline microperthite, 30 to 45 percent quartz, 5 to 10 percent arfvedsonite, minor amounts of equant opaque minerals and zircon, and trace amounts of yellow biotite. Locally, the mineralogy and textures reflect extensive, late-stage magmatic recrystallization and oxidation. The rock is cut by hematite-rich veins and mafic minerals are replaced by dark, hematite-rich clots. Ellipsoidal, pegmatitic segregations, as much as 20 cm in diameter, are locally abundant and probably crystallized from late-stage, volatile-rich fluids. Hematite-rich veinlets are present along grain boundaries. Amphibole is replaced by intergrowths of magnetite, quartz, calcite, and alkali feldspar.

The Ba'gham granite forms dikes that intrude the Hadn formation and contains roof pendants of Hadn volcanic rocks. Clasts of arfvedsonite-bearing peralkaline granite in the Zarghat conglomerate may have been derived from the Ba'gham granite. The gradational contact between the Ba'gham granite and undivided granite of the Ash Shu'bah complex suggests that the two units are comagmatic.

Jufayfah syenogranite

The Jufayfah syenogranite (sgj) crops out in the southern part of the Al Qasr quadrangle (Stoeser and Elliott, 1985) just north of the Wadi Ash Shu'bah quadrangle. The intrusion extends southward into the northcentral part of the Wadi Ash Shu'bah quadrangle near the village of Saqf. The Jufayfah syenogranite forms numerous, white to tan granite pinnacles that project as much as 100 m above very flat pediment and alluvial plains.

The rock is composed of a fine- to medium-grained, hypidiomorphic-granular intergrowth of 35 to 40 percent quartz, 40 percent microcline, 15 to 20 percent plagioclase, minor amounts of biotite and opaque minerals, with or without hornblende. Interstitial muscovite is present in some rocks but may be a secondary alteration product. Potassium feldspars have been pervasively altered to hematite, clay minerals, and muscovite. Biotite has been largely replaced by opaque minerals and chlorite.

Contacts with the Hadn, the Ma'a complex, the Juwayy Rashib complex and the Banana formation are clearly exposed; dikes of Jufayfah syenogranite penetrate all four units. The age of the Jufayfah syenogranite relative to the Zarghat formation is not known.

(p. 23 follows)

Biotite alkali-feldspar granite:

Plutons of biotite alkali-feldspar granite (afg) are clearly visible on Landsat imagery as high-albedo plains that are concentrated mostly in the northwestern part of the quadrangle. The largest plutons are characterized by white, grus-covered pediments and isolated, white to light-gray whalebacks.

The rock is composed of a medium- to coarse-grained (0.25-0.5 cm), hypidiomorphic-inequigranular intergrowth of perthitic alkali feldspar and quartz. Color indices rarely exceed 1; most rocks appear to be one-feldspar hypersolvus granite. Perthite grains contain blocky cores of white plagioclase, and in some samples, and the rock is truly a two-feldspar granite. Biotite, opaque minerals, sphene, and zircon are concentrated in small (less than 1 mm in diameter) interstitial clots. Within 10-20 m of the margins of the plutons, the rock is finer grained (less than 1 mm) and locally exhibits graphic texture, but it is mineralogically identical to the coarser-grained interior. Biotite alkali-feldspar granite intrudes the Hadn formation, the Hulayfah group, and the Ma'a complex. In the northwestern corner of the quadrangle, two small plutons of alkali-feldspar granite intrude the Zarghat formation.

Arfvedsonite alkali-feldspar granite:

Alkali-feldspar granite that contains minor amounts of arfvedsonite (afga) crops out in the northcentral, northeastern and northwestern parts of the quadrangle. The granite underlies steep hills that weather white to light gray. Fresh surfaces are light-purple to pink.

This unit is composed of a hypidiomorphic-granular- to graphic-textured intergrowth of 55 to 70 percent microcline perthite, 30 to 40 percent quartz, 1 to 2 percent ferromagnesian and opaque minerals, and minor amounts of sphene, zircon, and apatite. The ferromagnesian minerals are biotite, arfvedsonite, and locally, aegirine. The only significant alteration products are minor chlorite after biotite, partial replacement of amphibole by opaque minerals, and a turbid red-brown coloration of the feldspar.

