DEPARTMENT OF THE INTERIOR
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Geology of the Precambrian rocks of the Jabal Habashi quadrangle, sheet 26F, Kingdom of Saudi Arabia, with a Geographic map of the Jabal Habashi quadrangle compiled by F. J. Fuller

by

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CONTENTS

ILLUSTRATIONS
Plates are in back pocket

EXPLANATORY NOTES TO THE GEOLOGIC MAP OF THE PRECAMBRIAN ROCKS OF THE JABAL HABASHI QUADRANGLE, SHEET 26F, KINGDOM OF SAUDI ARABIA, WITH A GEOGRAPHIC MAP OF THE JABAL HABASHI QUADRANGLE

COMPILED BY F. J. FULLER

by. Peter R. Johnson[1] and Paul L. Williams[2]

ABSTRACT

The Jabal Habashi quadrangle contains formations of Lower Paleozoic and Cenozoic age, unconformably overlying part of the Precambrian Arabian Shield. The Precambrian formations include metamorphosed and strongly deformed volcanic and volcaniclastic rocks and plutons of calc-alkalic, mafic to intermediate composition, dated at about 645 Ma. These are unconformably overlain by the Maraghan formation of the Murdama group, composed of sandstone and siltstone deposited in a vast sedimentary basin present in the region between about 640 to 620 Ma. On the northwestern margin of this large basin, a smaller, fault-controlled basin was filled by the Hibshi formation, a sequence of conglomerate, sandstones, tuffs and minor lava flows, which dates from 632 Ma. Other volcanic rocks from this period probably accumulated around caldera-like volcanoes.

The deposition of the Maraghan and Hibshi formations was interrupted by moderate deformation and metamorphism. About 617 Ma ago, the region was intruded by many granodiorite, granite and subordinate gabbro, diorite and peralkaline granite plutons. Gold-bearing quartz veins formed as a result of this intrusive event.

A gap in the geologic record of nearly 40 Ma followed, ended by the emplacement of more evolved syenogranite and alkali-feldspar granite plutons. Hydrothermal alteration of one of these granites led to the formation of tin greisen; other granites contain anomalous amounts of rare-earth elements.

The stable rock mass created by these geologic processes was extensively eroded at the end of the Precambrian, and was subsequently covered by flat-lying Lower Paleozoic clastic rocks, the Saq Sandstone of Cambrian (?) to early Ordovician age, and the Tabuk Formation, largely siltstone and claystone, of early Ordovician to early Silurian age. Another major gap in the record, extending from the early Paleozoic to late

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Cenozoic, ended by the extrusion of basaltic lava flows and cinder cones in the northern part of the quadrangle, about 1.8 Ma ago. The volcanic activity, preceded by tilting of the region and the stripping back of the Paleozoic rocks to expose the Precambrian again, was linked to rifting in the Arabian Shield and the opening of the Red Sea.

The final event in the quadrangle was the onset of the present-day type of climate and erosion pattern, leading to the development of drainage channels partly filled by sand and small sabkhah deposits, and surfaces covered by recently cemented gravels.

INTRODUCTION

Location and geography

The Jabal Habashi quadrangle (26F) encompasses an area of about 16,600 km^2 between latitudes 26° 00' and 27° 00' N, and longitudes 42° 00' and 43° 30' E., straddling the east-central margin of the Arabian Shield, in the north-central part of the Kingdom of Saudi Arabia (fig. 1). Late Proterozoic rocks crop out in the western and southcentral two-thirds of the quadrangle; the remaining northeastern third is underlain by early Paleozoic sedimentary rocks deposited as a cover upon the Precambrian Shield. The area of Precambrian rocks is a flat desert plain of gentle relief at an altitude of about 650-900 m above sea level broken by isolated peaks and ridges rising to 1000-1300 m, and to nearly 1400 m, at the highest elevation within the quadrangle, on Jabal Habashi, for which the quadrangle is named. The area of Phanerozoic rocks is occupied by subparallel escarpments and gentle dip-slopes formed by the almost flat-lying monoclinal sedimentary succession. Surface runoff in the quadrangle follows consequent, obsequent, and subsequent patterns and feeds into two major wadi systems; in the southern and western parts drainage is generally southwards into Wadi ar Rimah, and in the northern and eastern parts it is eastward into Wadi at Turmus.

The climate is typical of large desert areas of lower middle latitudes, characterized by hot summers with temperatures as high as 45° C, cool winters with lows of about 0° C, and marked diurnal variation in temperature during most of the year. Scant rainfall, occurring mostly between November and March, supports a desert shrub vegetation. No standing water occurs in the quadrangle, although rainstorms create intermittent lakes on the floors of sabkhahs and khabras.

The population of the area is sparse, and includes bedouins whose economy is based on the grazing of goats, sheep, and camels, and a larger sedentary population who, in addition to pastoralism, grow food crops on irrigated tracts,

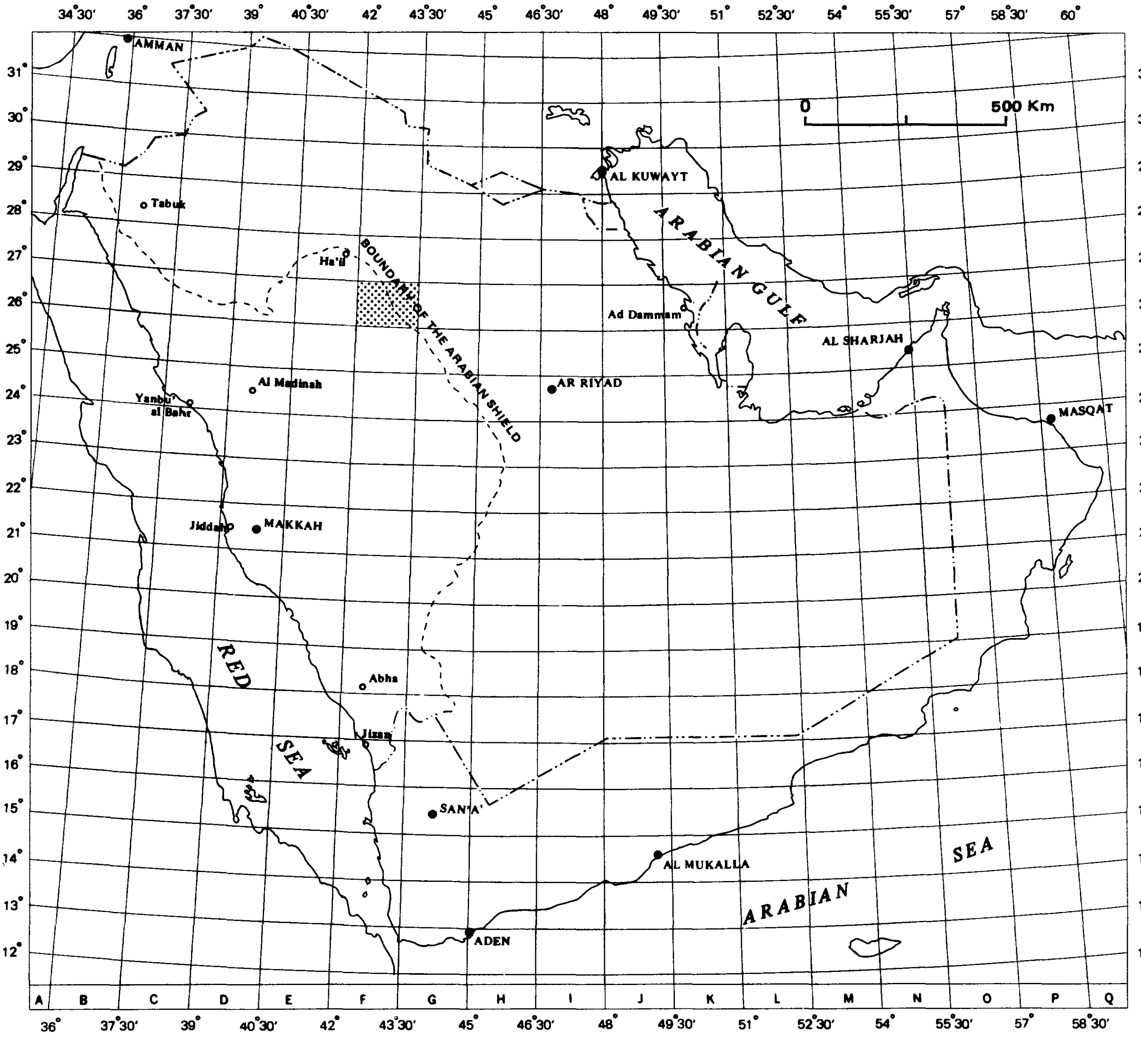


Figure 1.--Index map showing the location of the Jabal Habashi quadrangle.

particularly in the vicinity of Al Quwarah. These people live in villages of generally no more than a few hundred persons each, although Al Fawwarah, in the south-central part of the quadrangle, may approach 1000 inhabitants. Other villages include Ad Dulaymiyah in the southeast, Al Quwarah in the northeast, and Samirah in the west-central region.

A paved road, connecting Ad Dulaymiyah with the city of 'Unayzah, about 50 kilometers to the east, cuts the southeastern margin of the quadrangle, and feeds into a major east-west highway system south of the report area. Al Quwarah is linked to Buraydah and Qusayba to the east by a paved road. In the western third of the quadrangle, a new paved road is under construction running generally north-south which will connect Al Fawwarah with Samirah and then continue northwestward to the city of Ha'il, about 100 km beyond the quadrangle. The rest of the region is served by numerous unpaved dirt tracks. No commercial airports exist within the quadrangle; the nearest regular air service lands at Al-Qasim (Gassim) airport 40 kilometers east of the Jabal Habashi quadrangle.

Previous investigations

The area was first mapped in the early 1960s as part of the 1:500,000-scale geologic map of the Wadi ar Rimah quadrangle (Bramkamp and others, 1963). During the same decade much of the area was covered by an airborne magnetometer and scintillation-counter survey (BRGM, 1966). A preliminary 1:250,000-scale geologic map based on the interpretation of Landsat images was produced by Johnson (1981), but detailed mapping of the Precambrian portion of the quadrangle, at a scale of 1:100,000, was not completed until 1983 (du Bray, 1983a, Williams, 1983; du Bray, 1984a; Pallister, 1984). The petrology and petrogenesis of plutonic rocks within the quadrangle was studied by du Bray (1984b). Potassium-argon and uranium-lead dates for selected granites and volcanic rocks in the quadrangle have been published (Aldrich, 1978; Pallister, 1984; Stuckless and others, 1984), and preliminary dating results are available for other samples collected as an adjunct to detailed geologic mapping (J. C. Cole and C. E. Hedge, written commun., 1983).

The Phanerozoic rocks were previously studied by Powers and others (1966). Recent investigations include a major mapping program of the early Paleozoic "cover rocks" beyond the eastern boundary of the Arabian Shield by Bureau de Recherches Geologiques et Minieres.

Present work

The present work is a geologic compilation and a detailed summary based on the five 1:100,000-scale geologic maps covering the area of Precambrian outcrop (du Bray 1983a, in press, 1984a; Williams, 1983; Pallister, 1984, unpub. data). Field work was done with the aid of 1:60,000-scale air photos and 1:250,000-scale Landsat images, and was supplemented by standard laboratory studies. The geology was then compiled on a 1:250,000-scale Landsat mosaic base map (USGS, 1982). Correlation of the Precambrian rocks with those on the 1:100,000-scale source maps (Table 1) was aided by the results of radiometric age determinations (Pallister, 1984, unpub. data; Stuckless and others, 1984; C. E. Hedge, written commun., 1983; J. C. Cole and C. E. Hedge, unpublished data, 1983) and by the results of geologic mapping in areas immediately south and west of the quadrangle (Cole, unpub. data; Quick, unpub. data).

The layered Precambrian rocks are largely divided into formation-rank lithostratigraphic map units, defined and named in accordance with the recommendations of the Stratigraphic Code of the Deputy Ministry for Mineral Resources (DMMR, in press). Following the same code, the plutonic rocks are divided into complexes and suites. The nomenclature of the plutonic rocks, based on a study of representative thin sections and polished and stained slabs, follows the guidelines of Streckeisen (1976).

The description of mineral potential in the Precambrian rocks draws on reports by Schaffner (1956a), Mytton (1970), Matzko and others (1978), and Laurent and Al Nakhebi (1979); on the results of a regional stream-sediment geochemical survey by Allen and others (1984), on detailed studies of individual gold occurrences (Smith and Samater, 1984; Smith and others, 1984, unpub. data) and on data reported from work in progress by the Riofinex Geological Mission pertaining to tin mineralization (Riofinex, 1984).

The present work was carried out under a work agreement between the Ministry of Petroleum and Mineral Resources and the U. S. Geological Survey. The geologic map was compiled in 1983; the explanatory notes were written in 1984.

GEOLOGIC SETTING

The Jabal Habashi quadrangle includes two contrasted geologic terranes separated by a major unconformity. The southwestern two-thirds of the quadrangle is underlain by Precambrian sedimentary, volcanic and plutonic rocks, all probably of late Proterozoic age; the remaining third consists of virtually flat-lying early Paleozoic rocks resting above deformed, metamorphosed, and eroded Precambrian rocks.

The earliest Precambrian deposits include volcanic rocks, now metamorphosed to amphibolite and hornblende-feldspar-quartz schist, and sedimentary and volcanic rocks of the Bu'qaya and Qarnayn formations. The amphibolite and schist

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

Jabal Habashi 1:250,000 (This report)	Harrat al Hutaymah unpub data (Pallister, 1984)	Samirah (Williams, 1983)	Al Makhul (du Bray, 1984a)	Jabal as Sifsifah (du Bray, in press)	Jabal Saq (du Bray, in press)
		QUATERNARY-TERTIARY DEPOSITS			
Qa	Qal	Qs	Qal	Qal	Qal
Qg	--	Qg	Qaf	Qaf	--
Qtl	--	Ql	--	--	--
Qsb	--	Qsb	--	--	--
Qdc	--	--	--	--	--
Qtf	Qtf	--	Qbt	--	--
Qtr	Qtr	--	--	--	--
Qb	Qb	--	Qbt	--	--
Qc	Qc	--	--	--	--
QTgb	--	gb	--	--	--
		PALEOZOIC LAYERED ROCKS			
DSOtc	--	--	--	--	--
DSOt	--	--	--	--	DSOt
OGs	--	--	OGs	OGs	OGs
		PROTEROZOIC LAYERED ROCKS			
jb?	--	jb	--	--	--
dr	--	--	--	--	--
rql	--	rql	--	--	--
da	dc	--	--	mda	--
rr	--	--	--	rmr, mrt	--
ra	--	--	--	ma	--
tf	--	--	tf	--	--
try	--	--	mra	--	--
hs	--	hf	gw	--	--
hsc	--	hc	--	--	--
hss	hcu, hsm, hsu	--	--	--	--
hv	hvu	--	--	--	--
hvs	hsl, hvl, hvs, hcm	hf	--	--	--
hc	hcl	hbc	--	--	--
hb	hb	--	mb	--	--
hr	--	--	mr	--	--
ms	--	ha	--	mlg	--
mv	--	hap	--	--	--
mm	--	ham	--	--	--
qs	--	qs	--	qlg	--
qm	--	qm	--	--	--
qb	--	--	--	mb	--
qr	--	--	--	mr	--
qc	--	lpc	--	cg, spc	--
bs	--	--	--	blg	blg
am	am	--	am	--	--
as	--	--	--	--	--
		PROTEROZOIC INTRUSIVE ROCKS			
q	--	q	q	q	q
ap	--	--	--	ha, ap	--
afg	gag	sg	--	--	--
afsy	gap	--	--	--	--
afgs	sgr, qs	--	--	sag	--
afgm	mgh	--	--	fag, afg	um
qgy	--	ag	--	--	--
hmg	--	--	--	hmg	qm, hmg
to	--	--	to	to	--
gb	--	gb	--	--	--
df	--	df	--	--	--
dsg	--	--	--	dsg	dsg
smg	mg, mgu, mgn	mg	smg	smg	--
smgp	--	--	umg, mg	wmg	wmg
ymd	--	--	--	md	--
ydf	--	df	--	hqd, qd	--
ygd	--	gd	--	ggd, bgd, gd	tgd
yqm	--	qmd	qmd	sqm, mqm	qmz
mc	--	--	mc	--	--
mgb	--	mgb, df	--	mgb	mpr
mgbc	--	--	--	cr	--
j	--	--	--	j	--
gbo	gb	gb	--	--	--
lqd	dr	qdr	qd	--	--
sqm	--	gqmd	--	--	--
gn	--	gmg	--	--	--

were intruded by quartz diorite, approximately 645 Ma old, quartz monzodiorite, and monzogranite. Elsewhere in the Arabian Shield, volcanic, sedimentary, and associated intrusive rocks of similar age represent oceanic to continental-margin volcanic arc complexes and it is likely that these earliest rocks in the Jabal Habashi quadrangle are comparable in origin.

Younger Precambrian rocks form the Maraghan and Hibshi formations. They comprise the northernmost deposits of a large epicontinental sedimentary basin that extended some 600 km to the southeast. The basin was filled by the Murdama group, of which the Maraghan is one formation. Smaller volcanic rifts within the Murdama basin were filled with volcano-sedimentary sequences, represented in the Jabal Habashi quadrangle by the Hibshi formation, a name derived from a variant rendering of the Arabic name of the mountain. The Maraghan and Hibshi depositional basins were formed above a basement composed of the older, metamorphosed and deformed layered and plutonic rocks. The volcanic Raha formation south of the center of the quadrangle may be broadly contemporary with the Hibshi formation. The volcanic rocks are preserved in a fault zone but may have originated in a formerly more extensive caldera-like volcanic center. Plutonic rocks belonging to a second phase of magmatic activity intruded the Maraghan and Hibshi formations, and the Raha fault zone, between about 620 and 615 Ma. The plutons predominantly consist of granodiorite and monzogranite, but range in composition from gabbro to syenogranite.

The youngest Proterozoic intrusive rocks in the quadrangle are characterized by alkali-feldspar granite, part of a phase of intrusive activity widespread in the northeastern part of the Arabian Shield, between 580 to 565 Ma. Small exposures of young felsic volcanic rocks are spatially and geochemically related to the granitic rocks, and are probably extrusive analogues of the intrusive rocks. The youngest Proterozoic rocks in the quadrangle comprise a sedimentary sequence tentatively correlated with the Jibalah group. They are preserved adjacent to a west-northwest trending fault which represents some of the last effects of Proterozoic deformation in the region.

Following the cratonization of the Proterozoic rocks, an irregular erosion surface developed on the Shield, upon which Lower Paleozoic rocks of the Saq Sandstone and Tabuk Formation were nonconformably deposited. A major hiatus ensued, and subsequent geologic events in the quadrangle are represented by Tertiary to Quaternary alkali basalt lavas and pyroclastic rocks. The basalt is genetically related to rifting in the Red Sea, and forms one of several Cenozoic lava fields in Arabia. Overlying all rocks are Quaternary surficial deposits, mainly composed of alluvium and probably Early- to Middle-Pleistocene cemented gravels.

PROTEROZOIC LAYERED ROCKS

Introduction

The first geologic map of the region, by Bramkamp and others (1963), classified the layered rocks as lithostratigraphic units of formation rank, the most extensive of which they called the Murdama formation. Pre-Murdama layered rocks in the region were mapped as the Halaban formation, and post-Murdama layered rocks as the Hibshi formation and Shammar rhyolite. These names persisted as informal units in work by Brosset and Delfour (1972) immediately southwest of the quadrangle, although, in compiling their work in the 1:250,000-scale geologic map of the Nuqrah quadrangle, Delfour (1977) up-graded the Murdama and Shammar designations to group status, incorporated the Hibshi formation as the lower part of the Murdama group, and introduced the Hadiyah formation as the name for the upper part of the group.

Williams (1983) maintained the term Hibshi formation, and extended the Hadiyah formation into the southwestern part of the Jabal Habashi quadrangle. Following Delfour (1977), both formations were correlated with the Murdama group. Working farther east in the quadrangle, du Bray (1983a, in press) proposed a three-fold division of the Murdama group, thereby introducing the informal names Bu'qaya, Qarnayn and Maraghan lithic graywackes. However, in mapping immediately to the south, Cole (unpub. data) indicated that the Hibshi formation may be younger than the Murdama group, as originally mapped by Bramkamp and others (1963). Reconsideration of the stratigraphy and the metamorphic character of the rocks led Williams (unpublished map data, 1984) to the conclusion that the Qarnayn formation is older than the Murdama group, and that the Hibshi formation is demonstrably younger than both units. In the present compilation, the stratigraphy, correlation and lithostratigraphic nomenclature of the layered rocks were revised in an attempt to reconcile these variant terminologies, and incorporate current research.

Amphibolite and schist

An unnamed formation of dark-green to black foliated amphibolite (am) and strongly folded hornblende-feldspar-quartz schist containing interlayered coarse vitreous quartzite (as) crops out in low ridges and rolling hills in the west-central and central parts of the Jabal Habashi quadrangle (Williams, 1983; Pallister, 1984). The rock masses are of unknown thickness and form discontinuous exposures enclosed within plutonic rocks. The amphibolite is very fine grained and hypidiomorphic granular. In the western part of the quadrangle the rock consists of as much as 50 percent green hornblende and subordinate oligoclase, epidote, and quartz. South of Al Makhul some samples consist of intergrown quartz and feldspar, and interstitial red-brown biotite, although a more common assemblage comprises pale-green hornblende and clinozoisite set in an anhedral matrix composed of equigranular quartz and feldspar. The schist is quartz rich, commonly containing about 50 percent recrystallized quartz grains and lesser amounts of plagioclase, hornblende, and epidote-clinozoisite.

This formation is easily differentiated from all other units of layered rocks in the quadrangle by its relatively high metamorphic grade and strong deformation. It is intruded by quartz diorite dated at 646 ± 6 Ma (J. C. Cole and C. E. Hedge, unpublished data, 1983) and is unconformably overlain by the Hibshi formation. Possibly equivalent rocks of the Nuf formation in the Ha'il quadrangle are considered by Kellogg (1983) to be approximately 740 Ma old, analogous to the Afna formation of the Nuqrah quandrangle (Delfour, 1977).

Bu'qaya formation

The Bu'qaya formation (bs), a name modified from du Bray (1983a, in press) crops out at the eastern margin of the Arabian Shield between the villages of Bu'qaya and Adh Dhibiyah. It consists of steeply dipping, broadly folded sandstone interbedded with subordinate to rare siltstone and claystone. Its thickness is unknown as the base of the formation is not exposed. Near Bu'qaya, its top is drawn at a contact with stretched pebble conglomerate and pebbly graywacke of the Qarnayn formation.

The Bu'qaya sandstone is a massive to locally well-laminated, texturally and compositionally immature volcaniclastic graywacke. In general it is grayish green and fine to medium grained; silt- to medium-sand-sized clasts in the sandstone are poorly sorted and subangular, although grain size and angularity decrease up-section (du Bray, 1983a). About half the clasts are volcanic fragments; others include quartz, plagioclase, and detrital opaque oxides. Most volcanic fragments are very fine grained intermediate to felsic rocks; a few appear to be flattened and smeared-out pumiceous material. The matrix is clay-sized feldspar and local metamorphic biotite. The stable mineral assemblage indicates that this unit was metamorphosed to the lower greenschist facies.

The chemistry of the sandstone (Table 2) suggests that its volcanic component was primarily derived from a provenance of calc-alkalic composition. The formation is distinguished from the geochemically similar Qarnayn and Maraghan formations by the absence of conglomerate, and magnetic anomalies. Compared to the Maraghan formation, the Bu'qaya formation is finer grained and contains more pumiceous material, and more fine-grained, felsic-volcanic lithic fragments. In addition, the Bu'qaya formation displays a darker false-color Landsat-image tone than the Maraghan formation. Contact relations indicate that the formation is relatively older than the Qarnayn formation although its exact regional stratigraphic position is uncertain as the formation is separated from other layered rocks by the Raha fault zone or intervening intrusions.

Qarnayn formation

The Qarnayn formation, named after prominent exposures of graywacke and conglomerate at Hadb al Qarnayn (du Bray, in press), trends irregularly east-west across the central part of the quadrangle, from Bu'qaya to Jabal at Tin. The graywacke interfingers with metarhyolite and metabasalt exposed at Hadb al Qarnayn. The metavolcanic rocks are unnamed on the 1:100,000-scale geologic maps but are compiled with the Qarnayn sandstone in this report as the Qarnayn formation.

In the vicinity of Bu'qaya, the basal Qarnayn formation is graywacke and conglomerate resting on the Bu'qaya formation. Elsewhere, contacts between the Qarnayn formation and other layered rocks are faulted or obscured by younger intrusions and Cenozoic deposits; nevertheless, the greater degree of metamorphism of the Qarnayn formation suggests that it is older than the Maraghan formation of the Murdama group. Because the top is not exposed the thickness of the formation is unknown.