The pluton north of Jibal Ash Shu'bah contains roof pendants of Hadn volcanic rocks, and its convex shape against the Ash Shu'bah complex suggests that it is younger than the Ash Shubah complex. The pluton west of Jibal Ham crosscuts bedding in the Zarghat formation. The arfvedsonite-bearing alkali-feldspar granite may be related to the rest of the alkali-feldspar granite plutons because the two units are mineralogically and texturally similar except for the presence or absence of small amounts of arfvedsonite and aegirine. The biotite alkali-feldspar granite may have crystallized from a peraluminous parental melt that in some plutons was driven to marginally peralkaline compositions by fractional crystallization. The arfvedsonite alkali-feldspar granite may have crystallized from these slightly more evolved melts. This interpretation is supported by whole rock chemical analyses (Ekren, 1984; Stoeser, written commun., 1984) that demonstrate that the arfvedsonite-bearing pluton north of Jibal Ash Shu'bah has a peraluminous core and a peralkaline rim. Similar observations are reported by Kellogg (1984b) for the Salma complex in the Raq quadrangle.

Alkali granite:

Alkali granite (ag) forms large plutons at Jibal Rumman al Humr and at the village of As Sulaymi. These two plutons are considered to be essentially coeval and possibly consanguineous on the basis of their similar petrography. The rock is readily distinguished from the surrounding granites by its rugged topography. Medium-gray,

(p. 25 follows)

Dikes

Dikes are abundant throughout the quadrangle. The dikes weather red to black and are generally less than 2 m wide. They are readily discernable where they cut granite, granodiorite, or dioritic rocks because they are more resistant and weather to darker hues. In contrast, the dikes are similar in resistance and color to the volcanic rocks in the Hadn and Zarghat formations from which they are difficult to distinguish.

Most of the dikes are felsic in composition and are composed mainly of quartz and feldspar. Salmon-colored potassium feldspar is the most common phenocryst; quartz and plagioclase phenocrysts are less common. Diabase dikes are less common and are mostly restricted to a swarm intruding the Shuwayman suite in the north-eastern part of the quadrangle.

Most of the dikes are organized into sets within which there is a limited range of preferred orientations. The fact that the younger plutonic rocks are cut by fewer felsic dikes than the older plutonic rocks suggests that the dikes were emplaced episodically over a long span of time.

Intrusive rhyolite

Intrusive rhyolite (ry) crops out as a red aphanitic rock that occurs mostly in the western part of the quadrangle. The rocks are structureless, weather dark red to black and superficially resemble rhyolitic volcanic rocks because of their fine-grained texture. They are completely devoid of compositional layering, eutaxitic structures, and clasts, unlike volcanic rocks in the area. The rocks are composed of small (1-3 mm) phenocrysts of biotite and pink alkali feldspar in a felsic groundmass of minute grain size. The similarity in mineralogy between this rock and the felsic dikes suggests that they are genetically related. Locally, granophyre grades into intrusive rhyolite with decreasing grain size, which suggests that these rock types may be cogenetic where in contact.

Aplite

Aplite (ap) crops out in the western part of the quadrangle about 5 km west of Wadi Asmarah and in the eastern part of the quadrangle east of Jibal Abu Mughayr and north of Jibal Kutayfan. The rock is aphanitic, light purple to lavender on fresh surfaces and buff to light orange brown on weathered surfaces. Flow layering is developed locally but, for the most part, the rock is structureless.

The aplite is composed of an extremely fine-grained (0.1-0.2 mm) intergrowth of turbid alkali feldspar, quartz, and equant magnetite. The texture is typically xenomorphic-granular but euhedral potassium feldspar microphenocrysts occur locally.