Sandstone

The major part of the formation consists of a poorly sorted, well-indurated, volcaniclastic graywacke (qs), characterized by scattered pebbles of resistant rock types, locally interbedded with fine-grained and finely laminated felsic and pyritic volcanic ash. The graywacke is moderately to steeply dipping, finely laminated, and appears massive to thin bedded in outcrop. Texturally and compositionally, it is varied; alternating medium- and fine-grained sandstone beds are common. The sandstone grains consist of silt- to medium-sand-sized clasts comprising quartz, potassium feldspar, plagioclase, and volcanic rock fragments. The volcanic fragments are principally very fine grained felsic volcanic material composed of quartz and feldspar and their composition is reflected in the geochemistry of the rock (Table 2). The Qarnayn contains more microcline than other sandstones in the quadrangle (du Bray, in press). Detrital and metamorphic magnetite, comprising some 5 percent of the rock, is sufficiently concentrated to cause aeromagnetic anomalies over the formation. The sandstone matrix is an assemblage of fine-grained quartz, feldspar, biotite and lesser sericite, that represents a higher metamorphic grade than found in adjacent Proterozoic sandstones in the quadrangle.

Pebbles in the sandstone are widely distributed and matrix supported. The pebbles are 2 to 5 cm in diameter and well rounded, in contradistinction to clasts in conglomerate lenses elsewhere in the formation, which tend to be stretched. The pebbles are mainly composed of very fine grained felsic to intermediate volcanic material. In places, the pebbles are so numerous that the rock is a conglomerate.

Conglomerate

Conglomerate (qc) occurs discontinuously at the base of the formation and in two places on Jabal ar Raha, higher in the succession (du Bray, in press). The conglomerate weathers grayish blue green and is densely cleaved. It is characterized, particularly in the basal lens, by deformed and stretched clasts. The conglomerate is poorly sorted and massively bedded. Near Bu'qaya the clast content decreases southwards to within a kilometer of the Raha fault zone and the rock may grade to a weakly conglomeratic facies of the Qarnayn sandstone.

The conglomerate is largely intraformational in origin; the nearly homogeneous clast population is composed of sedimentary rock much like that of the sandstone matrix, except for a few clasts of limestone and fine-grained volcanic rock and extrabasinal clasts composed of mafic plutonic rock. Mafic plutonic clasts are particularly common in the upper lenses of conglomerate, and limestone clasts form 10 to 20 percent of the population in black to dark-green thick-bedded conglomerate on the east side of Jabal at Tin (Williams, 1983). The conglomerate matrix consists of subangular grains of monocrystalline and polycrystalline quartz, trachytic andesite, argillite, metamorphic epidote, and a trace of sphene.

Rhyolite

The western end of Hadb al Qarnayn is underlain by massive reddish-brown-weathering metarhyolite (qr) (du Bray, in press). The rhyolite is interlayered with metabasalt and both volcanic units are interbedded with and overlain by Qarnayn sandstone. Therefore, the volcanic rocks are included within the Qarnayn formation.

The rhyolite consists of small salmon-colored potassium-feldspar phenocrysts, 1 to 2 mm long, in a very fine grained matrix of anhedral quartz, feldspar, biotite and hornblende. The phenocrysts form about 10 percent of the rock. Relict glass textures, including flattened pumice blocks and shards, are locally preserved. Metamorphic epidote is common, forming irregular granular clusters several millimeters in diameter, and anhedral clusters of metamorphic almandine-spessatine garnet some 5 mm in diameter, partially replaced by epidote, are locally present. Secondary sericite and carbonate are present both in the matrix and as replacement products of feldspar phenocrysts. Apatite and opaque oxides are the principal accessory minerals.

Basalt

Weakly metamorphosed porphyritic basalt (qb) crops out at Hadb al Qarnayn, and is interbedded with metarhyolite just north of Bu'qaya (du Bray, in press). It forms massive, featureless units which probably represent thick flows. The basalt is characterized by strongly zoned, subhedral to euhedral, sericitized plagioclase phenocrysts as much as 3 mm long. Hornblende occurs as rare subhedral phenocrysts some 1.5 mm in length, and as pseudomorphic grains 3 mm in diameter, probably derived from subhedral grains of primary pyroxene. The basalt matrix is composed of stubby, anhedral to subhedral plagioclase crystals 0.2 mm long, and subhedral to euhedral laths of hornblende of a similar length, or is composed of very fine-grained plagioclase and opaque oxides. Some samples of basalt contain 5 percent quartz. Locally, trachytic layering of plagioclase laths is preserved and some of the rocks contain xenocrystic quartz. The basalt has been weakly metamorphosed: hornblende is locally altered to actinolite, and epidote is present in trace amounts.

Maraghan formation of the Murdama group

The Maraghan formation, named from prominent exposures along Wadi Maraghan (du Bray, 1983b), crops out extensively in the southern quarter of the quadrangle, and continues into the adjacent Aban al Ahmar quadrangle to the south (Cole, unpub. data) and the Wadi ash Shu'bah quadrangle to the west (Quick, unpub. data). The name replaces the designation Hadiyah formation as used by Williams (1983) in the Samirah quadrangle, despite its usage for a contiguous area within the Nuqrah quadrangle (Delfour, 1977). The authors consider Delfour's (1977) correlation of Murdama group rocks in the Nuqrah quadrangle with the Hadiyah formation type area over 300 km to the west to be unwarranted, and therefore utilize a locally derived designation, the precedence of the term "Hadiyah" notwithstanding.

The formation is a monotonous sequence of slightly metamorphosed sandstone, siltstone, and shale. It is in fault contact with other units of layered rocks, but is intruded by the Aydah suite and is therefore older than 615 Ma. The sub-Murdama unconformity and basal conglomerate characterizing the Murdama group elsewhere in the eastern Shield are not exposed. Total thickness of the Maraghan formation is not determinable because of medium- to large-scale folding combined with an absence of distinctive, continuous marker units. In the Nuqrah quadrangle the Hadiyah formation is about 2000 m thick (Delfour, 1977). A section probably two or three times as thick is poorly exposed in the southwest part of the Jabal Habashi quadrangle (Williams, 1983).

Sandstone

Brownish-green to olive-gray fine-grained sandstone (ms) having the petrographic character of lithic graywacke is the dominant rock type in the formation, interbedded with subordinate medium-grained sandstone and siltstone (du Bray, in press; Williams, 1983). The sandstone is poorly sorted, and in most places is massively bedded, although finely laminated strata are locally present. The sandstone grains are angular to subangular and among them volcanic lithic clasts, containing small plagioclase phenocrysts predominate. Other clasts include quartz, plagioclase, and a few grains of felsite and turbid argillite. Potassium-feldspar grains are extremely rare and, unlike the Hibshi formation, the Maraghan formation appears to be totally devoid of fresh amphibole or pyroxene, either in volcanic fragments, or as detrital grains (Cole, unpub. data). Silt, clay, and carbonate matrix makes up 20 to 40 percent of the sandstone. The matrix is composed of turbid, fine-grained intergrowths of clay minerals; where metamorphism has been more intense, particularly near plutons, biotite is common. Locally, the matrix is replaced by calcite and (or) ferruginous cement.

Siltstone, interbedded with minor shale, crops out as green to olive-gray, thin-bedded rocks. They are commonly well cleaved, but in places an uncleaved, poorly bedded, dark-gray to brown, calcareous argillite occurs, resistant to weathering and forming strike ridges.

Lithologically, the Maraghan formation sandstone and the Bu'qaya formation are similar, and it is difficult to distinguish the two in the field. However, the Maraghan formation tends to weather more recessively than the Bu'qaya formation, and it may be slightly coarser grained and contain fewer lithic clasts of felsic volcanic composition.

Marble

Lenses of marble (mm) are sporadically present throughout the Maraghan formation (Williams, 1983), although marble is shown on the map only along the thrust separating the Maraghan and Hibshi formations in the vicinity of Jabal Witidah, at the west end of Jabal Muwashsham, and at Jabal Safaq. The rock is more common in the Aban al Ahmar quadrangle to the south (Cole, unpub. data). In general the marble is light gray and massive; locally it is tan weathering, thin bedded, and dolomitic. The lenses are commonly several tens of meters thick, but reach thicknesses of 200-300 meters near the base, and locally are tectonically thickened to as much as 500 m. On Jabal Muwashsham, adjacent to younger plutons, calc-silicate minerals resulting from contact metamorphism are locally abundant.

Andesite and basalt

Mafic volcanic rocks (mv) crop out in the Maraghan formation at Dilay Rashid and the northern end of the Silsilah ring complex. At Dilay Rashid the volcanic rock forms a distinctive lens of well-preserved pillow lava about 300 m thick. At this locale, pillow shapes indicate that the section is upright. The rocks consist of abundant fine-grained hornblende, strongly aligned by primary flowage, in a fine-grained matrix of albite and chlorite; plagioclase phenocrysts are sparse and are largely replaced by chlorite and calcite. Because of the abundance of hornblende, the pillow lava is inferred to be andesite (Williams, 1983), although vesicular rock containing a small amount of felsic pyroclastic material crops out at the Silsilah ring structure and is inferred to be basalt (du Bray, in press).

Massive, black, and fine-grained metabasalt or meta-andesite, containing very small, sparse plagioclase phenocrysts, crop out elsewhere in the quadrangle, although the units are generally too small to show on the compilation. They are interbedded with Maraghan sandstone and are particularly common south of Jabal al Muwashsham, where they probably represent either sills or lava flows (Williams, 1983).

Hibshi formation

The Hibshi formation (Bramkamp and others, 1963) crops out as a strike ridge trending from Jabal Aba al Liqah, southwest into the adjacent Wadi ash Shu'bah quadrangle (fig. 2). The type area, at Jabal Habashi, consists of a homoclinal, southeasterly dipping section of very weakly metamorphosed sedimentary and volcanic rocks. The base of the formation, drawn at a major unconformity surface developed on older metamorphic and plutonic rocks is well exposed, but the top is obliterated by younger intrusions, or cut out by thrust faulting. An aggregate thickness of 3200 m occurs at the type area (Pallister, 1984, unpub. data); farther south, at Jabal al Khidar, exposed thickness decreases to 2000 m although, by projecting eastward under alluvium to the core of the syncline along Wadi al Jufrah, a maximum of 5000 m can be estimated (Williams, 1983). The Hibshi formation becomes progressively finer grained, and probably thinner, towards the southwestern margin of the quadrangle. Overall, the formation displays many facies changes along strike; individual members pinch and swell in

Figure 2.—Photoplate showing the lower part of the Hibshi formation at Jabal Habashi

thickness and some pinch out entirely along the ridge.

Detailed research by Pallister (1984, unpubl. data) is intended to elevate the unit to formal status. In our compilation, pending acceptance of his work, the unit is treated informally. For the purpose of compilation eight map units are utilized corresponding in part with informal members defined by Pallister (1984, unpubl. data) and other authors of the 1:100,000-scale source maps (du Bray, 1984a; Williams, 1983). Because of their narrow width and the scale of the compilation, not all the informally defined members can be shown; consequently some of the units described below include two or more members. They are referred to as compilation units, and are not members in a lithostratigraphic sense.

The stratigraphic position of the Hibshi formation is uncertain. Delfour (1977) correlated polymict conglomerate at the base of the Murdama group in the Nuqrah quadrangle with conglomerate at Jabal Habashi, implying that both are part of the Murdama group. Given current knowledge, such a correlation is probably unwarranted. Although conglomerate at Jabal Habashi and in the Nuqrah quadrangle occupy a similar structural position, and rest with a profound unconformity upon metamorphosed volcanic and mafic to intermediate plutonic rocks, the two areas are separated by mapped and inferred faults. Furthermore, in contrast with the metamorphosed volcanic clasts in the basal Murdama conglomerate, volcanic material in the Hibshi conglomerate tends to be fresh, containing primary amphibole, pyroxene, and delicate high-temperature crystallization features in plagioclase (Cole, unpub. data). Also, a thick wedge of Hibshi conglomerate contains abundant clasts of Maraghan formation sandstone and siltstone (Williams, 1983). For these reasons the Hibshi formation in this report is not included within the Murdama group, but is provisionally considered a younger lithostratigraphic unit. Its absolute age is uncertain, but the formation is younger than the Laban complex of 646±6 Ma exposed beneath the sub-Hibshi unconformity, and older than the Nimriyah monzogranite of 616±10 Ma which intrudes the formation, results which are consistent with a preliminary U-Pb date of 632±6 Ma from the upper volcanic member of the formation (C. E. Hedge, written commun., 1983).

Conglomerate

This unit (hc) is equivalent to the lower conglomerate (hcl) member of Pallister (1984 unpubl. data) and basal conglomerate (hbc) of Williams (1983). The conglomerate is lenticular, and varies in thickness from 0 to 1000 m. Typically, it directly overlies crystalline rocks of the basement, although arkosic sandstone, siltstone, or ash-flow tuff locally intervene. The conglomerate is gray to dark greenish gray, or iron stained, and is composed of moderately rounded pebble- to boulder-sized clasts in an arkosic matrix. The conglomerate is crudely bedded on a meter-scale and contains upward-coarsening bedding units that grade from pebble-sized, matrix-supported, angular-to-subrounded breccia, to matrix-supported, subrounded cobble- to boulder-sized conglomerate. Mafic plutonic rocks identical to those in the underlying Laban complex form most clasts; subordinate andesitic to dacitic clasts are similar to rocks of the Hibshi volcanic members, and indicate that locally Hibshi volcanism predated deposition of the basal conglomerate. In places intraformational conglomerate is present composed of sandstone clasts.

South of Jabal al Khidar the conglomerate unit is thin and discontinuous, filling channels cut into the basement; south of Wadi Safaq the conglomerate is apparently absent, and coarse-grained sandstone layers at the base of the formation contain grit and small pebbles.

Sandstone and dacite

Clastic rocks and interbedded subordinate dacitic tuffs (hvs) crop out on Jabal Habashi and Jabal Aba al Liqah. This unit lies between the basal conglomerate and a thick sequence of tuffs in the middle of the Hibshi formation. It is a composite unit, corresponding to the lower sandstone (hsl), lower volcanic (hvl), volcanic sandstone (hvs), and middle conglomerate (hcm) members of Pallister (1984, unpub. data).

At the southern end of Jabal Habashi the lower part of the unit consists of fine- to medium-grained, poorly to moderately sorted, mostly gray, arkose and lithic graywacke interbedded with lenses of conglomerate, and maroon or green siltstone, clays and shale. These rocks correspond to the lower sandstone member of Pallister(1984, unpub. data) The unit is as much as 240 m thick on Jabal Habashi, but progressively pinches out northwards.

The arkose and lithic graywacke is overlain by conglomerate 180 m thick which also pinches out northwards. The conglomerate, equivalent to Pallister's (1984) middle conglomerate member, resembles the rudaceous rocks at the base of the Hibshi formation except that, unlike the predominance of tonalite observed in the basal conglomerate, both quartz diorite and tonalite dominate the clast population, and clasts of syenogranite gneiss and alkali-feldspar granite porphyry are present.

At the northern end of Jabal Habashi, a discontinuous horizon of dacitic welded tuff and thicker volcanic sandstone laterally replaces the arkose, lithic graywacke, and conglomerate. The dacite was mapped by Pallister(1984, unpub. data) as the lower volcanic member. It consists of a single unit of porphyritic dacitic ash-flow welded tuff as much as 110 m thick. The tuff pinches out over a few kilometers towards the northeast and is not recognized southwest of the Al Ghumrah fault. The tuff is similar to and may have originated from the same volcanic center as dacitic tuff interbedded with the overlying sandstone, and thicker felsic volcaniclastic rocks present higher in the Jabal Habashi section of the formation.

The volcanic sandstone, mapped by Pallister (1984, unpubl. data) as the volcanic sandstone member (hvl), consists of gray-green lithic wacke interbedded with lithic breccia. The sandstone is typically fissile with a fracture cleavage parallel to the bedding. It is a medium-grained rock, composed of moderately to well-sorted, subangular to very angular fragments of plagioclase, dacite, lesser diorite, minor quartz and altered hornblende. It occurs in medium to thick beds on a scale of 10 cm to 10 m. The matrix consists of silt and devitrified, altered, or recrystallized volcanic ash. The rock was probably deposited during the early stages of volcanism that produced the overlying volcaniclastic unit of the Hibshi formation.

Andesite and dacite

The resistant crest of Jabal Habashi is constructed from andesitic and dacitic volcaniclastic rocks (hv) 100 to 500 m thick, corresponding to Pallister's (1984, unpubl. data) upper-volcanic member "hvu". In the northern part of Jabal Habashi, and the southern part of Jabal Aba al Liqah, the andesite and dacite are conformably overlain by sandstone, siltstone, and conglomerate; southward however, this upper contact coincides with a thrust, and the volcaniclastic rocks are progressively cut out.

Multiple cooling units of dacitic to andesitic and sparse rhyolitic welded ash-flow tuff-breccia predominate in the unit, interbedded with subordinate ash-fall and water-laid tuff and cannibalistic volcanic siltstone, sandstone, and breccia. The welded tuffs are gray or tan on fresh surfaces, and commonly display eutaxitic textures in their basal parts. Most are densely welded at the base and grade upwards into partly welded or nonwelded tops. Plagioclase phenocrysts are ubiquitous, and hornblende phenocrysts are locally preserved although most are pseudomorphed by aggregates of biotite or epidote and chlorite. Lithic clasts in the volcaniclastic rocks are mainly composed of pumice lapilli, and dacitic volcanic and volcanic sandstone clasts, derived from contemporary volcanic activity or the reworking of earlier Hibshi volcanic and volcaniclastic rocks. Sparse dioritic fragments probably originate from the older sub-Hibshi plutonic rocks, and minor basaltic fragments may derive from the basalt member of the Hibshi formation at Jabal Aba al Liqah. Volcanic sandstone and breccia interbeds are common in the sequence; they are composed of coarse-grained, poorly to well-sorted, subangular to angular plagioclase grains and dacitic volcanic clasts in a tuffaceous matrix.

Sandstone, siltstone, and conglomerate

At the northern end of Jabal Habashi and on Jabal Aba al Liqah, the upper part of the Hibshi formation consists of sandstone and subordinate siltstone, and conglomerate (hss) conformably overlying the andesite and dacite map unit. Farther south on Jabal Habashi the sedimentary rocks are thrust over the volcanic rocks. These sedimentary rocks correspond to the upper conglomerate (hcu), middle sandstone (hsm) and upper sandstone (hsu) members of Pallister (1984, unpub. data). The original thickness of the unit is unknown because its upper part is intruded by the Nimriyah and Shuwayman monzogranite plutons, but approximately 1300 m are presently exposed (Pallister, 1984, unpub. data). The lower part of the unit consists of lenticular, interlayered beds, 1 m thick, of conglomerate, feldspathic and lithic wacke, and siltstone. Minor thin black chert interbeds, less than 10 cm thick, probably represent recrystallized water-laid tuffs.

Conglomerate overlies the interlayered sandstone-siltstone rocks and, on Jabal Aba al Liqah, oversteps them to rest directly on the andesitic-dacitic unit. It is a distinctive matrix-supported cobble conglomerate, composed of about 10 percent cobbles in a fine- to medium-grained lithic-wacke matrix. Quartz-diorite granophyre or quartz monzodiorite are the dominant clast types but, in contrast to conglomerates lower in the formation, felsic volcanic rock clasts are abundant and include inverted sanidine-quartz porphyritic rhyolite, and biotite-plagioclase porphyritic dacite (Pallister, 1984, unpub. data). Other, less abundant clast types include biotite-tonalite and tonalite-gneiss, alaskitic monzogranite aplite, fine-grained lithic wacke and quartzite. This assemblage, and the matrix composition of angular quartz and plagioclase grains, felsic and mafic volcanic fragments, and abundant chlorite, indicate that the conglomerate was derived from a mixed volcanic-plutonic source area.

The upper, greater, part of this map unit consists of feldspathic or lithic wacke. The rock is very fine to coarse grained, and composed of moderately sorted, angular to subrounded grains. On Jabal Aba al Liqah, most outcrops are massive and bedding is not apparent. Overall, the sandstone appears to fine upwards, increasing in compositional and textural maturity. Unlike sandstones elsewhere in the formation, the matrix tends to be recrystallized. It contains a relatively high proportion of biotite and includes a greenschist assemblage of quartz, feldspar, chlorite, epidote, fibrous amphibole, biotite, magnetite, and local actinolite. The elevated metamorphic grade is believed to result from the proximity of post-Hibshi intrusions (Williams, 1983).

Rhyolite

Rhyolite overlies thin conglomerate at the base of the Hibshi formation on Jabal Aba al Liqah. Referred to in the present compilation as rhyolite (hr), it corresponds to metarhyolite (mr) mapped in the Al Makhul quadrangle (du Bray, 1984a). The unit includes weakly to moderately welded, light-gray to black rhyolite tuffs, and subordinate grayish red porphyritic, massive rhyolite flows and densely welded tuffs. The tuffs contain ubiquitous flattened pumice blocks, angular lithic clasts and crystals of albite, potassium feldspar and quartz set in a very fine-grained matrix of quartz and feldspar. Primary mafic silicates have not been identified, although very fine grained anhedral aggregates of both chlorite and epidote compose part of the matrix.

The relationship between the rhyolite and the adjacent andesite and dacite unit (hv) is uncertain. The considerable lithologic variation evident along strike and vertically within the Hibshi formation makes direct correlation difficult. Furthermore, the rhyolite represents a rock considerably more evolved than the andesite and dacite, as indicated by the greater abundance of microcline and quartz phenocrysts in the rhyolitic unit. On this basis it is inferred that the two units originated at different volcanic centers (Pallister, 1984, unpubl. data). The limited geochemical data available (du Bray, 1984a) indicate that the felsic volcanic rocks of the Hibshi formation belong to the high-potassium calc-alkalic series of Peccerillo and Taylor (1976) (fig. 3).

Basalt

The rhyolite of the Hibshi formation in the Jabal Aba al Liqah area is overlain by basalt (hb). Locally, 2 to 5 m of poorly sorted conglomerate containing clasts of quartz diorite, tonalite, granodiorite, and the underlying rhyolite, and a zone of interbedded basalt, rhyolite, and sandstone separate the two units. The basalt corresponds to a unit of metabasalt described by du Bray (1984a). Unlike the rhyolite unit (hr), the basalt unit has no lithologic counterpart elsewhere in the Hibshi formation. Geochemically the mafic rocks belong to the low-potassium calc-alkalic series of Peccerillo and Taylor (1976) (fig. 3), and together with the rhyolitic rocks, represent a bimodal volcanic suite originating at an ancient volcanic center in the vicinity of Jabal Aba al Liqah. The rock is dark gray and internally structureless. It forms thick massive flows of trachytic layered porphyritic basalt, composed of euhedral plagioclase and subordinate hornblende or clinopyroxene phenocrysts in an intergranular matrix of very fine grained chlorite, plagioclase, and opaque oxides. The mafic minerals are partly chloritized. Metamorphic anhedral grains of epidote and clinozoisite constitute between 1 and 10 percent of the rock.

Sedimentary clast conglomerate

The Hibshi formation contains a variety of conglomerates that are differentiated by their clast/matrix proportions and clast compositions. One of the more distinctive conglomerates forms the bulk of Jabal al Musawda'ah (hsc) (Williams, 1983). It consists almost entirely of sedimentary rock clasts derived from the Maraghan formation. These include fragments of fine-grained sandstone, siltstone, and shale in a coarse- to fine-sand matrix. Pebbles of marble, plutonic rocks, and chloritic vein quartz are rare. The clasts are subangular to subrounded, and range from 1 cm to 22 cm in diameter. The conglomerate is over 2000 m thick, and in some exposures several upward-fining cycles, each several meters thick, can be observed. The unit is faulted against the Qarnayn formation on the east but clearly conformably underlies sandstone of the Hibshi formation in the western part of Jabal al Musawda'ah, where the rocks form the eastern limb of the Jufrah syncline. The clasts are subangular to subrounded, and range from 1 cm to 22 cm in diameter.

Sandstone, undivided

Between Jabal al Khidar and Jabal Witidah, and extending northeast on the flanks of the Nimriyah and Shuwayman plutons, the Hibshi formation is compiled as a unit of undivided sandstone (hs). The rock closely resembles sandstone units elsewhere in the formation and, in the vicinity of the type area, the boundary between the undivided sandstone and other units of the formation is arbitrary. Southwest of Jabal Habashi the sandstone is in contact with the basal conglomerate or rests directly on the underlying crystalline basement and represents the entire Hibshi formation (Williams, 1983). The unit consists of dark-green and medium- to coarse-grained lithic sandstone in beds several meters thick, rare interbeds of recessively weathering shale and siltstone, and common beds of intraformational conglomerate composed of angular green shale clasts. Rock fragments, making up 45 percent of the sandstone, are dominantly of volcanic origin, and match with the basaltic to rhyolitic rocks elsewhere in the formation.

Turmus formation

The Turmus formation underlies the northcentral part of the quadrangle as a sequence of interbedded medium-dark-gray volcanic and clastic rocks (tf). The formation is named after particularly good exposure of the rocks about 15 km west of Wadi at Turmus (du Bray, 1984a). The rocks are moderately to vertically dipping, and disposed in broad, open folds. Contacts with adjacent rocks are not well exposed; the formation appears to be extensively intruded by plutonic rocks of the Makhul complex, but along its western margin may be in depositional contact with the Laban complex. It is believed to be broadly contemporaneous with the Hibshi formation. The overall thickness of the Turmus formation is unknown.

The formation is only weakly metamorphosed and the original lithology of the rocks is easily discerned. About 50 percent of the formation consists of andesite, 30 percent of andesitic tuff and agglomerate, and 20 percent of lithic graywacke; conglomerate forms a minor part of the formation. Hypabyssal dikes and sills of rhyolite (try) are locally common.

The andesite and agglomerate are both massive. Characteristically the flow rocks contain subhedral phenocrysts of plagioclase, 0.2 mm to 5 mm long, and anhedral to subhedral hornblende, as much as 1.5 mm long, set in an intergranular to felted matrix of very fine-grained plagioclase, opaque oxides, chlorite, amphibole and secondary calcite. Primary pyroxene is replaced by metamorphic epidote in isolated grains and clusters. The flow rocks grade progressively into and are interbedded with andesitic tuff and agglomerate composed of poorly sorted and subangular andesite clasts. Chemically the andesitic rocks resemble present-day calc-alkalic lavas (Table 2, fig. 3).

In contrast to the volcanic rocks, sandstone in the Turmus formation is generally well bedded, forming units 0.5 cm to 10 cm thick. The sandstone is a texturally and compositionally immature lithic graywacke derived from the volcanic rocks. It closely intertongues and is locally gradational with the flow and fragmental rocks.

Small lenses of polymict conglomerate are sparsely present in the Turmus formation. They include subangular to subrounded pebbles and cobbles of granodiorite, granite, and subordinate metavolcanic rock in a well-indurated matrix of sand grains.

Rhyolite and quartz latite

Porphyritic rhyolite and quartz latite (rql) crop out in low hills west of Wadi Samirah at the western margin of the Jabal Habashi quadrangle (Williams, 1983), and more extensively in the Wadi ash Shu'bah quadrangle to the west (Quick, unpub. data). The rocks are pink, red, and gray and form irregular, apparently steeply dipping, bodies. They are mostly felsic lava flows, although some are pyroclastic. One typical red unit consists of pink orthoclase and pale-pink sericitized plagioclase phenocrysts in a very fine-grained groundmass mosaic of quartz and feldspar. The gray units consist of phenocrysts of quartz, orthoclase, partly sericitized plagioclase, and slight amounts of biotite and green hornblende, in a fine-grained quartz-feldspar groundmass. The relationships between the rhyolite and quartz latite and their adjacent map units are not clear. Contacts are mainly obscured by alluvium and colluvium, although at one locality, immediately west of the quadrangle, pink rhyolite appears to intrude the Samirah monzodiorite, a relationship suggesting a hypabyssal origin for part of the unit (Williams, 1983). Because of their generally fresh, unmetamorphosed nature, these felsic rocks are considered to be relatively young. They may be of an age similar to or slightly younger than the Hibshi formation but appear to be older than the Hadn formation in the Wadi ash Shu'bah quadrangle (Quick, unpub. data).

Raha formation

Jabal ar Raha, in the south-central part of the Jabal Habashi quadrangle, is underlain by weakly metamorphosed rhyolite (rr) and subordinate andesite (ra) which are combined as a map-unit of formation rank by du Bray (in press), replacing the earlier Shammar group designation of Bramkamp and others (1963). Because of Cenozoic surficial cover, the relationship of the volcanic rocks to other map units in the quadrangle is uncertain, although andesitic and rhyolitic dikes included in the formation cut, and are therefore younger than, the Qarnayn formation. Furthermore, on the basis of its lesser degree of metamorphism, the Raha formation is very likely to be younger than the Maraghan formation, and may be coeval with the post-Murdama plutons which intrude the Raha fault zone.

Felsic volcanic rocks predominate in the formation, as brick-red-weathering metarhyolite porphyry (rr) containing salmon-colored microcline phenocrysts. The rock is holocrystalline and allotriomorphic granular; it locally displays micrographic texture. Euhedral microcline phenocrysts, as much as 5 mm long, and quartz phenocrysts, up to 1 mm in diameter, are set in a fine-grained, inequigranular matrix composed of poorly crystallized quartz and feldspar. Ragged and altered biotite flakes, as much as 0.4 mm long, locally comprise about 1 percent of the rock. The accessory mineral suite includes opaque oxides and a trace of zircon.

Near the center of Jabal ar Raha, metarhyolite tuff occurs in the rhyolite unit and is composed of euhedral phenocrysts of potassium feldspar as much as 1.5 mm long in a very fine-grained devitrified matrix of quartz and feldspar. The feldspar phenocrysts form about 5 percent of the rock; poorly formed phenocrysts of quartz and biotite, altered to chlorite, are less common. Relict glass structures and collapsed pumice blocks are locally preserved in the matrix, although much of the unit is stained reddish orange, probably due to deuteric alteration.

Small bodies of andesite porphyry (ra) are interbedded with the rhyolite. They occur as dark-gray-weathering, massive rock, locally characterized by trachytic layering. Conspicuous white plagioclase phenocrysts, 1 to 2 mm long, and smaller hornblende phenocrysts, occur in a very fine-grained matrix of feldspar and quartz. Most of the andesite probably represents flow rocks, although andesite porphyry dikes occur in some places. Samples of the formation are relatively rich in their alkali contents (Table 2) and plot in the field of high-potassium, calc-alkalic series lavas (fig. 3).

Dacite

A prominent black hill in the southern part of the quadrangle near Wadi Waqt is underlain by very slightly metamorphosed, dark-gray, distinctly porphyritic metadacite (da) (du Bray, in press). There is no obvious internal structure in the unit. Moderately zoned anhedral to subhedral phenocrysts of plagioclase are set in a devitrified, allotriomorphic granular matrix composed of quartz and feldspar. Biotite and hornblende, in approximately equal proportions, occur in ragged, fine-grained clusters. Zircon, opaque oxides, and apatite are the accessory minerals. The age relations between the dacite and other layered rocks in the quadrangle are unknown, but its discordant relation to the Maraghan formation suggests that it postdates the Murdama group.

Dacite and rhyolite

Dacite and rhyolite (dr) crop out in a narrow lenticular belt on the margin of the Gusal alkali-feldspar granite, northwest of Samirah village (Pallister, 1984, unpub. data). In the northern part, the belt contains eutaxitic welded tuff that is intruded by hornblende-biotite-plagioclase porphyritic dacite dikes which also cut the margin of the Gusal pluton. Towards the south, the rocks consist of plagioclase-sanidine (inverted) porphyritic rhyolite tuff and biotite-hornblende-plagioclase porphyritic dacite. The presence of pilotaxitic and granophyric groundmass textures indicates a lava-flow origin for some of the dacites (Pallister, 1984, unpub. data).

The age of the dacite and rhyolite is uncertain. The flow rocks appear to unconformably overlie the Kilab pluton, but are intruded by the Gusal alkali-feldspar granite, whereas dacite dikes with a phenocryst mineralogy similar to the dacite flows and therefore probably of common origin cut the pluton. These intrusive relationships suggest that the volcanic rocks and the Gusal alkali-feldspar granite are broadly coeval. Furthermore, the rhyolitic composition of some of the rocks is chemically equivalent to samples of the alkali-feldspar granite (Pallister, 1984, unpub. data) for which reason the dacite and rhyolite are tentatively considered to be the extrusive equivalents of the Gusal pluton.

Jibalah group (?)

Opposite the south end of Jabal al Khidar, at Wadi al Jufrah, steeply dipping sedimentary rocks that strike parallel to a west-northwest-trending, Najd-type, fault are tentatively assigned to the Jibalah group (jb?) (Williams, 1983). The rocks consist of dark-gray pebbly siltstone and sandstone. Principal framework constituents are quartz, feldspar, and lithic fragments. The fragments consist of granule- to pebble-sized, angular to subrounded, polycrystalline quartz grains, metachert, siltstone, and calcite-quartz aggregates closely resembling material from quartz veins in the Maraghan formation, as well as assorted types of volcanic rocks. The matrix comprises angular, silt-sized particles set in fine-grained sericite, chlorite, and quartz, containing some calcite. Locally pyrite makes up about 1 to 2 percent of the rock.

Because of its lithology and its position adjacent to a presumed Najd structure, the unit is tentatively assigned to the Jibalah group of Delfour (1970) which, in the Al Jifn syncline within the Nuqrah quadrangle, contains similar sandstones (Delfour, 1977).

Depositional environments of the layered rocks

Four depositional environments are represented by the Proterozoic layered rocks of the Jabal Habashi quadrangle. From oldest to youngest they include an oceanic volcanic environment, part of a large molasse basin, an epicratonic volcano-sedimentary rift, and an inferred caldera-derived volcanic field.

The oceanic environment is represented by the amphibolite and quartzofeldspathic schist exposed beneath the Hibshi formation. Geochemical and petrologic details or the original disposition of these rocks are unknown but it is possible that they represent a dismembered calc-alkalic volcanic arc, similar to pre-Murdama volcanic arcs common elsewhere in the Arabian Shield (Schmidt and Brown, 1982). The arc rocks closest to the present outcrops are the tholeiitic Nuf formation in part of the Ha'il quadrangle (Kellogg, 1983), some 95 km to the northwest, the Birkah formation in the Wadi ash Shu'bah quadrangle, some 45 km to the west (Quick, unpub. data), and the Saydun formation in the Aban al Ahmar quadrangle, over 70 km to the south (Cole, unpub. data).

The Bu'qaya and Qarnayn formations are less metamorphosed and deformed than the amphibolite and quartzofeldspathic schist, and therefore appear to be younger. However, because of their volcanic provenance, and because they likely constitute earlier formations than the Maraghan formation of the Murdama group, the Bu'qaya and Qarnayn formations are considered to relate to the volcanic-arc environment, rather than to the large molasse basin of the Murdama group.

The texture, composition and commonly massive appearance of the volcaniclastic graywacke of the Bu'qaya formation suggest that the rock was deposited mainly from proximal turbidites. Geochemically, the graywacke approximates a dacitic calc-alkalic volcanic rock (Table 2, fig. 3); because of the abundance of volcanic fragments in the rock, its composition is believed to reflect the composition of the volcanic source (du Bray, in press).

The Qarnayn formation represents continued deposition of volcaniclastic graywacke. However, felsic volcanic fragments and microcline are more abundant than in other sandstones in the region, implying that the sediment was derived from a more evolved volcanic terrane than, for example, the earlier Bu'qaya formation. Intrabasinal erosion and reworking of sediment during deposition of the sandstone resulted in sandstone-clast conglomerate, and similar erosion of volcanic rocks within the Qarnayn formation may have provided a significant part of the detritus forming the sandstone. Influx of sediment from extrabasinal sources also occurred however, as evidenced by a few clasts of mafic plutonic rocks and grains of metamorphic epidote. The pervasive diamictic texture of the sandstone suggests that much of the rock was formed by mass-flow transport; lenses of conglomerate were deposited in local depressions and were associated with the development of minor unconformities. The occurrence of basalt and dacite in the formation implies the presence of an ancient volcanic center in the vicinity of Hadb Qarnayn. Geochemically the rocks resemble present-day calc-alkalic-series lavas (Table 2, fig. 3).

The Maraghan formation is separated from older rocks by an orogenic episode which resulted in partial cratonization of the older volcanic and volcaniclastic rocks, and the replacement of an oceanic depositional environment by a largely continental one. Outside the quadrangle, a major unconformity at the base of the group is generally well exposed, and Murdama group deposition began with a polymict conglomerate. Because of faulting, neither basal contact nor basal conglomerate are exposed within the Jabal Habashi quadrangle, but it is inferred that the Maraghan formation rests unconformably upon a basement formed by the Qarnayn and Bu'qaya formations, and other units of layered and plutonic rocks. Marble is common in the basal part of the Maraghan formation. Du Bray (in press) concluded that the characteristics of the Maraghan sandstone are typical of deposits formed by the rapid subaqueous deposition of large volumes of chemically and texturally immature detritus derived from a volcanic provenance of intermediate composition (Table 2, fig. 3). The fine-to-medium grain size of the rocks, and their homogeneous

Table 2.--Major element analyses and CIPW norms (calculated for analyses normalized to 100 percent, anhydrous), for selected metasedimentary and metavolcanic rocks in the Jabal Habashi quadrangle, sheet 26F

[Analyses by X-ray Assay Laboratories Ltd., Don Mills, Ontario, Canada. All determinations by x-ray fluorescence except FeO, which was determined by wet chemistry. FeO/Fe_2O_3 ratio adjusted prior to norm calculation using guidelines proposed by Irvine and Barager (1971). Chemical analyses given below are pre-adjustment values. All values are in weight percent.]

	BU'QAYA FORMATION	QARNAYN FORMATION					MARAGHAN FORMATION				
unit:	lithic graywacke	lithic graywacke		basalt		dacite	lithic graywacke				
Sample number	181392	181198	181232	181330	181343	181344	181071	181087	181098	181161	181191
Latitude: N. 26°	19'23"	23'31"	17'41"	27'20"	24'28"	26'41"	13'18"	11'54"	04'16"	05'04"	13'48"
Longitude: E. 42°	58'39"	37'11"	38'46"	53'12"	45'28"	44'41"	46'42"	54'03"	50'30"	32'02"	35'32"
CHEMICAL ANALYSES											
SiO_2	63.7	64.6	60.4	51.9	48.6	67.7	60.1	58.5	63.8	50.8	58.1
Al_2O_3	15.2	14.8	16.2	19.3	17.0	15.7	15.7	17.2	16.2	14.6	15.9
Fe_2O_3	2.23	3.09	3.51	4.01	4.55	1.77	1.69	1.89	1.55	2.06	3.66
FeO	3.50	2.10	2.9	4.80	4.90	0.70	4.50	4.70	3.60	6.80	3.80
MgO	3.22	2.62	2.97	3.85	7.47	0.60	3.68	2.77	2.14	8.27	3.44
CaO	2.66	2.68	5.26	9.15	11.4	1.44	2.12	4.86	1.88	6.61	3.22
Na_2O	4.01	3.53	2.93	3.04	2.26	5.07	3.91	3.83	6.05	2.15	4.65
K_2O	1.75	2.40	2.17	0.39	0.43	4.29	1.65	1.25	1.48	2.45	1.49
TiO_2	0.75	0.65	0.87	1.12	0.70	0.60	0.88	0.86	0.69	0.83	0.88
P_2O_5	0.18	0.18	0.25	0.23	0.15	0.11	0.22	0.20	0.19	0.17	0.24
MnO	0.08	0.08	0.12	0.13	0.15	0.07	0.08	0.09	0.10	0.14	0.12
LOI (loss on ignition)	1.62	2.62	1.85	0.62	1.23	0.77	3.62	2.85	2.31	4.31	2.93
TOTAL:	98.9	99.4	99.4	98.5	98.8	98.8	98.2	99.0	100.0	99.2	98.4
CIPW NORMS											
Q	22.4	25.1	18.4	5.7	0	18.5	20.3	15.5	14.7	0.1	11.5
C	2.4	2.0	0.1	0	0	0.4	4.4	1.2	1.7	0	1.4
or	10.6	14.6	22.1	2.3	2.6	25.8	10.3	7.6	8.9	15.1	9.2
ab	34.8	30.8	44.5	26.2	19.5	43.7	34.8	33.5	52.2	19.0	41.1
an	12.3	12.5	3.6	38.5	35.7	6.5	9.6	23.6	8.2	24.0	15.0
wo	0	0	0	2.6	8.8	0	0	0	0	3.8	0
en	8.2	6.7	7.6	9.8	14.5	1.5	9.6	7.1	5.4	21.5	8.9
fs	4.2	3.2	4.7	8.3	8.6	0	5.4	5.7	4.1	10.7	6.9
fo	0	0	0	0	3.2	0	0	0	0	0	0
fa	0	0	0	0	2.1	0	0	0	0	0	0
mt	3.3	3.2	3.5	3.9	3.3	0.8	3.3	3.5	2.9	3.5	3.6
hm	0	0	0	0	0	1.4	0	0	0	0	0
il	1.5	1.3	1.7	2.2	1.4	1.2	1.8	1.7	1.6	1.6	1.7
ap	0.4	0.4	0.6	0.6	0.4	0.3	0.5	0.5	0.5	0.4	0.6

Table 2.--continued.

unit:	dacite	rhyolite	basalt		andesite		rhyolite	andesite
	HIBSHI FORMATION				TURMUS FORMATION		RAHA FORMATION	
Sample number	181596	181631	181593	181630	181670	181674	181221	181273
Latitude: N. 26°	44'11"	46'23"	44'07"	45'57"	52'08"	50'17"	16'15"	18'07"
Longitude: E. 42°	31'36"	33.35"	32'40"	34'53"	36'19"	40'00"	49'15"	46'45"
CHEMICAL ANALYSES								
SiO_2	67.9	72.3	52.2	51.0	61.2	55.9	72.1	57.4
Al_2O_3	15.0	13.4	15.9	18.8	16.1	17.9	13.9	13.9
Fe_2O_3	4.04	2.72	5.05	4.86	2.54	4.41	0.95	1.40
FeO	0.20	0	3.20	3.20	2.60	2.10	0.60	4.50
MgO	0.22	0.08	5.58	4.22	3.32	3.26	0.46	4.70
CaO	0.80	0.34	7.87	7.58	4.11	6.34	0.77	4.75
Na_2O	4.85	5.44	3.67	3.20	4.49	4.24	5.15	3.08
K_2O	4.45	3.89	1.12	0.86	1.93	1.96	3.66	2.64
TiO_2	0.55	0.27	1.19	1.02	0.74	0.88	0.23	0.65
P_2O_5	0.12	0.05	0.26	0.31	0.24	0.24	0.05	0.22
MnO	0.03	0.06	0.13	0.14	0.13	0.10	0.05	0.08
LOI (loss on ignition)	1.23	0.62	1.93	2.93	1.08	1.00	1.08	5.39
TOTAL	99.4	99.2	98.1	98.1	98.5	98.3	99.0	98.7
CIPW NORMS								
Q	20.9	25.6	2.5	5.1	14.0	5.6	26.5	12.2
C	1.1	0	0	0	0	0	0.02	0
or	26.8	23.3	6.9	5.4	11.7	11.9	22.1	16.6
ab	41.9	46.8	32.4	28.5	39.0	36.9	44.5	27.8
an	3.3	0.7	24.6	36.2	18.6	24.7	3.6	17.4
wo	0	0.3	6.0	0.5	0.3	2.5	0	2.6
en	0.6	0.2	14.5	11.1	8.5	8.4	1.2	12.5
fs	1.1	0	6.1	6.6	2.5	4.1	0	6.1
fo	0	0	0	0	0	0	0	0
fa	0	0	0	0	0	0	0	0
mt	3.0	2.2	4.1	3.8	3.3	3.6	1.5	2.9
hm	0	0.3	0	0	0	0	0.03	0
il	1.1	0.5	2.4	2.0	1.4	1.7	0.5	1.3
ap	0.3	0.1	0.6	0.8	0.6	0.6	0.1	0.6

Sources of data: Bu'qaya, Qarnayn, Maraghan and Raha formations- du Bray, in press
Hibshi and Turmus formations- du Bray, 1984a.

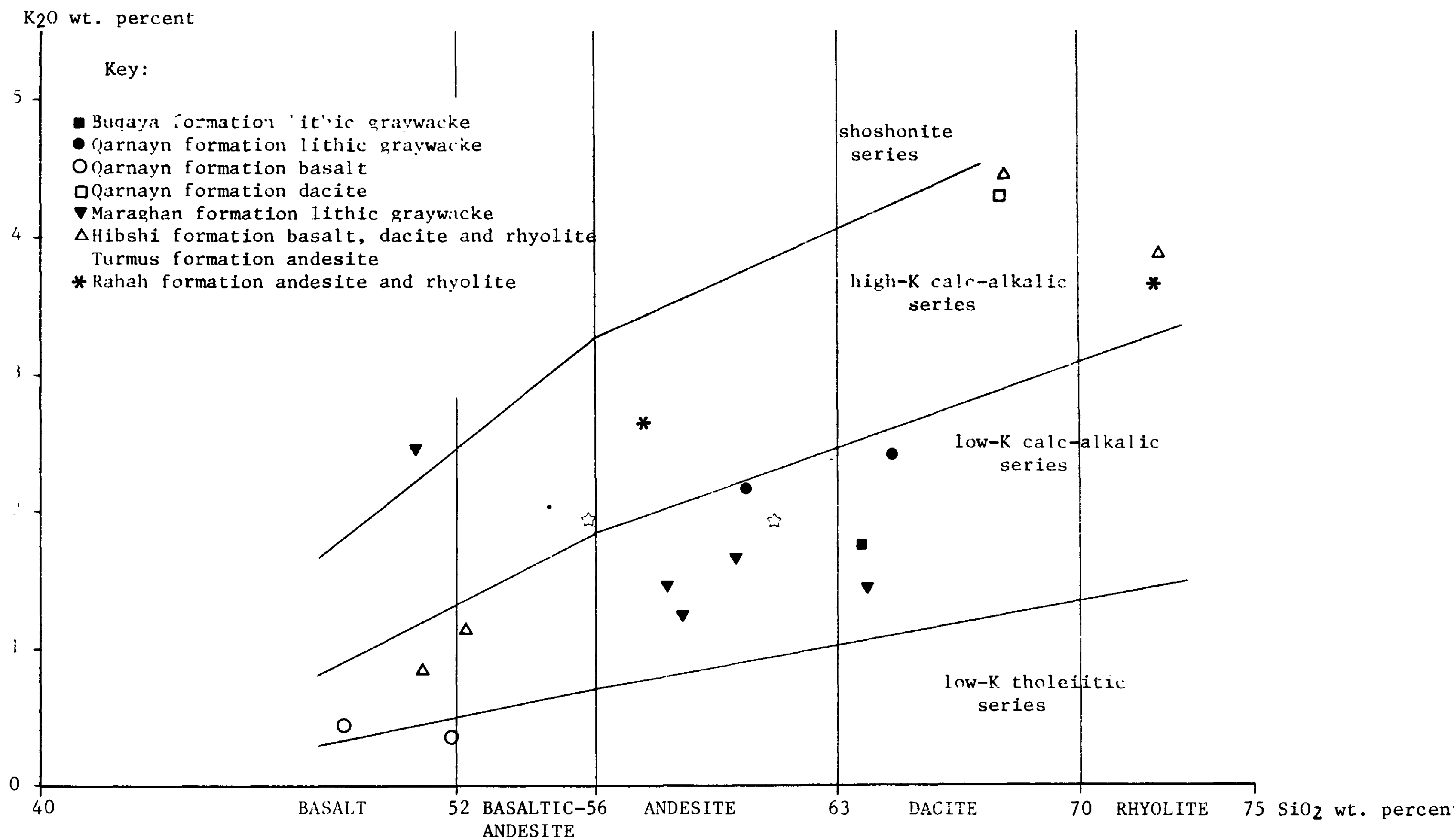


Figure 3--Plot of silica-potash contents of the layered rocks from the Jabal Habashi quadrangle, sheet 26F. (boundaries and nomenclature after Peccerillo and Taylor, 1976). Sources of data: du Bray, in press, 1984

character, suggest that they accumulated in a stable basin at some distance from the source of sediment. Volcanism in the Maraghan basin was of localized extent, resulting in lenses of pillow lava and pyroclastic rocks.

In contrast to the Maraghan formation, the unconformity at the base of the Hibshi formation is very well exposed. The formation is extremely heterogenous, and represents a volcano-sedimentary sequence which accumulated close to source. The dominant clastic source was the sub-Hibshi basement stretching west and north from the present outcrops of the Hibshi formation. Mafic plutons in the basement supplied 70 percent of the clasts in the basal conglomerate and a large proportion of clasts in other conglomerate units; they also supplied lithic fragments and grains of plagioclase and hornblende to Hibshi sandstones. However the nature of clasts in conglomerate in the middle and upper parts of the formation indicate that the composition of this dominant source changed as sedimentation proceeded. Evolved granites became exposed in the source area during mid-Hibshi time and, towards the end of Hibshi deposition, evolved felsic volcanic rocks became an important source of detritus.

Volcanic rocks formed a second source of clastic grains in the Hibshi formation. The unmetamorphosed nature of the volcanic fragments demonstrates that they were not derived from a pre-Murdama volcanic-arc sequence. Instead, it is indicated by their composition that they were likely derived from the intermediate and bimodal basalt and rhyolite volcanic centers in the vicinity of Jabal Habashi and Jabal Aba al Liqah. A third source of sedimentary material was provided by the Maraghan formation. The importance of this source is difficult to gauge, but the thick conglomerate at Jabal al Musawda'ah was derived almost entirely from this provenance.

The sedimentary rocks of the Hibshi formation were deposited in a high-energy environment in a confined epicontinental basin. The deposition resulted in lenticular bedding units, local cross-bedding, lenses of conglomerate in erosion channels, and the reworking of earlier sediment. The surface of deposition varied from subaqueous to subaerial, and both ripple marks and raindrop imprints are locally preserved. The morphology of the basin was probably controlled by faulting, and it had the character of a volcanic rift (Cole, unpub data). leading to the observed intertonguing of clastic rocks and ash-flows, mafic lavas, and their reworked derivatives adjacent to caldera-like volcanic centers (Pallister, 1984 unpub data).Differential uplift of the basin margins would cause differential exposure of bedrock and result in the observed variation of clast lithologies in the sequence (Williams, 1983).