The northwestern contact of the aplite is clearly exposed near Wadi Asmarah where it truncates the Zarghat formation. The age of the aplite relative to the other post-Zarghat intrusive rocks is uncertain.

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LATE PROTEROZOIC TO EARLY PALEOZOIC INTRUSIVE ROCKS

GABBRO

Gabbro (gb) crops out as small plutons, dikes, and plugs. Outcrops are typically covered by dark-ruddy-brown to black subangular boulders and greenish-gray regolith.

The primary mineralogy of the gabbro is a hypidiomorphic-granular to subophitic intergrowth of plagioclase, augite, and(or) green hornblende and magnetite. The grain size is variable, ranging from fine to coarse grained in a single body. The ferromagnesian minerals are interstitial to larger, subhedral plagioclase grains. In most places, augite and olivine are the predominant ferromagnesian minerals, but in some intrusions hornblende alone is present. In many places, the gabbro appears to be virtually unaltered but, locally, alteration has incompletely saussuritized plagioclase and replaced hornblende and augite by intergrowths of chlorite with or without actinolite. Calcite veins and laumontite are locally abundant.

The gabbro dikes intrude the Ash Shu'bah syenogranite and the large arfvedsonite alkali-feldspar granite west of Jibal Ham, and, therefore, are relatively young intrusive rocks. The gabbro bodies are essentially devoid of felsic dikes, which is consistent with a young age assignment. The apparent young age and basaltic composition suggest that the gabbro may be consanguineous with the diabase intrusions, perhaps related to the Jibalah-age basaltic volcanism, which is assumed to be latest Proterozoic to earliest Phanerozoic in age.

DIABASE

Diabase (di) forms dark-gray-weathering outcrops with virtually no relief. The rocks are fine grained and composed of laths of plagioclase and an intersertal matrix. The diabasic texture is evident in hand specimen, although locally the rocks are coarse grained enough to be termed either microdiorite or microgabbro.

Diabase intrudes the Zarghat formation in two small areas on the eastern side of Jibal Uahli and in multiple locations south of Wadi Al Qahad. One diabase-Zarghat formation contact is crosscut by a body of granophyre, indicating that, at least locally, the diabase is older than the granophyre. West of Jibal Ham and at Jibal Rumman as Sumr, diabase dikes, which are too small to map, intrude afrvedsonite alkali-feldspar granite and alkali granite along a system of northeast-trending faults. The diabase intrusions may be coeval with the alkali basalt flows of the Jibalah group (see Paleozoic sedimentary rocks).

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CENOZOIC VOLCANIC AND SEDIMENTARY ROCKS

BASALT

Cenozoic basalt (QTb) forms one isolated plug near the southern margin of the quadrangle, a small deeply eroded volcanic field south of Jibal Rumman Al Humr, and three long flows along the western margin of the quadrangle. The plug and volcanic field are tentatively assigned a Tertiary age because Kellogg (1983) reports a potassium-argon age of 23.4 Ma for a similar volcanic remnant in the Qufar quadrangle to the north. Three basalt flows extend from Harrat Ithnayn and Harrat Khaybar into the western margin of the Wadi Ash Shu'bah quadrangle. The flows are composed of black, vesicular basalt that have undergone virtually no modification by erosion suggesting that they are Quaternary extrusions.

TERRACE GRAVEL

Terrace gravel (Qtg) is mapped along the banks of Wadi Al Qahad and Wadi Ash Shu'bah and near Sabkhat al Habj. The deposits form low hills (less than 10 m high) that consist of unconsolidated angular fragments of silicic volcanic rock and granite in a unconsolidated matrix of silt and sand. The deposits locally contain primitive stone tools, suggesting that they are Pleistocene in age.

PEDIMENT GRAVEL

Pediment gravel (Qg) constitutes isolated deposits of subrounded to angular blocks of desert-varnished bedrock, generally less than 30 cm in diameter, in the eastern third of the quadrangle.

QUATERNARY DEPOSITS, UNDIVIDED

Undivided Quaternary deposits (Qu) are composed of colluvium, talus, flood plain and terrace deposits, and alluvium in channels too small to map.