The youngest layered Proterozoic rocks in the quadrangle are predominantly volcanic in origin, and most likely were originally associated with caldera formation (du Bray, in press). They represent the fourth type of depositional environment in the quadrangle. The present-day outcrop of the Raha formation is interpreted to represent the southern part of a caldera-like volcanic edifice preserved within the Raha fault zone (du Bray, in press). Some of the Raha rhyolite occurs as an arcuate intrusion, having textural features indicative of rapid crystallization, of the type associated with pressure quenching, and compatible with emplacement in a subcaldera ring fracture. Pyroclastic rock at the north-central end of Jabal ar Raha may represent material deposited within the inferred caldera.

The chemical similarity and intrusive relationships between the Gusal pluton and the discontinuous unit of dacite and rhyolite on its eastern margin, lead Pallister (1984, unpub. data) to suggest that the area of the Gusal alkali-feldspar granite may have been a small volcanic center. The ash and lava flows present may have originated from feeder dikes controlled by a ring fracture. By analogy with the intracaldera volcanic and resurgent-dome intrusive rocks described in the Baq'a' quadrangle just to the north (Kellogg, 1984), Pallister envisages that the extrusive phase was followed by caldera collapse and a resurgence of the main Gusal pluton. A similar volcano-tectonic setting may account for the rhyolite and quartz latite depicted on the western boundary of the Jabal Habashi quadrangle.

PROTEROZOIC INTRUSIVE ROCKS

Introduction

Proterozoic intrusive rocks comprise over half of the exposed area of Arabian Shield in the Jabal Habashi quadrangle. On the basis of mapped and inferred contacts, absolute and relative ages, characteristic compositions, and textural and structural features, the intrusive rocks are divided into more than fifteen map units, including suites, complexes, and other named intrusions. The units crop out as some forty plutons (fig. 4) ranging in area from less than 1 km^2 to more than 1000 km^2. In gross aspect the plutons are similar to the calc-alkalic and subordinate alkalic and peralkalic granitoid intrusive rocks that form a major part of the Arabian Shield (Schmidt and Brown, 1982). Plutons of monzogranite and granodiorite are the most numerous and areally extensive in the quadrangle, although syenogranite and alkali-feldspar granites are important in the northwest and south, and small bodies of diorite and gabbro have been mapped throughout.

The plutons were emplaced during three principal episodes. Small gabbro bodies, and plutons of quartz diorite, quartz

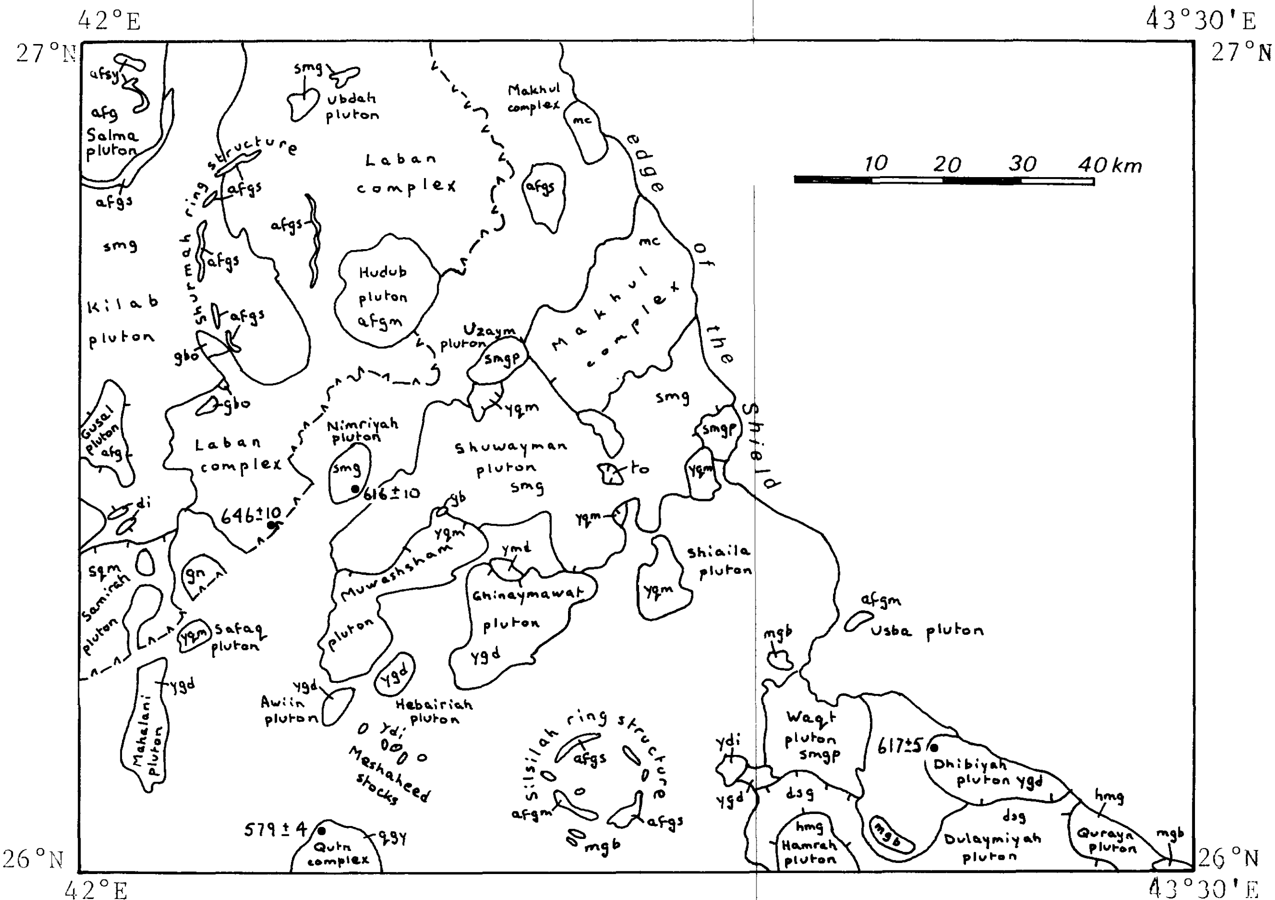


Figure 4--Simplified map of the Proterozoic intrusive rocks in the Jabal Habashi quadrangle: relative ages are shown by a tick on the side of older, intruded rocks; —^—^— marks the sub-Hibshi and sub-Turmus unconformities; • radiometric age.

Pre-Murdama intrusive rocks: ☐
gneissic monzogranite (gn); Samirah quartz monzodiorite (sqm); Laban complex (lqd); gabbro (gbo)

Post-Murdama intrusive rocks: ☐
metagabbro (mgb); Makhul complex (mc); Aydah suite quartz monzodiorite (yqm), granodiorite (ygd), diorite (ydi), monzodiorite (ymd); Shuwayman suite biotite monzogranite (smg), porphyritic monzogranite (smgp); Dulaymiyah syenogranite (dsg); tonalite, gabbro and diorite (to, gb, di)

Post-kinematic intrusive rocks: ☐
Hamrah monzogranite (hmg); Qutn complex syenogranite (qgy); alkali-feldspar granite suite, alkali-feldspar granite (afg), muscovite-bearing alkali-feldspar granite (afgm), soda-pribole-bearing alkali-feldspar granite (afgs), alkali-feldspar quartz syenite granophyre (afsy)

monzodiorite and monzogranite were emplaced and unroofed prior to deposition of the sandstones and conglomerates of the Maraghan and Hibshi formations. These plutons are minimally 645 Ma old (J. C. Cole and C. E. Hedge, unpublished data, 1983) and are referred to as pre-Murdama intrusions. The second group of plutons, the largest and compositionally most diverse of the three, range from gabbro to syenogranite. Referred to as the post-Murdama plutons, they intrude the older intrusive rocks and the layered Maraghan and Hibshi formations. Preliminary results of radiometric studies indicate that the granodiorite and monzogranite plutons in the group were emplaced about 615 Ma ago (J. C. Cole and C. E. Hedge, unpublished data, 1983). The final episode of plutonism consists of several small intrusions of monzogranite, syenogranite, and highly evolved alkali-feldspar granite. These intrusive bodies constitute a postkinematic group, so called because their mineral textures, and their round to smoothly elliptical outlines demonstrate an absence of post-crystallization deformation. On the basis of rubidium-strontium data for the region, the postkinematic plutonic episode occurred between 580 and 565 Ma ago (Stuckless and others, 1984).

Other intrusive rocks in the quadrangle include dikes of diverse ages and composition, quartz veins, small bodies of mafic to ultramafic rock emplaced along the Raha fault zone, and scattered gabbro stocks, some of which are of probable Tertiary age.

Geologic details concerning the intrusive rocks shown in the compilation are provided in the 1:100,000-scale source maps, but a major petrochemical study of the rocks by du Bray (in press) has been utilized extensively in preparing this section of the report.

Pre-Murdama intrusive rocks

Gneissic monzogranite

A pluton of gray, sheared, weakly gneissic monzogranite (gn), 7 km across, crops out west of the southern end of Jabal al Khidar (Williams, 1983). The pluton intrudes pre-Murdama hornblende-bearing schist, and is nonconformably overlapped by the Hibshi formation. The rock is hypidiomorphic and consists of potassium feldspar phenocrysts, forming 25 percent of the rock, in a fine-grained matrix of 35 percent quartz and 50 percent plagioclase (fig. 5.) The phenocrysts are coarse-grained and are arranged in a subparallel manner resembling flaser structure.

Samirah quartz monzodiorite

Gray quartz monzodiorite (sqm) occurs on the western border of the quadrangle (Williams, 1983) as part of a large pluton extending from the Wadi ash Shu'bah quadrangle (Quick, unpub. data). The pluton forms a flat, recessively weathered plain. It intrudes the pre-Murdama schist, is overlain by the Hibshi formation, and was subsequently intruded by the post-Murdama Kilab monzogranite.

Granodiorite is common in the pluton, although the composition varies from quartz monzodiorite to monzogranite (fig. 5). In texture the rocks are hypidiomorphic inequigranular, medium grained, and weakly gneissic. Subhedral, partly sericitized plagioclase forms 60 to 70 percent of the rock, anhedral quartz 20 to 30 percent, and interstitial microcline showing well-developed grid twinning 7 to 20 percent. Locally, coarse potassium feldspar phenocrysts are present. The mafic mineral comprises chloritized biotite forming about 4 percent of the rock. Fine-grained mafic inclusions commonly make up about 1 percent of the rock.

Laban complex

The predminantly mafic Laban complex (lqd) is the largest plutonic unit in the quadrangle (Williams, 1983; Pallister, 1984, unpub. data). The complex is 646±6 Ma old (J. C. Cole and C. E. Hedge, unpublished data, 1983); it intrudes pre-Murdama schist, is overlain by the Hibshi and Turmus formations, and is intruded by post-Murdama granites and many rhyolitic and andesitic dikes. It contains abundant amphibolitic xenoliths and roof septa. Like the amphibolite it intrudes, the Laban complex has been metamorphosed; it characteristically displays a weak cataclastic texture and metamorphic assemblages of amphibolite facies, although locally the rock is altered to a banded dioritic gneiss. There is no evidence of metamorphic convergence at the contacts with the amphibolite inclusions and, in general, the metamorphic grade of the inclusions appears to be greater than that of the complex; these features are believed to indicate that the amphibolite protoliths are considerably older than the Laban complex and were altered by a metamorphic event entirely prior to intrusion of the complex.

Texturally and compositionally the complex is inhomogeneous although much of the rock is medium to coarse grained and hypidiomorphic inequigranular. Biotite quartz diorite predominates (fig. 5), but samples include biotite and (or) hornblende diorite, tonalite, hornblende and pyroxene gabbro, monzogabbro, and subordinate granodiorite, monzogranite and syenogranite. In the predominant rock, plagioclase occurs as strongly sericitized, albite-twinned, anhedral to euhedral, mainly unzoned, laths, as much as 5 mm

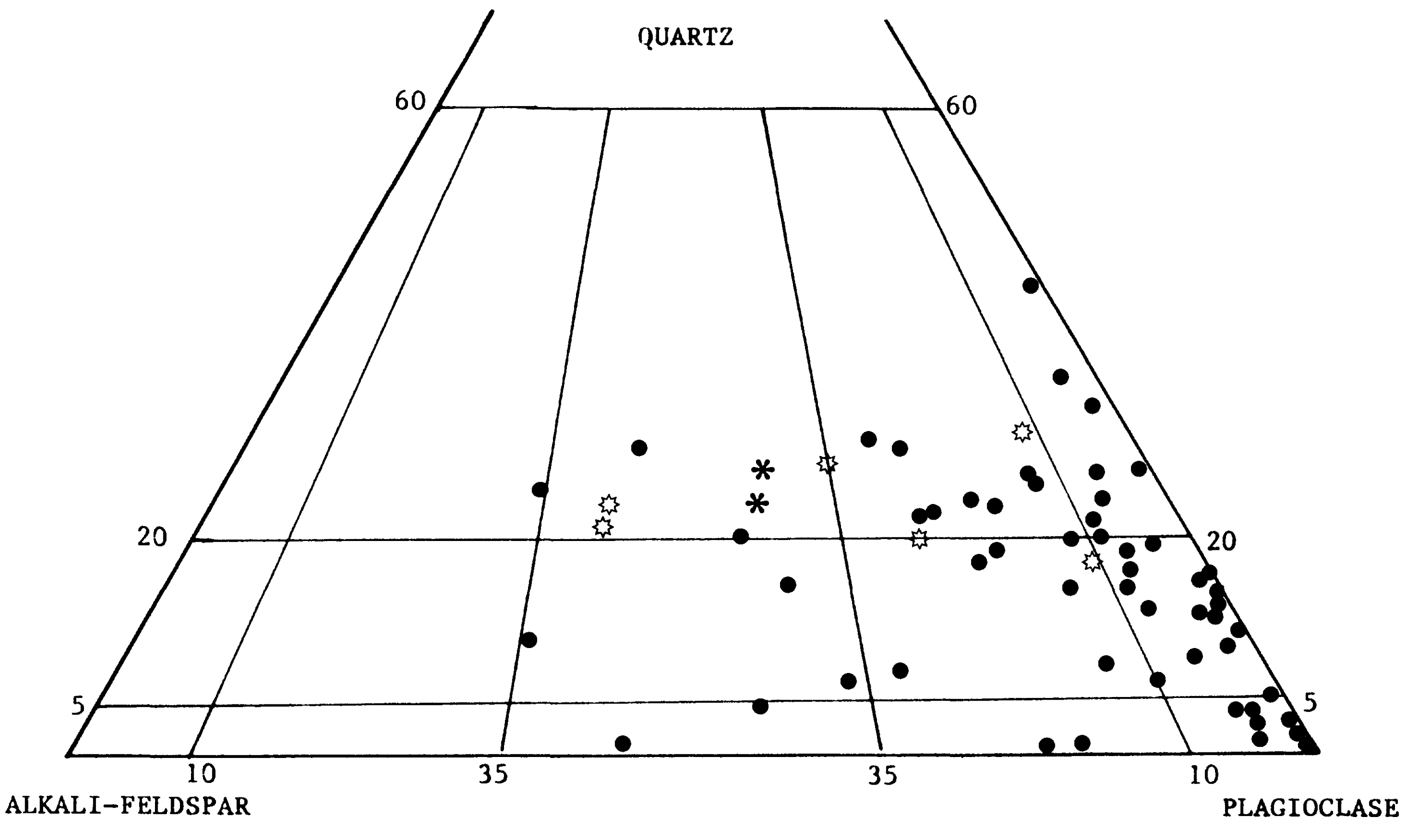


Figure 5--Quartz-alkali-feldspar-plagioclase (QAP) ternary diagram (Streckeisen, 1976), showing the modal composition of pre-Murdama intrusive rocks in the Jabal Habashi quadrangle: the sum of Q, A, and P is normalized to 100 percent; each plotted point represents a modal analysis for a single sample of between 400 and 700 points counted on a stained slab measuring at least 50 cm^2. ✱ gneissic monzogranite; ✡ Samirah quartz monzodiorite; ● Laban complex.

long. Quartz is anhedral and displays undulose extinction. Perthitic orthoclase forms subhedral to anhedral grains. Biotite consists of red-brown anhedral to subhedral partially chloritized grains as much as 3 mm long. Hornblende is pale green and is mainly replaced by chlorite and epidote. It forms laths as much as 4 mm long which, where unaltered, poikilitically enclose fine-grained quartz. Opaque oxides comprise the principal accessory mineral and trace amounts of apatite, zircon, and sphene have been identified (du Bray, 1984a). Interstitial calcite occurs as a secondary mineral.

Gabbro

Gabbro (gbo), believed to be pre-Murdama in age (Pallister, 1984, unpub. data) forms small plutons within the Laban complex. The unit is fine to coarse grained, hypidiomorphic, and locally displays a cumulus texture. It consists of dark-gray to black olivine-clinopyroxene gabbro, serpentinized melagabbro or plagioclase wehrlite, and phases of hornblende-olivine-clinopyroxene, clinopyroxene, and hornblende gabbro. The gabbro bodies south of Al Birka are small and poorly exposed; the pluton at Jabal Uraynibah however, is prominent, as is another at Wadi Aba al Kurush, in the north of the quadrangle.

Post-Murdama intrusive rocks

Metagabbro

Mafic plutonic rocks (mgb) crop out discontinously as small, isolated, dark-weathering ridges and knobs in and near the Raha fault zone and as large inclusions within the Muwashsham quartz diorite northwest of Hebairiah (du Bray, in press; Williams, 1983). It also forms small isolated hills 2 km south and southeast of Al Fawwarah, and is present in the southeast of the quadrangle. The exposures mainly consist of altered gabbro, but include lesser amounts of serpentinite, talc schist, peridotite, and tan-weathering carbonate rock. The age of the rocks relative to other intrusive rocks in the region is unknown; Williams (1983) suggests that they may be the oldest post-Murdama plutonic rocks in the quadrangle.

The metagabbro tends to be fine grained, and displays cataclastic to mylonitic textures. It is composed of altered plagioclase and varying amounts of secondary chlorite, epidote, and spinel minerals. Northwest of Hebairiah, plagioclase and dark-green chlorite are present, in approximately equal amounts. In the Raha fault zone, south of Bu'qaya, the rocks consist of irregularly shaped clusters of chlorite and less abundant spinel minerals set in a felty matrix of plagioclase; east of Jabal ar Raha subhedral epidote occurs in a turbid, felty matrix of unknown composition. Elsewhere in the quadrangle the metagabbro contains a slate-blue pleochroic amphibole that may be glaucophane (du Bray,). The metagabbro in the southeast corner of the quadrangle crops out as several dark-weathering hills, none more than 15 m high, composed of pyroxene gabbro containing actinolite, augite and biotite. The rock is very fine to medium grained and allotriomorphic to hypidiomorphic granular.

Small pods and discontinuous boudin-like masses of massive marble (mgbc) are associated with gabbro and ultramafic rocks in and along the Raha fault zone. The marble occurs as completely crystallized, bluish-gray, relatively pure carbonate rock, or as structureless, tan-colored material that is distinctly vuggy. The blue-gray marble is composed of anhedral calcite, and includes traces of hematite and quartz. The tan-colored carbonate is less pure; it contains variable amounts of quartz, trace amounts of sericite, between 1 and 5 percent spinel minerals, and possibly chromite. The intimate association and gradational contacts between tan-colored carbonate rock and mafic and ultramafic rocks in the fault zone, and the abundance of spinel, suggest that the carbonate is an alteration product of the plutonic rocks (du Bray in press), analogous to the listwanite or secondary carbonate developed along major faults elsewhere in the Arabian Shield (Thekair, 1976). However, because the Raha fault zone mostly occurs along the Maraghan-Qarnayn and Maraghan-Hibshi contacts, which are characterized by marbles of sedimentary origin in the Maraghan formation, it is probable that the "mgbc" unit is mainly of sedimentary origin.

A distinctive type of altered rock, mapped as jasper (j), crops out extensively between the bounding faults of the Raha fault zone south of Bu'qaya. The rock consists of anhedral quartz and hematite, and includes a trace of sericite. Open-space hydrothermal filling and replacement in part of the quartz body is demonstrated by the presence of coarse, dogtooth intergrowths of crystals. The jasper is associated with zones of carbonate-altered mafic and ultramafic intrusions and may represent a repository of silica, iron and other components which remained after alteration of the intrusive rocks. Anomalous concentrations of chromium and nickel, presumably derived from the ultramafic rocks, occur at the site of ancient trenches excavated in the jasper (du Bray, in press).

Makhul complex

Named after Wadi Makhul (du Bray, 1984a), this mafic intrusive complex (mc) is exposed in the north-central part of the quadrangle. Its contacts are poorly exposed, but the complex appears to intrude, and is therefore younger than, the Turmus formation. However, as it is penetrated by felsic dikes emanating from the adjacent Shuwayman monzogranite, it is older than the monzogranite.

The Makhul complex is distinguished by its extreme textural and compositional variation, although the rocks generally are medium grained and hypidiomorphic inequigranular. A weak gneissic texture in parts of the complex results from poorly defined mineral banding caused by postcrystallization deformation. Much of the complex consists of quartz diorite and granodiorite (fig. 6d), and minor monzogranite, tonalite, quartz monzonite, quartz monzodiorite, diorite, poikilitic hornblende gabbro, and gabbro (du Bray, 1984a). The plagioclase forms stubby, anhedral to subhedral laths, as much as 1 cm long which, in most samples, are strongly and complexly zoned, albite twinned and sericitized. Rare microcline forms interstitial and weakly perthitic grains. Interstitial quartz grains characteristically display undulose extinction. Hornblende, locally altered to chlorite and opaque oxides, are the dominant mafic minerals although small variable amounts of biotite and lesser clinopyroxene are present. Hornblende occurs mainly as anhedral to subhedral laths as much as 1 cm long, but also forms round, subhedral grains, largely altered to actinolite, some 2 cm in diameter. Clinopyroxene occurs as anhedral interstitial grains in the poikilitic hornblende gabbro and also forms the cores of some hornblende grains. Biotite is anhedral to subhedral and interstitial; it occurs both as pale-straw yellow to pale greenish brown, and pale yellow to deep-reddish brown pleochloric varieties. Accessory minerals include opaque oxides and euhedral sphene, and apatite, allanite, and secondary calcite are present in trace amounts.

Aydah suite

Several plutons of mafic to intermediate rock in the Jabal Habashi quadrangle are correlated with the Aydah suite of the Aban al Ahmar quadrangle (Cole, unpub data). The correlation is based on age, composition, general shape, and contact features. The intrusive rocks are post-Murdama in age and on the basis of U-Pb data for the Dhibiyah pluton are about 617 Ma old (J. C. Cole and C. E. Hedge, unpublished data, 1983). Contact relations indicate that the suite is broadly coeval with the Dulaymiyah syenogranite and with the monzogranite of the Shuwayman suite, which is dated at about 616 Ma old (J. C. Cole and C. E. Hedge, unpublished data, 1983). The plutons are characterized by their relative homogeneity and, particularly in the granodiorite members, by the presence of numerous small, elliptic mafic inclusions. The plutons tend to be recessively weathering and crop out as small to medium sized, oval to irregularly-shaped bodies. The thermal metamorphic effects of the intrusions are more conspicuous than for any other group of intrusive rocks in the quadrangle. These include the formation of discrete, conspicuous hornfels rings in the country rocks, and annular magnetic halos caused by the growth of metamorphic magnetite. Small plutons of the suite, furthermore, are typically associated with the formation of

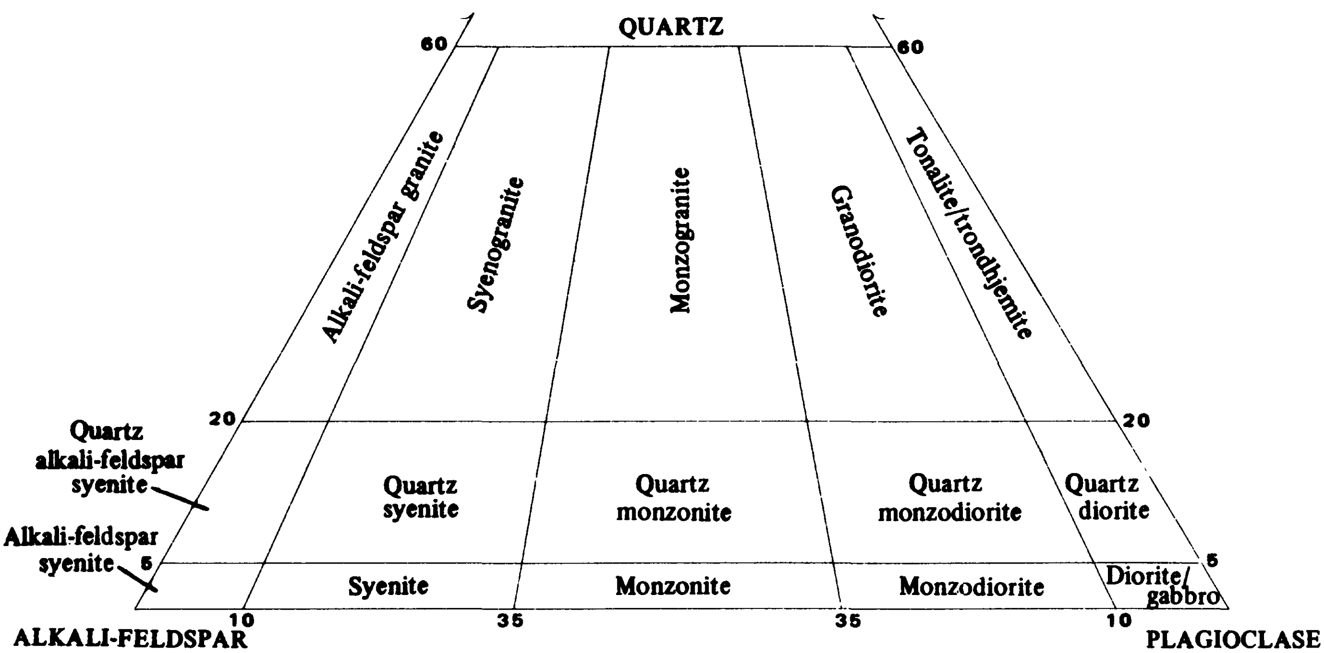


Figure 6.--Quartz-alkali-feldspar-plagioclase [QAP] ternary diagram (Streckeisen, 1976), showing the modal composition of post-Murdama intrusive rocks in the Jabal Habashi quadrangle:

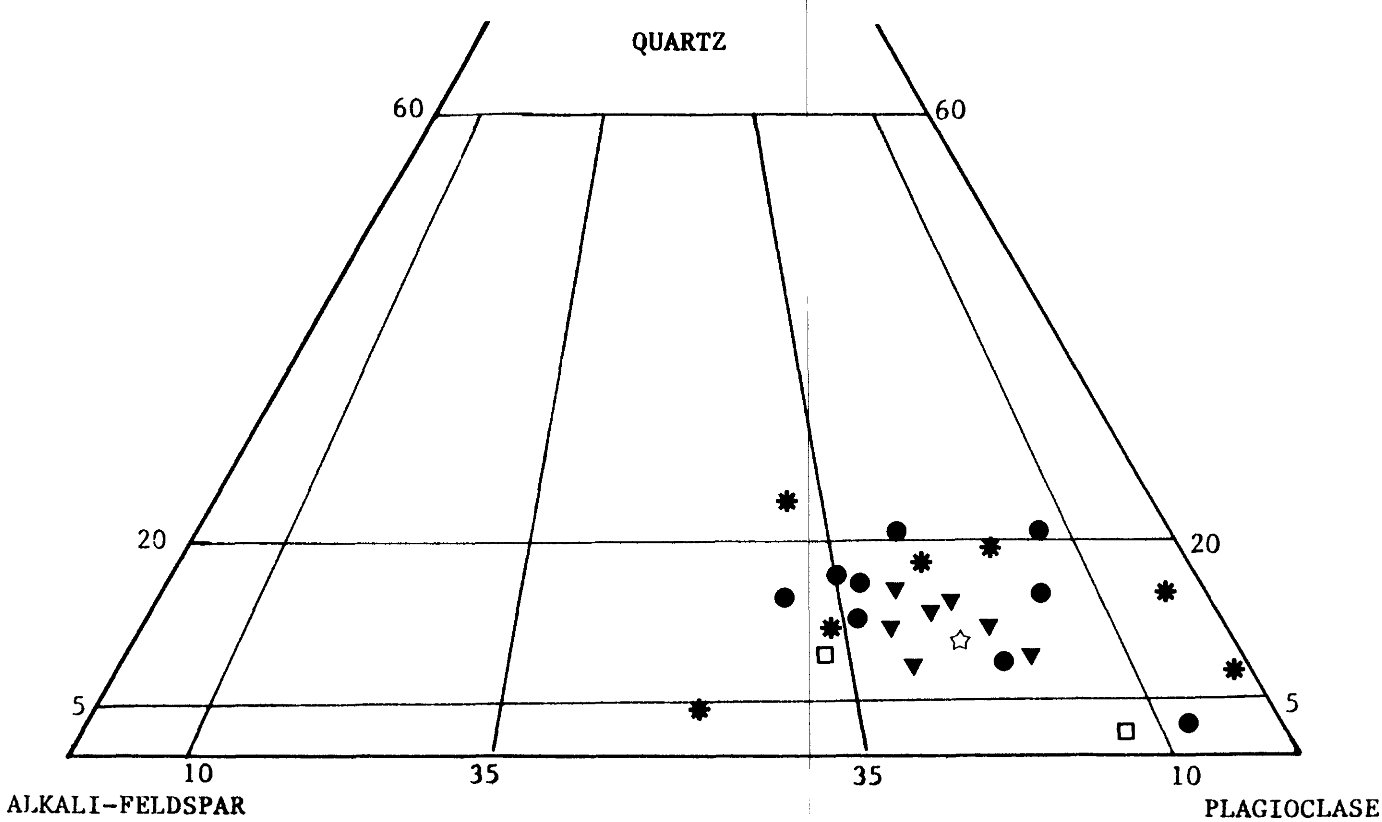


Figure 6a-- Post-Murdama quartz monzodiorite and monzodiorite: ☆ Safaq pluton; ● Muwashsham pluton; ✱ Shiaila pluton; ▼ small unnamed quartz monzodiorite plutons; □ unnamed monzodiorite pluton.

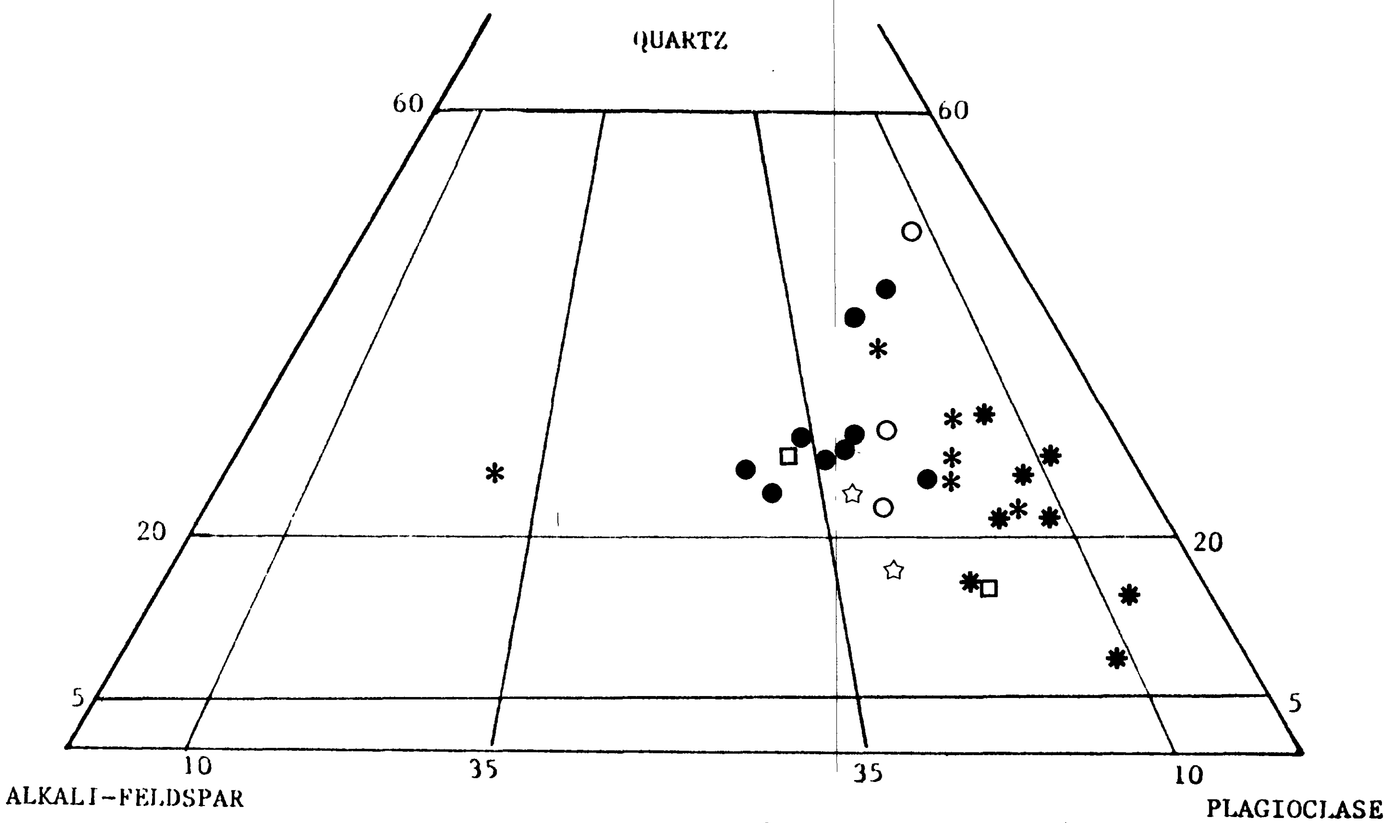


Figure 6b-- Post-Murdama granodiorite: ● Ghinaymawat pluton; ☆ Awlin pluton; ○ Mahalani pluton; □ Hebairiah pluton; ✱ Dhibiyah pluton; * unnamed granodiorite plutons.

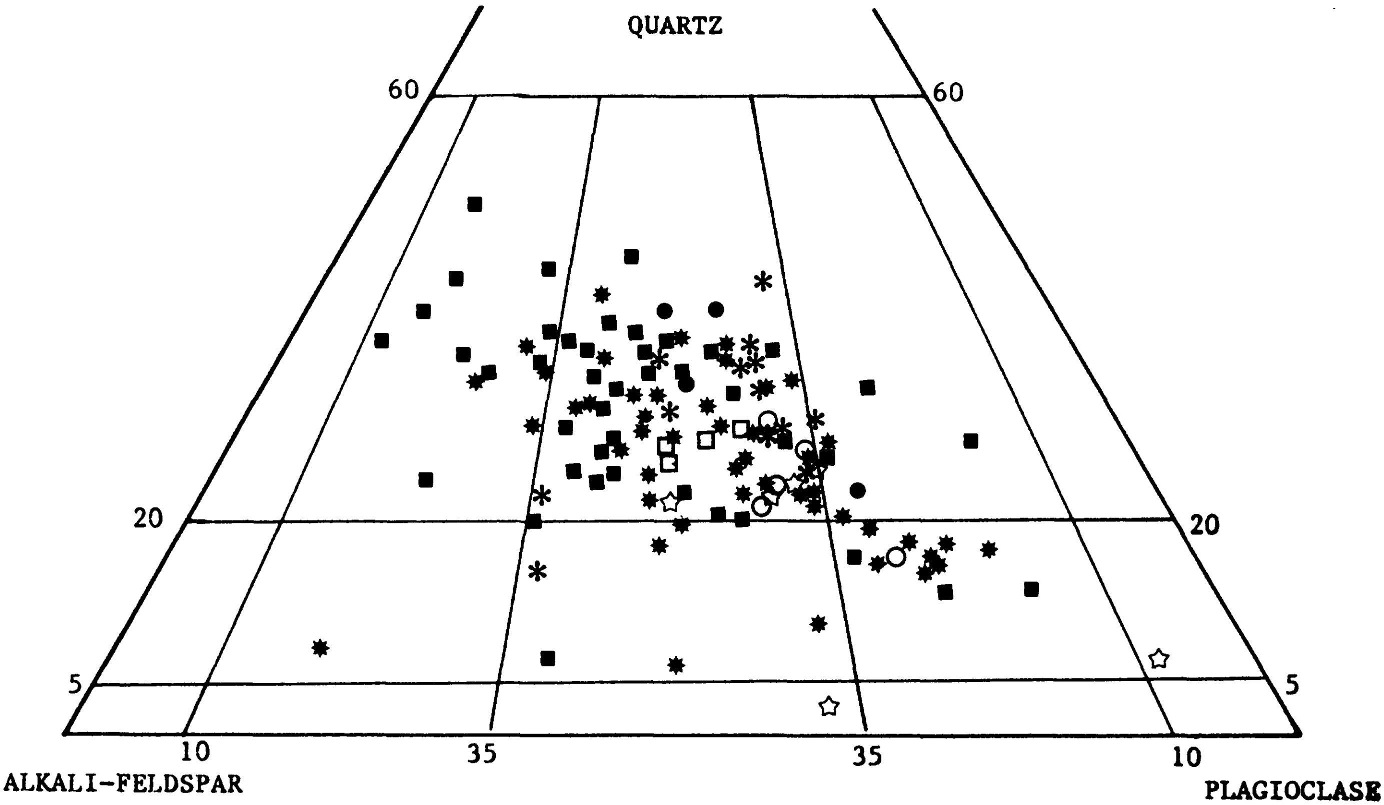


Figure 6c-- Post-Murdama monzogranite: ✱ Kilab monzogranite; □ Udbah monzogranite; ☆ Nimriyah monzogranite; * Waqt monzogranite; ○ Uzaym monzogranite; ■ Shuwayman monzogranite; ● unnamed monzogranite pluton.

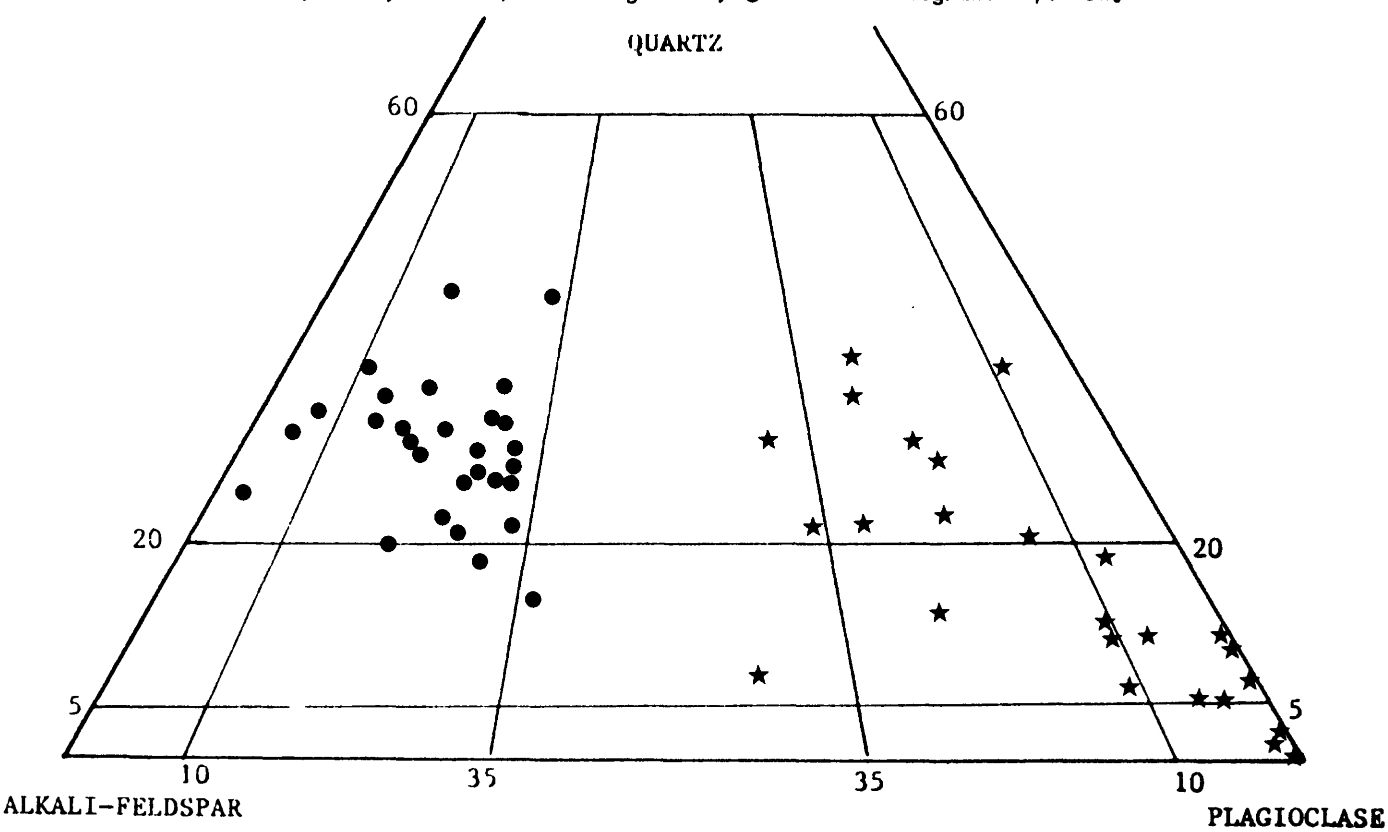


Figure 6d--Post-Murdama Makhul complex and D ulaymiyah syenogranite: ★ Makhul complex; ● D ulaymiyah syenogranite.

hydrothermal gold-bearing quartz veins.

Four members of the suite are recognized in the Jabal Habashi quadrangle: the two most common consist of quartz monzodiorite and granodiorite; less extensively represented are diorite and monzodiorite.

Quartz monzodiorite.--Quartz monzodiorite of the Aydah suite (yqm) occurs in irregularly shaped plutons of moderate size (Table 3), which crop out in a broad east-west trending zone in the south-central part of the quadrangle (du Bray, in press, Williams, 1983). The plutons are mainly composed of dark- to medium-gray, recessively weathered, quartz monzodiorite, although individually they are compositionally inhomogeneous, and range from diorite to monzogranite (fig. 6a). Some plutons may be composite in origin. They intrude the Hibshi, Qarnayn and Maraghan formations, and in the central part of the quadrangle, contain abundant mafic dikes.

Typically the quartz monzodiorite is medium grained, and hypidiomorphic granular to inequigranular, although fine- to coarse-grained, and subporphyritic phases occur. Locally the rock is weakly gneissic. Commonly plagioclase in the rock occurs as strongly zoned, subhedral, poikilitic laths; quartz and microcline are both interstitial. Variable amounts of biotite and hornblende compose as much as 32 percent of the rock; usually biotite is more abundant than hornblende, except in the Muwashsham pluton, which also contains more mafic inclusions than other plutons of the quartz monzodiorite.

Granodiorite.--Granodiorite of the Aydah suite (ygd) crops out as small- to medium-sized, oval- to irregularly shaped plutons in the southern part of the quadrangle. In general the intrusions consist of medium-grained hypidomorphic inequigranular to equigranular rock although, locally, subporphyritic textures are present. Most of the rock is massive, but the irregularly shaped Ghinaymawat pluton has a weakly fractured texture, indicating possible protoclastic deformation during emplacement. Mafic inclusions as much as 15 cm across are common in granodiorite in the southwestern part of the quadrangle; dikes are generally few in number except within the plutons in the vicinity of Adh Dhibiyah.

The granodiorite plutons are relatively homogeneous in composition (Table 4). The majority of modal analyses of samples from these plutons plot within the granodiorite field (fig. 6b) although overall the samples range from diorite to monzogranite. The mafic component, which increases towards the east, comprises varied amounts of biotite and hornblende. Generally the granodiorite is metaluminous, but the Awiin, Mahalani, and Ghinaymawat plutons are weakly peraluminous.

Table 3. Descriptive summary of quartz monzodiorite from the post-Murdama Aydah suite, Jabal Habashi quadrangle, sheet 26F

name	outcrop features	color/texture	color index	average composition	petrographic comment
SAFAQ PLUTON	forms recessively weathering, small pluton 10 km^2, intrudes Hibshi formation	medium gray, weakly gneissic	22	plagioclase: 50% K-feldspar: 15% quartz: 8% biotite: 15% hornblende: 5% augite: 2%	COMPOSITION: hornblende-biotite-quartz monzodiorite.
MUWASHSHAM PLUTON	forms recessively weathering, irregular pluton; 29 km long; intrudes Qarnayn and Maraghan formations; intruded by Shuwayman monzogranite; mafic to intermediate dikes abundant	dark-gray weathering, medium coarse grained subporphyritic, hypidiomorphic granular; numerous mafic inclusions; locally flow-foliated composite batholith		plagioclase: 43-50% K-feldspar: 10-20% quartz: 8-20% biotite/hornblende: 6-32%	COMPOSITION AND TEXTURE: inhomogeneous, diorite to quartz monzonite, predominantly biotite-hornblende quartz monzodiorite. COMPOSED OF: euhedral to subhedral zoned plagioclase, 1 cm long; nonperthitic, anhedral, interstitial microcline; weakly poikilitic, enclosing quartz and K-feldspar; interstitial quartz; hornblende/biotite variable content, ratio 5:1; both interstitial; hornblende subhedral; accessory sphene, zircon, opaque oxides
SHIAILA PLUTON	forms irregular elongate north trending pluton; 15 km long; many dikes of quartz monzodiorite intrude the surrounding Qarnayn formation.	dark weathering, texturally and compositionally inhomogeneous, fine to coarse grained, allotriomorphic inequigranular	25	plagioclase: 48% K-feldspar: 18% quartz: 11% biotite/hornblende: variable ratio	COMPOSITION: variable, hornblende-biotite-quartz monzodiorite; COMPOSED OF: anhedral to subhedral, strongly zoned plagioclase; weakly perthitic interstitial grains of microcline; biotite generally more abundant than hornblende, both anhedral and interstitial; accessory sphene, opaque oxides, apatite, zircon, and allanite.
unnamed quartz monzodiorite pluton on NW margin of Shuwayman pluton.	forms recessively weathering; small pluton; 12 km^2; cut by numerous dikes; intrudes Hibshi formation; intruded by Shuwayman monzogranite.	medium gray; medium grained; hypidiomorphic inequigranular; contains few mafic inclusions.	21	plagioclase: 50% K-feldspar: 18% quartz: 11% biotite: 10% hornblende: 11%	COMPOSITION: biotite-hornblende quartz monzodiorite; COMPOSED OF: subhedral, moderately to strongly zoned, albite twinned laths as much as 4 mm long; weakly perthitic interstitial microcline; yellowish brown to medium yellowish brown, anhedral, mainly interstitial biotite; yellowish green to green hornblende laths as much as 4 mm long; accessory opaque oxides, sphene, trace apatite, zircon.
unnamed quartz monzodiorite pluton on SE margin of Shuwayman pluton.	forms subcircular pluton; 5 km in diameter.	medium grained, inequigranular, locally subporphyritic, hypidiomorphic granular.	22	plagioclase: 53% K-feldspar: 16% quartz: 9% biotite: 13% hornblende: 9%	COMPOSITION: hornblende-biotite quartz monzodiorite; COMPOSED OF: subhedral, strongly zoned plagioclase laths, poikilitically enclosing quartz and perthite; perthitic, interstitial K-feldspar; accessory opaque oxides and sphene to apatite.

Table 4: Descriptive summary of granodiorite from the post-Murdama Aydah suite, Jabal Habashi quadrangle, sheet 26F

name	outcrop features	color/texture	color index	average composition	petrographic comment
MAHALANI PLUTON	forms recessively weathering, medium sized oval pluton, 19x6 km; contains few dikes; intrudes Maraghan formation; circumscribed by annular metamorphic and magnetic halos.	medium gray, medium grained, hypidiomorphic equigranular; up to 5% mafic inclusions.	4-12	plagioclase: 50% K-feldspar: 15% quartz: 32% biotite: 6% hornblende: trace	COMPOSITION AND TEXTURE: inhomogeneous, fine-grained to slightly porphyritic biotite granodiorite. COMPOSED OF: euhedral to subhedral, zoned sodic plagioclase subhedral to anhedral, perthitic orthoclase; subhedral to anhedral quartz; biotite only mafic silicate; weakly peraluminous.
AWIIN PLUTON	forms recessively weathering, small oval pluton, 15 km^2; contains few dikes; intrudes Maraghan formation; circumscribed by annular metamorphic and magnetic halos.	medium gray, medium grained, hypidiomorphic equigranular; up to 5% mafic inclusions.	4-12	plagioclase: 51% K-feldspar: 23% quartz: 18% biotite: 3% hornblende: 3%	COMPOSITION AND TEXTURE: inhomogeneous; fine-grained to slightly porphyritic biotite-hornblende granodiorite; COMPOSED OF: euhedral to subhedral zoned sodic plagioclase; subhedral to anhedral perthitic orthoclase; subhedral to anhedral quartz. biotite/hornblende ratio approx. 1:1; weakly peraluminous
HEBAIRIAH PLUTON	forms recessively weathering, small oval pluton, 23 km^2; contains few dikes; circumscribed by annular metamorphic halo.	medium gray, medium grained, hypidiomorphic equigranular; up to 5% mafic inclusions.	4-12	plagioclase: approx. 50% K-feldspar: 20% quartz: 20% biotite: 6% hornblende: 6%	COMPOSITION AND TEXTURE: inhomogeneous; fine-grained to slightly porphyritic biotite-hornblende granodiorite; COMPOSED OF: euhedral to subhedral zoned sodic plagioclase; subhedral to anhedral, perthitic orthoclase; subhedral to anhedral quartz; biotite/hornblende ratio approx. 1:1; metaluminous
GHINAYMAWAT PLUTON	recessively weathering, medium sized, irregular pluton, 20x15 km; truncates dikes which penetrate the Shuwayman monzogranite, therefore younger than the monzogranite; intrudes Qarnayn and Maraghan formations and Raha fault zone	very light gray, medium-grained, hypidiomorphic inequigranular, subporphyritic; mafic inclusions common; weakly-fractured appearance indicates protoclastic deformation during emplacement.	11	plagioclase: 42% K-feldspar: 19% quartz: 28% biotite/hornblende: 11% combined.	COMPOSITION: hornblende-biotite granodiorite and monzogranite. COMPOSED OF: strongly zoned stubby, partly sericitized plagioclase laths; anhedral, interstitial perthitic microcline; locally poikilitic, resulting in subporphyritic texture; biotite principal mafic silicate; trace hornblende partially replaced by biotite; accessory zircon, sphene, apatite, opaque oxides, allanite; weakly peraluminous.
Unnamed pluton on ~~NE margin of Ghi-~~naymawat pluton	forms small oval pluton, 18 km^2, ~~consisting~~ of small inselbergs; truncates dikes which penetrate the Ghinaymawat granodiorite; therefore younger than the latter; intrudes Qarnayn formation.	medium grained, hypidiomorphic inequigranular.	24	plagioclase: 46% K-feldspar: 10% quartz: 20% biotite/hornblende: 24% combined	COMPOSITION: hornblende-biotite granodiorite. COMPOSED OF: very strongly zoned plagioclase laths containing sericitized cores; interstitial K-feldspar; biotite/hornblende ratio 3:2, mainly interstitial; a few subhedral hornblende laths; accessory opaque minerals, zircon, and sphene.
Unnamed pluton NE of Samra Waqt	forms recessively weathering, small irregular pluton, 12 km^2; cut by east-trending rhyolite and andesite dikes; textural and compositional variation at margins suggest that it intrudes the Dulaymiyah syenogranite.	medium grained, hypidiomorphic granular to subporphyritic.	15	plagioclase: 42% K-feldspar: 24% quartz: 28% biotite: 15% hornblende: trace	COMPOSITION: hornblende-biotite granodiorite. COMPOSED OF: moderately zoned, anhedral to subhedral plagioclase laths, partially sericitized; mainly perthitic and interstitial K-feldspar; scarce anhedral phenocrysts result in subporphyritic texture; dominant mafic silicate red-brown interstitial biotite; trace hornblende partially altered to biotite; accessory zircon, especially abundant within biotite, apatite, allanite, and secondary epidote.
DHIBIYAH PLUTON 1617±5 Ma]	forms oval, medium-sized pluton, 20x8 km; mafic dikes common; probably younger than the Dulaymiyah syenogranite.	medium grained, hypidiomorphic inequigranular; mafic inclusions common.	28	plagioclase: 50% K-feldspar: 7% quartz: 15% biotite/hornblende: 28% combined	COMPOSITION: biotite-hornblende granodiorite, subordinate diorite and quartz monzodiorite. COMPOSED OF: strongly zoned, locally sericitized plagioclase laths; interstitial and poikilitical K-feldspar; hornblende and biotite, in ratio 3:2, present as abundant interstitial grains; accessory zircon, sphene; trace apatite, allanite and opaque oxides.