ALLUVIUM

Alluvium (Qal) consists of unconsolidated sand and silt that is actively being moved in large wadi channels. These sediments are generally lighter colored, better sorted, and more mature than the undifferentiated Quaternary deposits.

PLAYA LAKE DEPOSITS

Playa lake deposits (Qp) consist mostly of clay and fine silt and lesser amounts of evaporative salts deposited in small playa lakes.

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GEOCHRONOLOGY

Table 3 presents the available isotopic age data for the Wadi Ash Shu'bah quadrangle and relevant data from nearby quadrangles. Ages of 738 Ma on the Ma'a complex at Jibal Ma'a and 651 Ma on the Shuwayman suite near Bi'r Sabsab reinforce the interpretation that these lithologies are among the oldest plutonic rocks in the quadrangle. The Hadn formation, which unconformably overlies the granodiorite and monzogranite in both places, is younger than 651 Ma. Furthermore, the Banana formation, which is intruded by the granodiorite of the Ma'a complex, must be older than 738 Ma.

Ages on the Jufayfah syenogranite, the alkali-feldspar granite at Jibal Salma, the Ba'gham granite and the alkali granite at Jibal Rumman as Sumr suggest that the more evolved syenogranite, alkali-feldspar granite, and alkali granite was emplaced over a period of time that ranged from 580 to 600 Ma. These dates establish a lower age limit of 600 Ma for the Hadn formation. The resulting age brackets for the Hadn formation (600-651 Ma) are roughly consistent with the direct age determination on the Hibshi formation (632 Ma) and suggests, although does not require, that the two formations may be coeval. The Maraghan formation is constrained by cross-cutting relationships to be older than 621 Ma, but is also presumed to be older than the Hadn and Hibshi formations because of its greater deformation. The age of the Zarghat formation may be estimated assuming that the Ba'gham granite is the source of the alkali granite clasts in its basal conglomerate, and that the alkali-feldspar granites that intrude it are the same age as those at Jabal Salma, that is about 580 Ma. This hypothesis suggests that the Zarghat formation was deposited between 600 and 580 Ma ago.

These data demonstrate that, within the Wadi Ash Shu'bah quadrangle, an information gap of approximately 100 Ma exists between the deposition of the Hulayfah group before 738 Ma and the deposition of the Hadn, Hibshi, and Zarghat formations during the interval of 651 to 580 Ma. A tight age constraint is not available for the Maraghan formation or Jurdhawiyah group near the Wadi Ash Shu'bah quadrangle. The potassium-argon age for the Jibalah group must be considered a minimum age to allow for possible argon loss; nevertheless, geologic evidence is consistent with deposition of the Jibalah group later than 580 Ma ago.

(p. 33 follows)

MAGMATIC EPISODES

Four Precambrian and Paleozoic magmatic episodes are proposed for the Wadi Ash Shu'bah quadrangle based on the relative ages from stratigraphy and cross-cutting relationships, and from absolute isotopic dating. That each episode is represented by truly cogenetic or even truly coeval rocks is by no means certain. Nevertheless, it appears that plutonic and extrusive rock types of similar compositions may be confined to definable although possibly broad time intervals.

The oldest episode is represented by greenstone of the Banana formation and the Juwayy Rashib complex. These rocks are thought to be truly coeval and cogenetic. The two lithologies generally crop out near one another, and petrographic examination suggests that the dioritic rocks of the Juwayy Rashib complex have appropriate bulk compositions to be plutonic equivalents of some of the volcanic rocks of the Banana formation. This episode is interpreted to predate 738 Ma.

A second episode is represented by post-Hulayfah granodiorite, tonalite, and monzogranite. Although a cogenetic origin for some of these rocks is suggested by similar texture, mineralogy, and gradational mutual contacts, the two available age dates span much too great an interval (740 to 635 Ma) to consider all of them to be cogenetic. Collectively, however, these rocks record a broad time interval characterized by relatively unevolved granite plutonism that predates the onset of voluminous rhyolitic volcanism in the shield.