Diorite, quartz monzonite, quartz diorite and trondhjemite.--This unit (ydi) includes small to very small plutons of mafic to intermediate rock which intrude the Maraghan formation and are therefore post-Murdama in age, but do not have exposed contacts with other intrusive rocks. However, on the basis of their composition and association with gold mineralization they are assigned to the Aydah suite. Several plutons of this unit are aligned along a northwest trend between Jabal Asha and the Meshaheed prospect in the southwestern part of the quadrangle (Williams, 1983). The rock is generally dark gray, fine grained, and commonly porphyritic. It consists of about 65 percent lath-shaped anhedral sericitized plagioclase, and 1 or 2 percent interstitial quartz. The mafic minerals include 10 to 20 percent hornblende and a generally lesser amount of moderately to intensely chloritized biotite.

Quartz diorite, and locally trondhjemite, also assigned to this unit, crop out southwest of Al Fawwarah and north of Samra Waqt (du Bray, in press). The plutons intrude the Maraghan formation and, with respect to the layered rocks, are preferentially cut by andesite and rhyolite dikes and auriferous-quartz veins. The rock is fine to medium grained, hypidiomorphic inequigranular to equigranular, and has color indices of 44 and 42. The felsic constituents include 50 to 54 percent sericitized plagioclase laths, 2 to 4 percent potassium feldspar, and 5 to 6 percent interstitial quartz. Variable amounts of hornblende and biotite form the mafic-silicate minerals. The smaller intrusion near Al Fawwarah contains only hornblende altered to chlorite and opaque oxides; the larger intrusion near Samra Waqt contains hornblende and biotite in a ratio of 3:2. In this rock the hornblende forms pale-green to pale-brown anhedral to subhedral laths and minor interstitial grains. Red-brown biotite is interstitial and locally replaces hornblende. Apatite, opaque oxides, zircon and epidote form the accessory minerals.

Monzodiorite.--Monzodiorite (ymd) is rare in the quadrangle, forming a small compositionally inhomogeneous, unnamed pluton immediately south of Jabal al Muwashsham (du Bray, in press). It cuts the Ghinaymawat granodiorite pluton and the Qarnayn formation. The rock is medium grained and hypidiomorphic inequigranular. The plagioclase occurs as strongly zoned, locally sericitized, subhedral laths. Scarce, nonperthitic microcline poikilitically encloses quartz. Two samples are plotted on Figure 6a. Interstitial biotite and hornblende in a ratio of 5:1 form the mafic mineral suite. The accessory minerals include sphene, apatite, opaque oxides, and zircon.

Shuwayman suite

Post-Murdama monzogranite of the Shuwayman suite (smg) forms several plutons of varied sizes in Jabal Habashi quadrangle (du Bray, 1983a, in press; 1984a; Williams, 1983; Pallister, 1984, unpub. data). The suite is named after prominent exposures in the Shuwayman pluton in the center of the quadrangle. It comprises the most extensive map unit of intrusive rocks in the quadrangle and, as the Kilab pluton, possibly extends west into the Wadi ash Shu'bah quadrangle (Quick, unpub. data). In the southern part of the quadrangle, the suite temporally overlaps with the emplacement of the Aydah suite; it intrudes older units of intrusive rocks and layered rocks of the Maraghan and Hibshi formations, and has been dated by the U-Pb method as 616±10 Ma old (J. C. Cole and C. E. Hedge, unpublished data, 1983).

Although the Kilab pluton is included in the suite for the purpose of this compilation, its relationship with the other suite members is problematic. In composition it is more variable than the other plutons in the suite, and its stratigraphic position is ambiguous because it either cuts older rocks or has exposed contacts in the Wadi ash Shu'bah quadrangle of uncertain significance (Quick, unpub. data). Furthermore, Pallister (1984, unpub. data) suggests that the Kilab pluton may be pre-Murdama in age and that it overlaps in time with emplacement of the Laban complex, on the basis of a preliminary U-Pb (zircon) radiometric age date of 651±5 Ma (J. C. Cole and C. E. Hedge, written commun., 1984) on monzogranite in the Qufar quadrangle (Kellogg, 1983) that is considered to be part of the Kilab. The pluton is therefore only tentatively considered part of the Shuwayman suite.

The suite consists predominantly of biotite monzogranite but there is considerable compositional variation within individual plutons, ranging from quartz diorite to alkali granite (Table 5, fig. 6c). Typically, the rocks are recessively weathered; an exception is in the southern part of the Shuwayman pluton in the center of the quadrangle, where inselbergs and whaleback hills occur. The monzogranite is mainly pinkish gray, varying to pale orange or light gray in some plutons. The granite is generally massive to weakly foliated and granoblastic. In most plutons the rock is medium grained and allotriomorphic to hypidiomorphic granular, although in parts of the Kilab and Shuwayman plutons and throughout the Waqt and Uzaym plutons porphyritic monzogranite occurs, consisting of anhedral microcline phenocrysts as large as 4 cm across, in a medium- to coarse-grained hypidiomorphic inequigranular groundmass. It appears from contact relationships that the porphyritic rocks represent a relatively young phase of the monzogranite suite, and in some cases plutons of the porphyritic rock were mapped separately as "smgp".

Table 5: Descriptive summary of the post-Murdama Shuwayman suite of monzogranite, Jabal Habashi quadrangle, sheet 26F

name	outcrop features	color/texture	color index	average composition	petrographic comment
KILAB PLUTON	forms recessively weathering large batholith extending into W. ash Shu'bah quadrangle to the west; intrudes pre-Murdama amphibolite schist, quartz diorite, and quartz monzodiorite; also apparently intrudes rhyolite.	light gray to pinkish gray, massive to weakly foliated, medium grained, allotriomorphic granular to granoblastic.	5-10	plagioclase: 40% K-feldspar: 30% quartz: 25% biotite: 2-3% hornblende: trace	COMPOSITION AND TEXTURE: variable; consists of biotite and hornblende-biotite monzogranite, subordinate biotite alkali-feldspar granite, biotite syenogranite, muscovite-bearing peraluminous granite and biotite-hornblende granodiorite; COMPOSED OF: euhedral to subhedral zoned plagioclase, subhedral to anhedral microcline perthite; variably recrystallized quartz; green hornblende and/or biotite and minor titanite; weakly peraluminous.
NIMRIYAH PLUTON (616±10 Ma)	forms recessively weathering medium-sized pluton, 26 km²; intrudes Hibshi formation.	pink, medium to coarse grained; hypidiomorphic to allotriomorphic equigranular.	7	plagioclase: 44% K-feldspar: 26% quartz: 21% biotite: 5% hornblende: 2%	COMPOSITION: biotite and hornblende-biotite monzogranite and granodiorite; includes dark quartz-diorite border phase; metaluminous.
SHUWAYMAN PLUTON	forms large irregularly shaped batholith, consisting of inselbergs and whale-backed outcrops in south; more recessively weathering in north; intrudes Qarnayn and Hibshi formations, Muwashsham and Shialia quartz monzodiorites, and Makhul complex and tonalite; considered to be younger than these rocks; batholith cut by many NNW-trending mafic to intermediate dikes.	pinkish gray to pale orange, medium grained allotriomorphic to hypidiomorphic equigranular; less homogeneous in north; locally porphyritic; no mafic inclusions observed.	3-6	plagioclase: 30-50% K-feldspar: 25-36% quartz: 25-30%	COMPOSITION: biotite monzogranite; COMPOSED OF: weakly zoned albite, gridiron twinned microcline poikilitically enclosing plagioclase and biotite; biotite is only significant mafic phase; trace sericite and hornblende present; accessory sphene, apatite; porphyritic phase includes feldspar phenocrysts 1 cm long, and slightly more biotite and sphene; weakly peraluminous (corundum normative).
WAQT PLUTON	forms recessively weathering medium-sized pluton, 16x15 km; believed to be younger than Dulaymiyah syenogranite and Dhibiyah granodiorite.	light colored porphyritic, megacrysts set in medium- to coarse-grained, hypidiomorphic inequigranular groundmass, few mafic inclusions.	10	plagioclase: 35-35% K-feldspar: 25-27% quartz: 27-29%	COMPOSITION: biotite monzogranite; COMPOSED OF: megacrysts of anhedral perthitic microcline up to 4 cm across, poikilitically enclosing plagioclase and quartz; plagioclase consists of moderately to complexly zoned, subhedral, slightly sericitized laths red-brown interstitial grains of locally chloritized biotite; trace ferroedenite, zircon, opaque oxides; weakly peraluminous
UZAYM PLUTON	forms recessively weathering small pluton, 9 km²; cut by mafic to intermediate dikes.	very light gray, porphyritic phenocrysts set in medium to coarse grained hypidiomorphic granular groundmass; contains mafic border phase against, and probably younger than Shuwayman monzogranite.	5	plagioclase: 46% K-feldspar: 27% quartz: 22%	COMPOSITION: biotite monzogranite; COMPOSED OF: anhedral, strongly perthitic microcline phenocrysts up to 1.5 cm across; albite-twinned subhedral, complexly zoned, plagioclase laths; interstitial, locally chloritized biotite grains; accessory sphene; opaque oxides; trace zircon, apatite; metaluminous.
Unnamed monzogranite pluton at the eastern margin of the Shuwayman pluton	forms recessively weathering small pluton, 3 km²; cut by felsic dikes; contact relations poorly exposed.	pinkish gray, subporphyritic, medium-grained hypidiomorphic granular; contains hydrothermal alteration at contact with, and probably younger than Shuwayman monzogranite; no mafic inclusions observed.	10	plagioclase: 33% K-feldspar: 26% quartz: 31%	COMPOSITION: hornblende-biotite monzogranite COMPOSED OF: subphenocrysts of weakly perthitic microcline up to 8 mm long, poikilitically enclosing other minerals; strongly zoned, albite-twinned, anhedral to subhedral plagioclase laths 4 mm long; interstitial biotite grains; trace hornblende; accessory opaque oxides and sphene; trace zircon, apatite; metaluminous.

Biotite is the only significant mafic-silicate mineral in the monzogranite, although it comprises less than 5 percent of the rock; hornblende occurs only in minor amounts. A few mafic inclusions are present in some of the plutons. The Shuwayman and Uzaym plutons are cut by dikes of mafic to intermediate composition. A small porphyritic monzogranite pluton on the eastern margin of the Shuwayman pluton is cut by felsic dikes, and the Kilab pluton contains sparse, centimeter- to meter-scale bull quartz or quartz-feldspar pegmetite veins and pods associated in one case with a small zone of possibly peraluminous zinnwaldite granite (Pallister, 1984 unpubl. data). In common with the post-Murdama granodiorite and syenogranite, the monzogranite of the Shuwayman suite is generally metaluminous, except for the weakly peraluminous granite in the Shuwayman, Waqt, and parts of the Kilab plutons.

Gabbro, diorite, and tonalite

Small mafic intrusions are associated with the post-Murdama monzogranite and granodiorite of the quadrangle. These bodies include gabbro, diorite, and tonalite. Tonalite may be the oldest; it is penetrated by felsic dikes that emanate from the Shuwayman monzogranite, whereas diorite and gabbro both intrude plutons of monzogranite.

Tonalite (to) crops out in the Shuwayman monzogranite as a small pluton, 4 km^2 in area, of recessively weathering, medium-grained, and hypidiomorphic and inequigranular rock (du Bray, in press; 1984a). It consists of 52 to 54 percent plagioclase, 5 percent microcline, and 11 to 18 percent quartz. The euhedral plagioclase laths are weakly zoned; the scarce perthitic potassium feldspar is interstitial, as are biotite and hornblende, which form about 30 percent of the rock and occur in a ratio of 5:1. Dominant apatite and sphene, and lesser opaque minerals and zircon comprise the accessory minerals.

Elongate plugs of hornblende diorite (di) intrude the Kilab monzogranite near the western border of the quadrangle (Williams, 1983). The black, boulder-weathering rock is medium grained, hypidiomorphic inequigranular, and consists of 50 to 60 percent partly sericitized plagioclase, 30 percent hornblende, a few percent interstitial quartz, and accessory sphene.

Post-Murdama gabbro (gb) intrusions tend to be emplaced within or close to bodies of other plutonic rocks in the quadrangle (Williams, 1983). North of Jabal Muwashsham, a small gabbro intrudes the contact between the Shuwayman and the Muwashsham plutons. Other gabbro intrudes the Maraghan formation immediately northeast of Hebairiah. The gabbro forms black-weathering, small, locally boulder-covered hills consisting of 35 percent calcic plagioclase, 30 percent coarse crystals of green hornblende poikilitically enclosing other minerals, 20 percent augite, and 15 percent of a mafic silicate tentatively identified as olivine, the original mineral having been largely replaced by antigorite, iron oxides, and secondary tremolite-actinolite.

Dulaymiyah syenogranite

The southeastern corner of the quadrangle is underlain by a large undeformed pluton of homogeneous syenogranite (dsg) (du Bray, 1983a, in press). The granite extends into the Aban al Ahmar quadrangle to the south (Cole, unpub data), cropping out as recessively weathered flat slabs and locally prominent inselbergs. It is cut by several dikes of intermediate composition, although not by the dikes in the Dhibiyah granodiorite. For this reason du Bray (1983a) considers the syenogranite to postdate the granodiorite. The Dulaymiyah syenogranite appears to be intruded in turn by the post-Murdama Waqt monzogranite and the postkinematic Hamrah monzogranite. The supporting contact relationships are poorly exposed however, and Cole, unpub data) concludes that in the Aban al Ahmar quadrangle the syenogranite is younger than the Hamrah monzogranite, and postkinematic in age.

The syenogranite is characteristically coarse grained and hypidiomorphic inequigranular. It contains no mafic inclusions, and the color index varies from 7 to 10. In composition, it is homogeneous (fig. 6d). In many places, strongly perthitic, subhedral potassium feldspar poikilitically encloses quartz and albite. The principal mafic silicates are the soda-bearing hornblende, ferroedenite, and biotite. These form about 7 and 3 percent of the syenogranite respectively; both are interstitial. Accessory minerals include opaque oxides, zircon, allanite, and sphene. East of Samra Waqt the syenogranite has been locally affected by weak cataclastic deformation; most mafic minerals have been replaced by hematite and the rock is fractured, reddened and weathers distinctively red.

Postkinematic intrusive rocks

Hamrah monzogranite

Spanning the southeastern boundary of the Jabal Habashi quadrangle are two plutons of postkinematic biotite monzogranite (hmg), the northernmost representatives of a major expanse of monzogranite exposed in the Aban al Ahmar quadrangle to the south. The monzogranite, compiled as an intrusive rock unit of formation rank, is named after the village of Shurayb al Hamrah (Cole, unpub data). The granite is characteristically recessively weathering and forms flat pediment surfaces unrelieved by inselbergs. Outcrop is poor and the boundary of the eastern, Qurayn pluton, in particular, is based on tonal characteristics of Landsat images and on stained-slab modes. The granite contains no mafic inclusions and has a color index of 5 to 8. The absolute age of the monzogranite is unknown, but contact geometry suggests that the western, Hamrah pluton intrudes the Dulaymiyah syenogranite (du Bray, in press).

Samples from both the Hamrah and Qurayn plutons plot within the monzogranite field (fig. 7c), but those from the Hamrah pluton are texturally and compositionally more homogeneous. The monzogranite is fine to medium grained, allotriomorphic inequigranular and subporphyritic to porphyritic. The phenocrysts consist of weakly to strongly perthitic potassium feldspar.

Red-brown biotite, locally altered to chlorite, forms numerous distinctive subround net-like segregations up to 1 cm in diameter, containing zircon grains. Accessory minerals include traces of zircon, allanite, muscovite, and opaque oxides.

The granite is weakly peraluminous and plots in or near the field of S-type, muscovite-bearing granites (White and Chappell, 1977). It is visually distinguishable from other granites by its relatively fine-grained groundmass, potassium-feldspar phenocrysts, and clotted segregations of biotite. The allotriomorphic granular character of the rock suggests simultaneous, rapid crystallization of the feldspars and quartz, and the small size of the potassium-feldspar phenocrysts suggests limited crystallization of that mineral before simultaneous crystallization commenced (du Bray, 1984b, unpub. data).

Qutn syenogranite

Postkinematic syenogranite (qgy) crops out in a circular pluton about 12 km in diameter astride the southern boundary of the quadrangle (Williams, 1983). The granite forms the prominent, steep-sided, whale-back masses of Jabal Qutn, topographically controlled by a strong west-northwest set of joints. The granite is further distinguished by its radioactive signature, two to four times above the regional background. The granite intrudes the Maraghan formation but is not in contact with other plutonic rocks. It has been dated by the Rb-Sr method at 579±4 Ma (Stuckless and others, 1984), and is therefore one of the youngest rocks in the quadrangle.

The granite is light-orange gray, coarse grained, and hypidiomorphic granular with a porphyritic core and a nonporphyritic, coarse-grained biotite-granite rim 1 km thick. Compositionally, it is relatively homogeneous (fig. 7c). Throughout, the potassium feldspar is perthitic and is coarsely crystalline, forming grains as much as 2 cm long in

Figure 7--Quartz-alkali-feldspar-plagioclase [QAP] ternary diagram (Streckeisen, 1976), showing the modal composition of postkinematic intrusive rocks in the Jabal Habashi quadrangle: each sum of Q, A, and P is normalized to 100 percent; each plotted point represents a modal analysis for a single sample of between 400 and 700 points counted on a stained slab measuring at least 50 cm^2. Albite is counted as plagioclase for samples of alkali-feldspar granite.

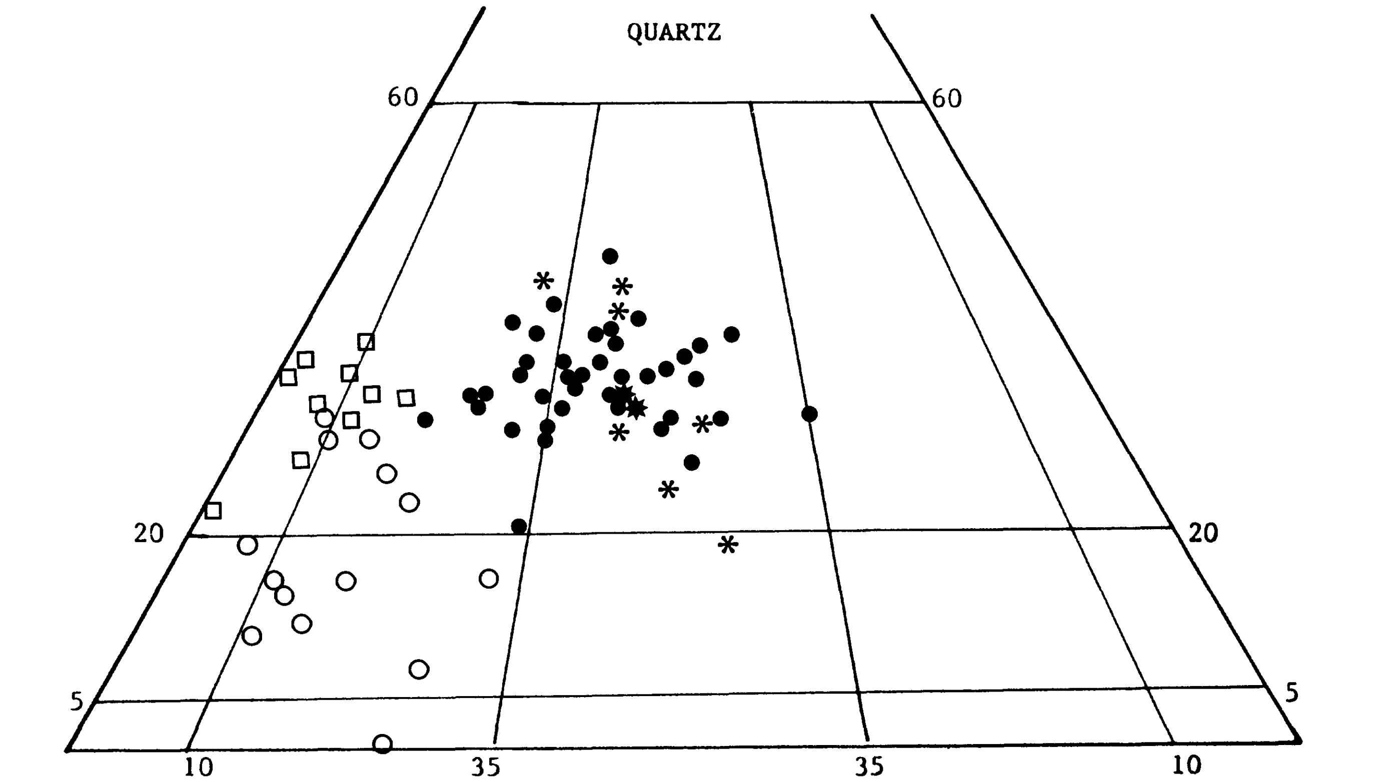


Figure 7a--Postkinematic alkali-feldspar granite: □ Salma pluton; ○ Gusai pluton; Muscovite-bearing alkali-feldspar granite: * Hudub pluton; ● Fawwarah pluton; ✱ Usba pluton.

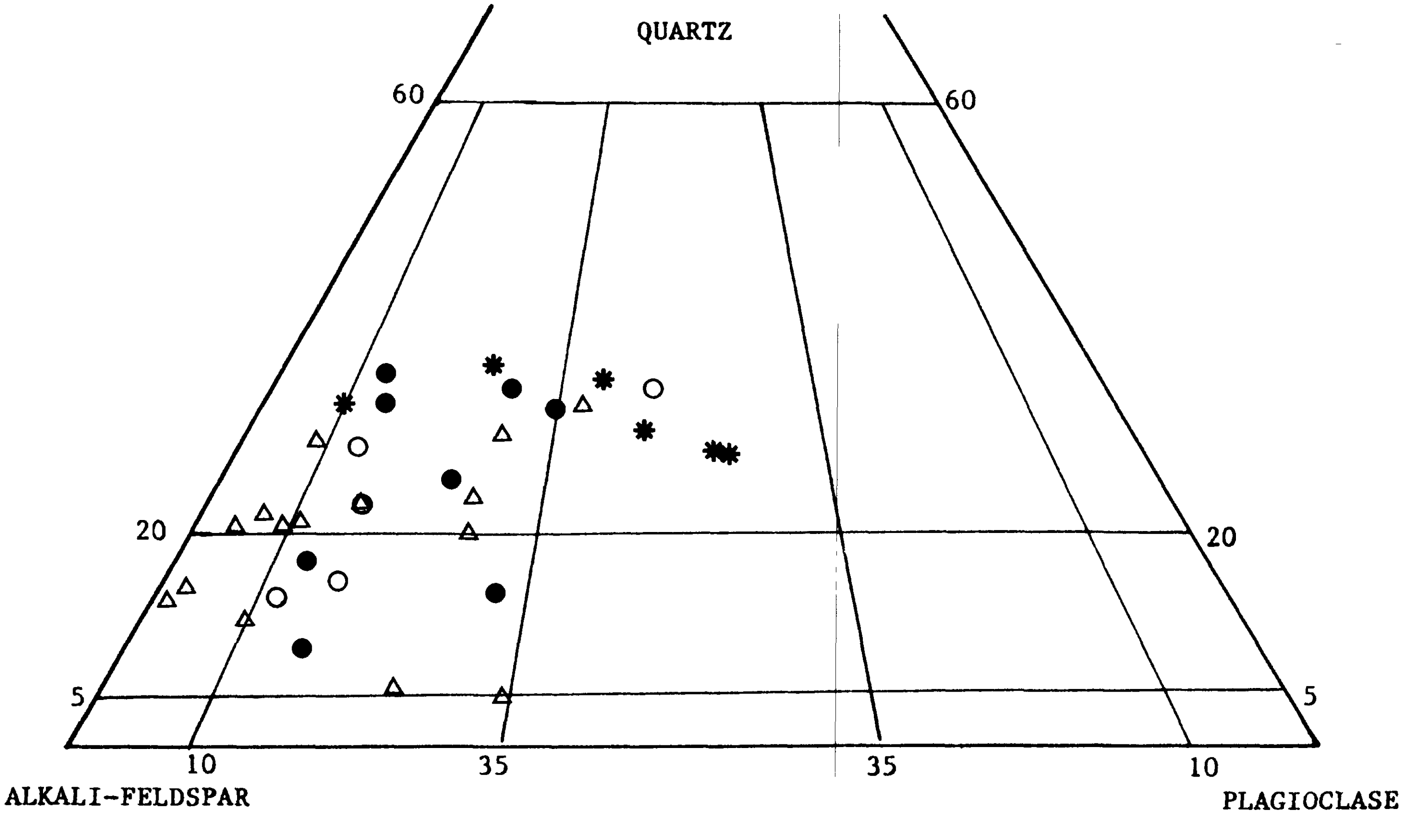


Figure 7b--Postkinematic sodic pyribole-bearing alkali-feldspar granite: ○ Shurmah pluton; △ Silsilah pluton; ✱ Unnamed plutons; ● Border phase of Salma pluton.

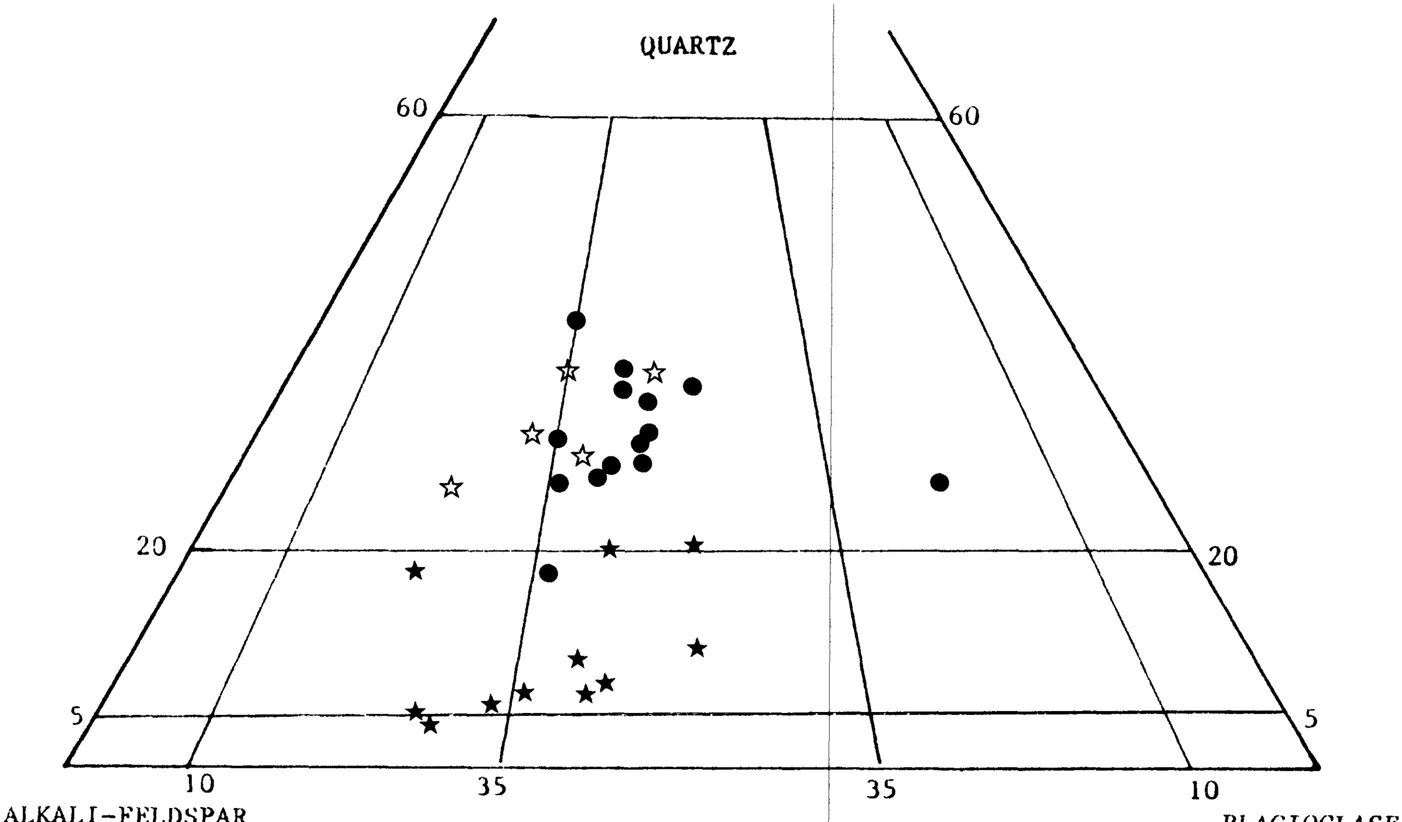


Figure 7c--Postkinematic granite and aplite: ● Hamra monzogranite; ☆ Qutn syenogranite; ★ Hadhir aplite.

the central, porphyritic, part of the pluton, up to twice the length of quartz and plagioclase crystals. Sodic plagioclase is composed of euhedral and subhedral phenocrysts that are slightly smaller than the potassium feldspar and quartz. Anhedral quartz locally occurs as clusters of grains. The chief mafic mineral is biotite, forming 1 to 4 percent of the granite, although weakly pleochroic muscovite, occurring with biotite, was observed in several samples. Coarse-grained granite at the peak of Jabal Qutn is capped by flat-lying, dark-red-brown siliceous felsite 10 m thick. The felsite is porous, contains numerous miarolitic cavities, and has sparse biotite and quartz phenocrysts. Locally the underlying granite is present as a strongly altered breccia, healed by the felsite.

Dikes are locally abundant in the pluton but only rarely penetrate the Maraghan formation. At its eastern margin, the pluton is cut by thin, plagioclase-pyroxene mafic dikes aggregating 3 m in thickness. Elsewhere the peripheral zone of the pluton contains aplite and medium-grained leucogranite dikes 1 to 10 cm thick, which appear to dip inward towards the center of the pluton.

The syenogranite is strongly peraluminous and subsolvus; it also contains anomalously high amounts of uranium although the potential for uranium mineralization is judged to be low (Stuckless and others, in press). No segregations of uranium-bearing minerals were found during the course of mapping, and its elevated radioactivity probably partly results from the abundance of potassium-rich feldspars (Williams, 1983). Samples of the pluton plot in or near the field of S-type granites (Chappell and White, 1974), and it has the characteristics of a metallogenically specialized granite (du Bray, 1984b, unpub. data). The pluton is associated with enriched values of lead, tin, yttrium, niobium and lanthium in sediment from surrounding wadi streams, and is a potential source of tin, tungsten, and rare-earth elements (Allen and others, 1984; du Bray, 1984b, unpub. data).

Alkali-feldspar granite suite

The most characteristic postkinematic intrusive rock in the quadrangle consists of alkali-feldspar granite. Because of shared characteristics, particularly their relatively young age and similar petrology, the granite bodies are compiled as an intrusive-rock unit of suite rank. Work in progress in the Aban al Ahmar quadrangle to the south (Cole, unpub. data) will describe the reference area and assign a name for the suite. Rb-Sr data in the northeastern part of the Arabian Shield indicate that such granites are approximately 580 to 565 Ma old (Stuckless and others, 1984); they therefore comprise some of the youngest Proterozoic intrusive rocks in the Shield.

The 1:100,000-scale source maps categorize the granites in the suite as alkali-feldspar granites, alkali granite, and alkali-feldspar quartz syenite granophyre. In this compilation four categories are used: alkali-feldspar granite (afg); muscovite-bearing alkali-feldspar granite (afgm); soda-pyribole-bearing alkali-feldspar granite (afgs): and alkali-feldspar quartz syenite granophyre (afsy).

Alkali-feldspar granite.--Alkali-feldspar granite (afg) crops out along the western and northwestern margins of the quadrangle. In the Salma pluton the rocks form the southern extension of a major postkinematic granite complex (Kellogg, 1984); similar rocks of the Gusal pluton extend into the Wadi ash Shu'bah quadrangle (Quick, unpub data). The plutons are leucocratic, light gray to pink, medium to coarse grained and hypidiomorphic granular. Their composition is tends to be variable (Table 6, fig. 7a), locally including syenogranite and monzogranite. Biotite is the chief mafic silicate mineral, although trace amounts of hornblende occur in the Gusal pluton. The rocks have a peralkaline affinity and some samples are acmite normative (du Bray, 1984, unpub data). The allotriomorphic to hypidiomorphic intergrowths of feldspar and quartz in the granite indicate that the plutons are products of eutectic crystallization, and the compositions and inferred water vapor pressure during crystallization, of some plutons are consistent with an emplacement depth of between 2 and 7 km (du Bray, 1984b

In common with peralkaline granites elsewhere in the Arabian Shield these plutons have potential for mineralization in zirconium, niobium, tantalum, uranium, thorium, tin, yttrium and rare earth elements (Drysdall and Drysdall, 1982). They appear to be the source of anomalous concentrations of some of these elements in sediment samples from streams draining the plutons (Allen and others, 1984).

Muscovite-bearing alkali-feldspar granite.--Three bodies of muscovite-bearing alkali-feldspar granite (afgm) are known in the quadrangle, the Hudub circular pluton, the Usba pluton which crops out as a window in the Phanerozoic rocks, and the Fawwarah granite which forms part of the Silsilah ring structure. The granite is of major importance as a host rock for tin-bearing greisen; the plutons are also characterized by scintillation-count anomalies of twice the background, although uranium minerals have not been located.

The rock has a relatively uniform composition (fig. 7a) and is leucocratic, light gray to pink, fine to coarse grained, and typically allotriomorphic granular. The Hudub pluton displays a chilled granite porphyry border zone. The mafic silicates include biotite, as do most members of the alkali-feldspar granite suite, but the plutons are particularly distinguished by the presence of as much as 7

Table 6.--Descriptive summary of the postkinematic alkali-feldspar granite suite, Jabal Habashi quadrangle, sheet 26F

name	outcrop features	color/texture	color index	average composition	petrographic comment
		ALKALI-FELDSPAR GRANITE			
SALMA PLUTON	forms rugged topography controlled by prominent NE-trending joint system; is part of major granite complex, mainly exposed in Baq'a' quadrangle to north; intrudes Kilab pluton	light gray, medium to coarse grained, hypidiomorphic granular.	5	plagioclase: 10% K-feldspar: 63% quartz: 32% combined mafics: 3%	COMPOSITION: biotite alkali feldspar granite; part of granite complex stretching north of quadrangle and including biotite syenogranite, quartz syenite porphyry, monzogranite and diabase dikes. COMPOSED OF: subhedral perthitic orthoclase, subhedral quartz, and minor subhedral albite; no data on accessory minerals; locally peralkaline (acmite normative).
GUSAL PLUTON	forms narrow, elongate, north-trending pluton; intrudes Kilab pluton.	pink to gray, hypidiomorphic inequigranular, porphyritic		plagioclase: 10% K-feldspar: 65% quartz: 35% biotite: 4% hornblende: trace	COMPOSITION: alaskitic, alkali-feldspar granophyre, alkali-feldspar quartz-syenite granophyre, and alkali-feldspar granite. COMPOSED OF: hornblende and(or) biotite microcline or quartz and microcline phenocrysts; locally peralkaline (acmite normative).
		MUSCOVITE-BEARING ALKALI-FELDSPAR GRANITE			
HUDUB PLUTON	forms circular pluton 15 km in diameter; marked by annular magnetic anomaly; surrounding subdued signature over the pluton; intrudes Laban complex and Hibshi formation.	light gray to pinkish gray, massive, medium to coarse grained, allotriomorphic to hypidiomorphic granular; chilled border phase at contact with Hibshi formation.		plagioclase: 30% K-feldspar: 38% quartz: 27% combined mafics: 1%	COMPOSITION: alaskitic, biotite-magnetite alkali-feldspar granite. COMPOSED OF: subequal twinned albite, microcline (locally perthitic or microperthitic) and quartz; minor magnetite, biotite and trace muscovite; border phase is biotite-bearing quartz-microcline-plagioclase granite porphyry containing very fine-grained intergranular quartzo-feldspathic groundmass.
USBA PLUTON	forms window in cover rocks; size unknown; relative age unknown; radioactivity 2x background	undeformed, fine- to medium-grained, allotriomorphic inequigranular; no mafic intrusions		plagioclase: 28% K-feldspar: 35% quartz: 30% muscovite: 7%	COMPOSITION: muscovite alkali-feldspar granite. COMPOSED OF: subhedral, unzoned, albite laths as long as 1.5 mm; interstitial anhedral, nonperthitic microcline; subhedral quartz; colorless to olive green or pale tan pleochroic muscovite; no mafic silicates; accessory fluorite and zircon, trace opaque oxides; weakly peraluminous.
FAWWARAH ALKALI-FELDSPAR GRANITE	forms part of Silsilah ring structure; contains greisen and Sn mineralization; contains no mafic inclusions; associated with radioactive anomaly; intrudes Maraghan formation.	light gray fine to to medium grained, allotriomorphic equigranular.		plagioclase: 23% K-feldspar: 35% quartz: 35% biotite: 4% muscovite: 2%	COMPOSITION: muscovite-biotite alkali-feldspar granite. COMPOSED OF: anhedral, unzoned albite (An less than 5); perthitic microcline, poikilitically enclosing plagioclase and quartz; subhedral, interstitial, colorless to light brown pleochroic biotite; subhedral interstitial, colorless to pale-tan or pale-bluish-green pleochroic muscovite; accessory interstitial fluorite, topaz, zircon (esp. in micas); trace opaque oxides; weakly peraluminous; associated with Sn greisen.

Table 6.--continued

name	outcrop features	color/texture	color index	average composition	petrographic comment
				SODA-PYRIBOLE-BEARING ALKALI-FELDSPAR GRANITE	
SILSILAH ALKALI-FELDSPAR GRANITE	forms part of Silsilah ring structure; intrudes Maraghan formation;	light gray, mainly holocrystalline fine-grained allotriomorphic inequigranular; contains no mafic inclusions.	5	plagioclase: 9% K-feldspar: 69% quartz: 17%	COMPOSITION: predominantly soda-pyribole bearing alkali-feldspar granite, containing subordinate devitrified rhyolite and porphyritic micrographic granite. COMPOSED OF: incipiently exsolved phenocrysts of K-feldspar and phenocrysts of quartz in a fine-grained matrix of quartz and alkali feldspar in graphic intergrowths; includes mafic silicate suite of arfvedsonite, aegirine, aenigmatite, katophorite and ferroedenite; accessory zircon fluorite and opaque oxides; peralkaline.
SHURMAH RING STRUCTURE	forms 10 to 100 m wide, 15x27 km oval ring dike; locally feeds thin easterly trending dikes; intrudes Laban complex and Kilab pluton.	pinkish-gray to pink, fine grained allotriomorphic granular, graphic or granophyric.	5	plagioclase: 11% K-feldspar: 67% quartz: 21% combined mafics: 3%	COMPOSITION: variable; alastikic, and biotite- or soda-pyribole-bearing alkali-feldspar granite and orthoclase quartz porphyritic granite porphyry. COMPOSED OF: euhedral to subhedral orthoclase and quartz phenocrysts; orthoclase pervasively sericitized; locally contains minor sub-calcic amphibole (arfvedsonite?); accessory fluorite and muscovite; peralkalic granite (acmite normative).
Unnamed pluton NE of Jabal Aba al Liqah	forms extremely recessively weathering irregular oval pluton, 45 km^2; contains few dikes; intrudes Turmus formation, local radioactivity 2x background.	undeformed, grayish-orange pink, medium grained, allotriomorphic inequigranular		plagioclase: 24% K-feldspar: 44% quartz: 30% hematite: 2%	COMPOSITION: alkali-feldspar granite. COMPOSED OF: anhedral to subhedral, albite-twinned plagioclase laths as much as 1 mm long; as anhedral, gridiron-twinned, strongly perthitic microcline; anhedral quartz grains, 4 mm in diameter; generally no mafic minerals, excepting hematite; one sample contains biotite altered to chlorite; trace zircon, sphene, apatite, and fluorite; peralkaline affinity.

percent primary muscovite and by accessory fluorite. The Fawwarah pluton additionally contains accessory topaz. In common with granites discussed above, the mineralogical features of the rock are indicative of metallogenically specialized granites (Tischendorf, 1977), and they plot in or close to the field of S-type granites favorable for tin and tungsten mineralization (Chappell and White, 1974; du Bray, in press; 1984b, unpub. data). Tin greisen is developed in parts of the Fawwarah granite, beneath the Hadhir aplite, and tin, beryllium, niobium, molybdenum, and copper concentrations are found in stream sediment derived from the granite (Allen and others, 1984).

Soda-pyribole-bearing alkali-feldspar granite.--Alkali-feldspar granites of comparatively variable composition are compiled in this unit (afgs) (Table 6, fig. 7b), but they are characterized by the presence of soda-pyribole minerals and (or) a strong peralkaline affinity. They are allotriomorphic inequigranular, tend to be finer grained than other members of the alkali-feldspar granite suite, and vary in color from light gray to pink and orange. Two examples of the granite occur in ring structures, the Silsilah and the Shurmah granites (du Bray, in press; Pallister, 1984, unpub. data). The third example is irregularly oval in shape. In the Silsilah granite quartz and potassium feldspar occur as phenocrysts, the latter incipiently exsolved, contained in a fine-grained graphic intergrowth of quartz and alkali feldspar. The rock contains no mafic inclusions, and has a color index of 5 resulting from a mafic silicate suite of arfvedsonite, aegirine, aenigmatite, kataphorite, and ferroedenite. Kataphorite is locally replaced by arfvedsonite and occurs as overgrowths on aegirine. Accessory minerals include opaque oxides, zircon, and fluorite.

In parts of its eastern and northeastern sectors, the Silsilah ring structure manifests small exposures of fine-grained aphanitic or locally porphyritic rocks within the alkali granite (du Bray, in press). Too small to be shown at map-scale in the compilation, these bodies of rock include devitrified rhyolite and porphyritic microgranite. They consist of round phenocrysts of quartz and euhedral perthitic potassium feldspar in a felsophyric groundmass. Locally, the rocks are characterized by a felted texture of fine-grained feldspar laths; elsewhere micrographic intergrowth of quartz and alkali feldspar is common. The only accessory grains are doubly terminated crystals of zircon.

Alkali-feldspar quartz syenite granophyre.--Small bodies of biotite alkali-feldspar quartz syenite granophyre (afsy) intrude the Salma pluton as dikes 10 to 100 m thick and as an irregular roof-carapace (Pallister, 1984, unpub. data). The rock is light gray, fine grained, and porphyritic. It has a color index of less than 5, and contains fine-grained phenocrysts a few millimeters long, composed of subhedral microperthitic orthoclase, subhedral to anhedral quartz, and subhedral to anhedral albite in a granophyric groundmass of microperthitic orthoclase and quartz, and minor albite and quartz.

Aplite

Aplite (ap) crops out in a small resistant plug about 1 km^2 in size, 6 km southwest of Shuwayman, and in a sheet-like mass less than 50 m thick atop the hills on the southwest side of the Silsilah ring structure. The aplite sheet is named the Hadhir aplite by du Bray (in press). The plug of aplite intrudes, and is therefore younger than, the Ghinaymawat granodiorite. In the ring structure, the Hadhir aplite subhorizontally overlies the Fawwarah alkali-feldspar granite, but predates the granite (E. A. du Bray, oral commun., 1984)

The aplite is fine grained, aphanitic to saccharoidal, and characterized by an allotriomorphic granular to inequigranular texture. In the plug, the aplite is subporphyritic, and contains anhedral plagioclase phenocrysts. Biotite is the sole mafic silicate, and forms less than 1 percent of the rock. Other minerals include traces of muscovite, and opaque oxides. The Hadhir aplite plots in the quartz monzonite and quartz syenite fields (fig. 7c); biotite, containing abundant zircon grains, comprises about 1 percent of the rock. Scarce, round phenocrysts of quartz and ragged phenocrysts of biotite, 2 mm long, give the rock a distinctive subporphyritic appearance. In the matrix, plagioclase is present as anhedral, unzoned grains of albite, and anhedral, perthitic grains of potassium feldspar poikilitically enclose quartz and plagioclase. Locally, the matrix is characterized by a graphic intergrowth of quartz and feldspar. Accessory minerals include zircon and fluorite.

Quartz veins and plugs

Late-stage segregations of quartz (q) occur in several parts of the quadrangle, particularly as plugs of quartz in monzogranite and syenogranite plutons, and as veins in the Maraghan formation and diorite of the Aydah suite.

The plugs are composed of massive, milky-white, unmineralized quartz probably derived from the hosting granites (du Bray, 1984a). They weather as conspicuous, low mounds of quartz rubble.

Quartz veins are particularly common in the Maraghan formation or within and adjacent to small plutons of the Aydah suite. The quartz is predominantly milky white but harbors local iron-stained fractures, notably in the vicinity of ancient gold workings. Individual veins are of limited extent, and their geometry is controlled by the regional fracture system (Smith and Samater, 1984). Quartz-rich lag deposits resulting from weathering of the veins provides a highly reflective weathered surface over parts of the Maraghan formation.

Dikes

Dikes are ubiquitous in the plutonic rocks of the quadrangle but prominent swarms are particularly associated with the Laban complex, the Muwashsham and Dhibiyah plutons of the Aydah suite, and the Kilab and Shuwayman plutons. The dikes were mapped largely from aerial photographs and their compositions were inferred from their color and phenocryst composition.

Felsic, mafic and undifferentiated dikes are shown in the Laban complex. They include metarhyolite, meta-andesite, granophyre, granite, and metadiabase (Pallister, 1984, unpub. data). Most of the felsic dikes also intrude the Kilab monzogranite and are related to post-Murdama granitic rocks. Mafic dikes are more common in the Laban complex than in the younger plutons.

The Muwashsham quartz monzodiorite pluton is cut by a set of north-northwest-trending mafic dikes composed of basalt and andesite. They weather grayish black and are typically fine grained and porphyritic. Trachytic flow textures are prominent and the rocks are composed of calcic plagioclase phenocrysts and lesser amounts of hornblende in a fine-grained matrix of plagioclase, actinolite, and (or) chlorite, and as much as 10 percent iron oxides (du Bray, in press). The otherwise similar basalt and andesite dikes cutting the Dhibiyah pluton trend approximately east-west.

The Kilab pluton contains a conjugate set of dikes (Pallister, 1984, unpub. data). Red- or pink-weathering altered rhyolite or alkali-feldspar granophyre dikes, and light-gray- to tan-weathering altered dacite to andesite and rare trachytic dikes trend west-northwest. They are cut by a younger northwest-trending set of basaltic and andesitic dikes. The latter parallel northwest-trending faults in the area and displace the older felsic dikes with the left-lateral sense of movement typical of Najd faults. In contrast, a major set of undifferentiated northwest-trending dikes in the Shuwayman pluton cut and displace a conjugate set of mafic to felsic dikes by both left- and right-lateral senses of movement. The felsic dikes have a distinctive field appearance; they usually weather brick-red and are strongly porphyritic. Rounded phenocrysts of quartz and euhedral, though exsolved, phenocrysts of potassium feldspar are conspicuous, and are set in a fine-grained matrix composed of micrographic intergrowths of quartz and alkali-feldspar, or unidentified fine-grained allotriomorphic granular material. Biotite, muscovite, and chlorite are common (du Bray, in press).

PALEOZOIC ROCKS

Flat-lying Paleozoic rocks of the Saq Sandstone and Tabuk formation crop out in the northeastern third of the Jabal Habashi quadrangle. The rocks were originally mapped by Bramkamp and others (1963), and were discussed by Powers and others (1966). A detailed study of the Phanerozoic rocks of the Jabal Habashi quadrangle has been undertaken by D. Vaslet and other geologists of the Bureau de Recherches Geologiques et Minieres Saudi Arabian Mission. The results of this work are not yet published; consequently this report only includes summary descriptions of the two units taken from Bramkamp and others (1963), and du Bray (1983a).