A third episode is represented by the Hadn, Hibshi and Zarghat volcanic rocks and post-Hadn alkali granite, syenogranite, alkali-feldspar granite, and alkali granite intrusions. Again, it is emphasized that dates on these rocks span a large time interval (650 to 580 Ma). Furthermore, stratigraphic considerations alone indicate that the Zarghat formation is significantly younger than the Hadn formation. Therefore, the rocks assigned to this magmatic episode cannot be truly comagmatic. The important point is that the igneous history of the shield during about 60 Ma appears to have been dominated by intrusion of evolved granitic rocks and extrusion of rhyolitic and rhyodacitic volcanic rocks. Many of these plutons probably are cogenetic with the nearby silicic volcanic rocks and, in many places, may have intruded their own volcanic piles.

The fourth and last episode is represented by gabbro and the younger diabase intrusions and is estimated to be approximately coeval with the Jibalah basalt and andesite.

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A low-angle "thrust fault" and a set of high-angle, imbricate thrust faults are exposed in the northeastern corner of the Wadi Ash Shu'bah area near Jibal Musamma. The low-angle fault places Hadn formation over underlying Sufran formation; the compilers, during a two-day reconnaissance of the Al Awshaziyah quadrangle, recognised that these rocks are separated by a shear zone approximately 5 m wide that is exposed on Dil an Sabil. The fault may have formed at the base of a huge gravity slide. A Proterozoic age is postulated for this feature because it is inferred to be truncated by post-Hadn quartz monzogranite. Imbricate, northwest-dipping thrust faults are exposed on Jibal Musamma. These structures juxtapose slices of Hadn formation, monzogranite of the Shuwayman suite, and the Hulayfah group.

FOLDS

Only the Hulayfah group and Maraghan formation appear to have a regionally defined pattern to their internal deformation. The Hulayfah group is deformed into nearly vertical, isoclinal, north-northeast-striking, mesoscopic folds in the Ar Rawdh quadrangle. Similar folds are apparent where carbonate beds of the Hulayfah group are exposed in other parts of the Wadi Ash Shu'bah quadrangle. The structure of the Hulayfah group, however, is not well documented. East of the Wadi Ash Shu'bah quadrangle, the Maraghan formation is also deformed into northerly-trending folds.

The Hadn and Zarghat formations tend to be preserved in structural depressions between large plutons. Folds are larger and significantly more open than in the Hulayfah group or Maraghan formation, and they are interpreted to have formed by deformation of the Hadn and Zarghat formations during diapiric emplacement of the younger granitic plutons. As such, these structures do not relate directly to a regional stress regime.

(p. 37 follows

GOLD

Nine gold or gold/silver ancient workings have been identified in the Wadi Ash Shu'bah quadrangle. All but one are located in the southern half of the quadrangle. All but two, which are in the Maraghan formation, are in rocks assigned in this report to the Hulayfah group. The largest working is about 2-3 km south of Jabal Dibi (MODS 3897) and consists of pits, trenches and building foundations that run for about 1 to 1.5 km along strike with quartz veins in the Hulayfah group.

DATA STORAGE

Unpublished data generated during the course of the DMMR sub-project 2.02.42 is available for examination as Data-File USGS-DF-04-41 in the archive library at the Jiddah office of the USGS Mission.

The following new entries were made into the Mineral Occurrence Documentation System (MODS) during the course of this project:

MODS	3897	Jabal Dibi	MODS	4221	Jabal Wasmah (SE)
	3898	Dulu Alasmarah		4222	Jabal Wasmah (NE)
	3899	Al Jayb		4234	Wadi Sha (NE)
	3900	Summer Saf		4235	Wadi Sha'bah (E)
	3901	Tulqah		4246	Jabal Alqunnawat (S)
	3902	Humaymah		4247	Jabal Idhkiri (W)
	3903	Al Gharra		4249	Wadi Sha (SW)
	4220	Jabal Wasmah (S)		4250	Wadi Sha (NW)

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