The rocks nonconformably overlie the Precambrian basement and local relief on the erosion surface appears to be small, probably not greater than 10 m (du Bray, *in press*). Locally, Precambrian rocks composed of the Usba granite and the Makhul complex appear in small windows in the Saq Sandstone.

Saq Sandstone

The Saq Sandstone (O€s) is a buff to gray and white, moderately well-sorted sandstone composed of medium to coarse, subangular to subrounded grains of monocrystalline quartz that show various degrees of strain. The carbonate cement is locally replaced by ferruginous material that case hardens the sandstone and gives it a reddish-brown color. Polycrystalline quartz grains are a trace component. The sandstone is relatively well compacted and is grain supported. Porosity ranges from 20 to 30 percent.

Within the area mapped by du Bray (1983a), the Saq Sandstone is homogeneous. Neither silty, conglomeratic, shaley, nor pebbly beds were observed, although such beds are reported to occur elsewhere in the formation (Bramkamp and others, 1963). The sandstone is massively bedded although small-scale crossbedding is locally present. Close to the contact with the Tabuk formation the sandstone is shown to be approximately 600 m thick in a section constructed by Bramkamp and others (1963). Powers and others (1966) provide a summary of the efforts made to establish the age of the Saq Sandstone, and indicate that it records Early Cambrian through Early Ordovician sedimentation.

Tabuk Formation

The Tabuk Formation (DSOt) overlies the Saq Sandstone. Bramkamp and others (1963) report that it is a buff, brown, and red- to pink- and light-gray sandstone that is locally micaceous and silty. Three sandstone units and three shale units, found at the base of the Formation and between the sandstone units form a 700-m-thick section near the northeastern corner of the quadrangle. The uppermost brown and tan sandstone (DSOtc) transgresses the lower and middle parts of the Formation and comes to rest upon the Saq Sandstone (Bramkamp and others, 1963). Micaceous, silty, and sandy-shale members are blue gray, olive brown, olive green, purple, and varicolored. A discussion of the Tabuk Formation, including its heavy-mineral suite, is presented by Powers and others (1966). The sandstones are locally crossbedded and contain abundant scolite. The lowermost part of the Tabuk Formation contains graptolites, and palecypods, gastropods, and brachiopods are locally present 500 m above the base. From this fossil evidence, Powers and others (1966) suggest that the Tabuk Formation represents deposition from Early Ordovician through Early Devonian time.

CENOZOIC ROCKS AND DEPOSITS

Tertiary to Quaternary volcanic rocks

Alkali-olivine basalt crops out in the northwestern part of the quadrangle as the southern extremity of Harrat al Hutaymah, a basalt field composed principally of flow rocks, but also including cinder cones and explosive tuff-ring deposits. The volcanic centers form two major north-trending chains, and basalt extrusion may have been fracture controlled. The westerly chain is dominated by tuff rings, the easterly chain by cinder cones (Coleman and others, 1983). As summarized by these authors it is generally agreed that the basaltic rocks are the result of volcanism associated with the rifting of the Arabian-Nubian Shield and the Cenozoic opening of the Red Sea. Together with coeval lava fields in the Yemen Arab Republic and Ethiopia, the extrusive rocks in Saudi Arabia represent one of the largest provinces of alkali-olivine basalt in the world, although within Arabia, Harrat al Hutaymah comprises the smallest of the lava fields and is the most distant from the Red Sea spreading axis.

Within the quadrangle, exposure of the volcanic rocks is discontinuous, concentrated around separate volcanic cones. Farther north the volcanoes and their explosive products coalesce and completely cover the Precambrian rocks. A single K-Ar date, obtained from flow rocks in a volcanic cone at the northern margin of the quadrangle gives an age of 1.80 ± 0.05 Ma (Pallister, 1984, unpub. data).

Basaltic tuff

Annular rings of basaltic tuff (Qtf) surrounding phreatomagmatic explosive centers are the most distinctive feature of the lava field in the quadrangle. The rings consist of poorly consolidated and poorly sorted, massive to bedded layers of basaltic tephra. The tephra includes basaltic ash, cinder, and spatter lava, blocks and bombs of alkali-olivine basalt and xenoliths of peridotite, diorite, and granitic rocks. The matrix contains abundant xenocrysts of olivine, pyroxene, and amphibole, as much as 75 percent glass, and moderately abundant flattened pumice blocks.

Where measured in the crater walls at the explosive centers, the tuff forms deposits as much as 250 m thick. In bedded sections, the deposits are present in cyclically graded layers, a few centimeters to about 5 m in thickness; both upward-fining and upward-coarsening graded layers occur (Pallister, 1984, unpub. data), the latter being typical of base-surge deposits.

In parts of the lava field, thin blankets of alluvially reworked basaltic tuff (Qtr) form outwash aprons around the volcanic craters. The reworked tuff consists of tuffaceous sand and silt deposited in small channels on the flanks of the tuff rings and extending as a thin veneer over the surrounding area (Pallister, 1984, unpub. data).

Alkali-olivine basalt

Aa and minor pahoehoe flows of alkali-olivine basalt (Qb) are present in a few parts of the quadrangle. Marked by very flat tops, the flows are as much as 10 km long, several kilometers wide, and a few meters thick. They emanate from breached cinder cones or from fissure vents associated with or overlain by cinder-cone deposits. The basalt is characterized by anhedral to subhedral olivine phenocrysts as much as 3 mm in diameter. Many flows also contain clinopyroxene phenocrysts, and some contain spinel phenocrysts (Pallister, 1984, unpub. data). Trachytic flow banding of euhedral plagioclase laths is common, but vesicles are not extensively developed. The groundmass is an intergranular mixture of plagioclase, opaque oxides, and augite. Most flows contain sparse peridotite xenoliths and olivine or pyroxene xenocrysts derived from peridotite (Pallister, 1984, unpub. data) although these are not as common as in the tuff rings.

Cinder cones

Cinder cones (Qc) aligned along northwesterly trends are present in the area north of the Shurmah ring structure. The cones consist of unconsolidated to agglutinated olivine basaltic cinder, spatter, and bombs. Rare granitic or dioritic xenoliths are present, but peridotite xenoliths are generally lacking.

Tertiary to Quaternary gabbro

The poorly exposed quartz monzodiorite body at the northeastern end of Jabal Witidah is host to several small, irregular olivine gabbro plugs (QTgb). One sample of black equigranular hypidiomorphic rock contained about 60 percent calcic plagioclase, 20 percent fresh olivine containing abundant minute inclusions of opaque minerals, 15 percent hypersthene, and 5 percent brown, probably uralitic hornblende. An absence of alteration of the mafic minerals suggests that the rock may be of Cenozoic age and related to Cenozoic volcanic rocks in the northwest of the quadrangle (Williams, 1983).

Quaternary surficial deposits

Large areas of the quadrangle are mantled by surficial deposits of Quaternary age that commonly conceal geologic relations between bedrock units. The Quaternary units are divided into duricrust, lag deposits, eolian deposits, alluvial fan deposits, alluvium, and sabkhah deposits, but no attempt has been made to determine the relative ages of the different sediment types.

Duricrust

Calcareous duricrust (Qdc) occurs in the northeastern part of the quadrangle. where it forms small, flat, smooth-surfaced mesas bounded by scarps several meters high. It commonly masks the underlying rocks by forming a protective carapace on easily eroded rocks of the Tabuk formation. The crust, which varies in thickness from a few centimeters to three or four meters, consists of gravel cemented by red, brown, gray, tan, and yellow sandy limestone.

Lag deposits

In parts of the Wadi Mahalani drainage area in the southeast of the quadrangle, the Maraghan formation is eroded to a flat plain mantled with white chips of quartz mapped as lag deposits (Qtl). This mantle is 0.5 to 1 m thick and results from the mechanical erosion of quartz veinlets, 0.5 to 5 cm thick, that are abundant in the Maraghan formation (Williams, 1983).

Alluvial fan deposits

Aprons of poorly sorted material formed by coalescing alluvial fans (Qg) flank Jabal al Khidar, Jabal al Musawda'ah, Jabal at Tin, Jabal as Silsilah, and Jabal Aba al Liqah. The coalescing deposits consist of gravel containing cobble-to-boulder sized, subangular to subrounded clasts, in poorly sorted silt to coarse-sand matrix. The base of the gravel is rarely exposed; laterally migrating distributary channels are incised as much as 15 m below the alluvial fan surface, and are filled with angular material ranging from silt to boulder size.

Alluvium

Drainage in the Jabal Habashi quadrangle consists of a branching network of generally shallow intermittent stream channels. Alluvium (Qa) in the channels consists of a light-brown mixture of sand, silt, clay, and, in larger wadis, fine gravel, no thicker than 1 to 2 m. In active channels the alluvium is moderately to well sorted, but adjacent to areas of high relief the channel-fill includes poorly sorted colluvium and talus, and in the larger streams includes fine wind-blown material.

Sabkhah deposits

Sabkhah deposits (Qsb) form beds of intermittent playa lakes. They are common in the northeastern corner of the quadrangle, where they lie on strike valleys of the Tabuk formation, but are found less commonly throughout the area, in areas of low relief. The deposits consist of light-brown silt, clay and sand, mixed with saline layers and encrustations resulting from the evaporation of water accumulating from sporadic rainfall.

GEOCHRONOLOGY

Compared to other quadrangles in the Arabian Shield, few radiometric dates from samples within the Jabal Habashi quadrangle exist in the published literature. Biotite mineral ages are reported by Aldrich (1978) for the Muwashsham quartz monzodiorite, referred to in the reference as the Jabal at Tin granite, and samples of the Qutn syenogranite were recently dated by Stuckless and others (1984). Other dates listed in table 7 are preliminary results of works in progress.

Layered rocks

Establishing correlations among the slightly metamorphosed, moderately deformed layered rocks of the northeastern Shield is particularly difficult because of the similar lithology of many of the units. Absolute age data are therefore very important. A preliminary result of U-Pb measurements on zircon from dacite in the type area of the upper volcanic member of the Hibshi formation yields an age of 632+6 Ma (C. E. Hedge, written commun., 1983, cited in Pallister, 1984). The Hibshi formation and Murdama group are currently being studied using the techniques of basin analysis and additional radiometric determinations are underway (C. A. Wallace and P. J. Rowley, oral commun., 1984, cited in Pallister, 1984, unpub. data). The Hibshi formation is intruded by the Nimriyah monzogranite and rests on the Laban complex. The monzogranite is dated by the U-Pb method at 616±10 Ma, and the underlying complex is dated at 646±6 Ma, using the same method. Therefore, the 632±6 Ma age for the upper volcanic

Table 7. Radiometric-age determinations for rocks within the Jabal Habashi quadrangle, Sheet 26F

Location number and name	sample type	method	date	source
PROTEROZOIC LAYERED ROCKS				
1. Hibshi formation, upper volcanic member dacite	zircon	U-Pb	632±6 Ma	1
PRE-MURDAMA INTRUSIVE ROCKS:				
2. Laban complex	zircon	U-Pb	646±6 Ma	2
POST-MURDAMA INTRUSIVE ROCKS:				
3. Dhibiyah granodiorite	zircon	U-Pb	617±5 Ma	2
4. Nimriyah monzogranite	zircon	U-Pb	616±10 Ma	2
5. Jabal at Tin granite	biotite	Rb-Sr	610±40 Ma	3
	biotite	K-Ar	645 Ma	3
POSTKINEMATIC INTRUSIVE ROCKS:				
6. Qutn syenogranite	whole rock	Rb-Sr*	579±4 Ma	4
CENOZOIC ROCKS:				
7. Harrat al Hutaymah	Tertiary	K-Ar	1.80±0.05 Ma	5

*Initial ratio: 0.7055±.0011
sources: 1. C. E. Hedge, written commun., 1983, cited in Pallister, 1984, unpub. data; 2. J. C. Cole and C. E. Hedge, unpublished data, 1983; 3. Aldrich, 1978; 4. Stuckless and others, 1984; 5. J. S. Pallister, 1984, unpub. data.

member is consistent with reported geologic relations.

Alkali-olivine basalt at the Harrat al Hutaymah tuff-ring crater close to the northern margin of the quadrangle has a K-Ar age of 1.80±0.05 Ma (Pallister, 1984, unpub. data). This age is approximately that of the Tertiary-Quaternary boundary, 1.80 Ma (van Eysinga, 1975). The Harrat al Hutaymah lava field is therefore designated a Tertiary-Quaternary map unit. Elsewhere in Arabia, Cenozoic volcanic rocks are as old as 30 Ma, associated with initial spreading of the Red Sea rift. Sporadic eruptions continued through the Miocene, but a phase of vigorous, renewed spreading within the Red Sea basin, about 4 to 5 Ma ago, resulted in an increase in volcanism which has persisted into historic times (Coleman and others, 1983). The

Harrat al Hutaymah lava field belongs to this renewed episode of eruption.

Intrusive rocks

Limited radiometric data, consistent with observed geologic relationships in the quadrangle, indicate that three episodes of magmatic activity were largely responsible for emplacement of the plutonic rocks in the quadrangle. A U-Pb date of 646±6 Ma (J. C. Cole and C. E. Hedge, unpublished data, 1983), for zircon extracted from the Laban complex, gives a minimum age for the oldest episode. The complex is believed to be the youngest pre-Murdama plutonic rock in the area (Williams, 1983); it intrudes the amphibolite and hornblende-feldspar-quartz schist units (am, as), is overlain by the Hibshi formation, dated at 632 Ma, and is intruded by the post-Murdama monzogranite of the Kilab pluton.

U-Pb ages for the broadly coeval Dhibiyah granodiorite, at 617±5 Ma, and Nimriyah monzogranite, at 616±10 Ma (J. C. Cole and C. E. Hedge, unpublished data, 1983), delimit emplacement of the post-Murdama intrusive episode. The Nimriyah pluton cuts the Hibshi formation; the Dhibiyah pluton is probably a relatively young member of the Aydah suite.

In a study of the postkinematic granites in the northeastern Shield, Stuckless and others (1984) conclude that granites north of the main zone of Najd faulting are between 580 and 565 Ma old. This group of granites includes the Qutn pluton, which was sampled on its northern margin within the Jabal Habashi quadrangle, and yielded a six-point Rb-Sr isochron of 579±4 Ma. The result is very similar to those obtained in the same study from Jabal Aban al Ahmar (574±5), south of the quadrangle, and from the Salma granite complex (580±5) in the southwestern part of the Baq'a' quadrangle, immediately to the north.

The reliability of the biotite mineral ages obtained for the Muwashsham quartz monzodiorite at Jabal at Tin (Aldrich, 1978) is uncertain. On the basis of data from elsewhere in the Shield (Fleck and others, 1976), it is expected that a regional thermal heating event may have reset K-Ar ages, resulting in a date lower than the age of intrusion, although comparison with the Rb-Sr mineral data suggests that the resetting may not have happened in this instance.

STRUCTURE

The Proterozoic rocks of the Jabal Habashi quadrangle constitute two contrasted structural regions. Northwest of the outcrop of the sub-Hibshi unconformity surface is a region containing pre-Murdama structures and locally superimposed post-Murdama faults; to the southeast is a terrane of younger rocks which display post-Murdama structures.

Pre-Murdama structures

Pre-Murdama structures in the quadrangle are preserved in the amphibolite and hornblende-feldspar-quartz schist exposed beneath the Hibshi formation. They include a weakly to moderately well developed metamorphic foliation, associated with centimeter- to meter-scale isoclinal folds, and lineations parallel to the small fold axes. The foliation planes tend to be steeply dipping, but changes in attitude across exposed parts of the rock units reflect the presence of larger-scale, northerly plunging anticlines and synclines.

Amphibolite and schist are associated with variably deformed and metamorphosed mafic rocks of the Laban complex, and are intruded by gneissic quartz monzodiorite of the Samirah pluton. Some structures in the layered rocks obviously reflect the tectono-metamorphic events which affected the plutonic rocks although, in general, the grade, and therefore the age, of the metamorphism in the layered rocks appears to be greater than that of the Laban complex.

Post-Murdama structures

Folds

Large- to small-scale folds, both broad, open and isoclinal, are widespread and common in the layered rocks in the southern part of the quadrangle (du Bray, in press). They are particularly conspicuous on aerial photographs and Landsat images. In general, the fold axes plunge steeply, trend northeast to north-northeast, and bedding dips subvertically. Two large synclines occur in the Maraghan and Hibshi formations; an anticline in the Maraghan formation has been intruded by the Mahalani pluton.

Minor folds are mapped in the Maraghan formation west of the Silsilah ring structure. They mainly trend east and have wave-lengths of about 1-2 km. These folds are generally symmetrical and have dips of 60-80° on both limbs (Williams, 1983).

Fracture cleavage

Most of the metasedimentary rocks are cut by a well-developed, near-vertical fracture cleavage. In the southcentral part of the quadrangle the cleavage trends about N 60° W; trends elsewhere are not reported. The cleavage affects all rock types, although the spacing varies considerably. In coarse conglomerate of the Hibshi formation the cleavage is present as irregular fractures some 20 to 30 cm apart. Sandstones in the Hibshi and Maraghan formations possess steeply dipping, generally irregular fracture cleavage composed of planes spaced 1 to 5 cm apart (Williams, 1983). In contrast, slaty cleavage is well developed in argillaceous rocks in both the Hibshi and Maraghan formations; spacing of the cleavage planes is a few millimeters or less, and contributes to the poor resistance to erosion of the rocks. The fracture cleavage appears to be a regional structural feature, although its relationship to folding in the area is, as yet, unexamined. Pebbles in some conglomerate, particularly in the Qarnayn formation, are flattened in the plane of the cleavage. Northeast of Jabal Raha, the long axes of the clasts range between 2 and 25 cm, and their length-width ratios vary between 2:1 and 10:1 (du Bray, in press). The elongation of the clasts lies within a plane of steeply dipping cleavage parallel to bedding and imparts a subhorizontal linear fabric to the rock. The upper lenses of conglomerate are less cleaved and their clasts are less elongate; the greatest degree of elongation appears to be present in regions where two cleavages co-occur (du Bray, in press).

Raha fault zone

Faults of several types cut the rocks of the quadrangle. The most complicated are structures in the Raha fault zone, a major structural discontinuity which trends irregularly from east to west across the southern part of the quadrangle (du Bray, in press). The fault zone is most clearly traced from southeast of Bu'qaya, past Jabal ar Raha as far as the Ghinaymawat pluton. Farther west, the zone is extensively cut by intrusions and terminates against, or is offset by, the Safaq transcurrent fault. In its central part, near Jabal ar Raha, the fault zone consists of two nearly parallel faults bounding a zone within which numerous, smaller imbricate faults occur. The two principal fault strands are locally several kilometers apart and are characterized by the presence of mafic and ultramafic rock, and spinel-bearing carbonate rock, or listwanite derived from alteration of peridotite. The faults separate a terrane to the north characterized by high-frequency magnetic anomalies, from a second terrane to the south characterized by a relatively homogenous magnetic signature.

West of the Ghinaymawat pluton, the fault zone appears to consist of only one fault, separating the Qarnayn from the Maraghan formation. In the east of the quadrangle no faults are mapped, but poorly exposed metagabbro and carbonate material which outcrops between the Bu'qaya formation and the Dulaymiyah pluton are interpreted by du Bray (1983a) to represent the trace of the fault zone. Large plutons occur in this part of the quadrangle, obliterating much of the structure in the layered rocks.

The origin of the Raha fault zone is uncertain. The presence of listwanite and a tentative identification of the high-pressure mineral glaucophane in metagabbro (du Bray, in press) suggest that the fault zone may penetrate the crust to a considerable depth. The sense of movement on the fault is unknown. Du Bray (in press) suggests that it is a relatively low-angle thrust dipping north, along which an allochthonous terrane of the Qarnayn and Bu'qaya formations has been thrust over the younger Maraghan formation. Farther west the fault zone appears to be a steep normal fault with the south side down (Williams, 1983). Alternatively, however, the fault may equally well be an overthrust dipping steeply to the south. According to this model, the thrust would subparallel the bedding, and form a surface along which the Maraghan formation was thrust north over the Qarnayn formation. If this model is correct, it implies that the thrust fault along Jabal Witidah, which continues into the Wadi ash Shu'bah quadrangle (Quick, unpub data) is a continuation of the Raha fault zone, offset by the transcurrent Safaq fault. Because it is cut by the Aydah and Shuwayman suites, the fault zone is older than 617 Ma, but is presumably younger than the Hibshi formation dated at 632 Ma.

Transcurrent faults

Several transcurrent faults associated with left-lateral displacement occur in the western part of the quadrangle. Along the Safaq fault the sub-Hibshi unconformity shows only small offset, but towards the southeast the displacement increases and the fault separates Maraghan formation on the south from Hibshi formation on the north. For part of its length, the fault is flanked on the northeast side by the Jibalah (?) group.

The Al Birka fault, between Jabal al Khidar and Jabal Habashi, is a left-lateral transcurrent fault offsetting the Hibshi formation and associated vertical dikes by some 3 km (Pallister, 1994, unpub data). It cuts the Kilab pluton in the northwest but terminates against the Shuwayman pluton in the southeast.

The Safaq fault coincides with a strong aeromagnetic lineament and the Al Birka fault approximately coincides with a linear magnetic boundary (M. D. Kleinkopf, written commun., 1984). On this basis it is expected that a strong linear aeromagnatic anomaly in the southeastern part of the quadrangle also marks a fault line, although no structural discontinuity has yet been observed at surface (du Bray, 1983a). In their sense of movement and relative age, the transcurrent faults are similar to Najd-type faults mapped throughout the northern Shield (Moore, 1979), except that elsewhere such faults tend to be major, through-going structures. Movements on the faults in the Jabal Habashi quadrangle appear to be of several ages. The Al Birka fault cuts monzogranite of the Kilab pluton, but does not displace monzogranite of the Shuwayman pluton; this implies that movement on the fault had ceased by about 616 Ma, the age of some members of the Shuwayman suite. Conversely, a small fault southwest of Jabal Shurmah displaces the Shurmah ring structure, one of the postkinematic granites of the quadrangle; this fault was therefore active at least until about 580 to 565 Ma, the age of such granites in the northeastern Shield.

METAMORPHISM

In general, the late Proterozoic layered rocks in the Jabal Habashi quadrangle have been subjected to only very low-grade metamorphism; exceptions include the pre-Murdama rocks, and rocks within the thermal aureoles of post-Murdama Aydah suite intrusions.

Within the pre-Murdama rocks (am, as), amphibolite-grade, synkinematic prograde regional metamorphism accompanied by penetrative deformation resulted in well-developed gneissic foliations and a mineral assemblage which includes hornblende-oligoclase-epidote-quartz. The protoliths were probably interbedded mafic volcanic and clastic rocks.

Metasedimentary rocks in the Qarnayn, Bu'qaya, and Maraghan formations generally contain matrix-mineral assemblages of fine-grained sericite, chlorite, epidote, and quartz, whereas metavolcanic rocks contain partially sericitized plagioclase and mafic minerals replaced by calcite, epidote, and tremolite-actinolite. These assemblages represent low-greenschist metamorphic facies but, in places, and particularly within the Qarnayn formation, mineral assemblages of higher metamorphic grade are present. Du Bray (in press) interprets the characteristic higher metamorphic grade of the Qarnayn formation as caused by a metamorphic event predating deposition of the Maraghan formation. In the Qarnayn formation, all argillaceous material has been converted to fine-grained aggregates of biotite and lesser sericite. Metarhyolite and metabasalt in the Qarnayn formation contain metamorphic assemblages diagnostic of amphibolite-facies conditions, including epidote in irregular granular clusters, anhedral clusters of almandine-spessatine garnet, and hornblende which is locally altered to actinolite.

Younger layered rocks in the quadrangle are weakly altered. The rhyolite of the Raha formation contains partially sericitized plagioclase and slightly altered biotite; the Hibshi formation has undergone zeolite or lower-greenschist metamorphism and mafic silicates in rhyolite and basalt in the formation are replaced by chlorite or by fine-grained aggregates of chlorite and epidote; the matrix of the Jibalah group contains fine-grained sericite, chlorite, quartz, and calcite.

Contact metamorphic aureoles are well developed adjacent to mafic to intermediate plutons of the post-Murdama Aydah suite, and around the Qutn pluton, but few other post-Murdama or postkinematic intrusive rocks appear to have had much effect on their wall rocks. Metasedimentary rocks surrounding the plutons occupy a darkened zone as much as 1 km wide. Sedimentary structures are partially preserved, although overall, the rocks in these zones are slightly more indurated than elsewhere, and are characterized by a hornfelsic texture. Randomly oriented red-brown biotite, muscovite, and tremolite-actinolite are present in sandstone and shale; at the contact with the Qutn syenogranite, one sample of Maraghan formation shale is entirely recrystallized to fine-grained quartz, muscovite, biotite, and cordierite (Williams, 1983). At Jabal al Muwashsham, marble in the Maraghan formation contains abundant calc-silicate minerals (Williams, 1983).

An additional feature of thermal metamorphism in the region is the growth of metamorphic magnetite (du Bray, in press). Magnetite of detrital origin may be responsible for the close-spaced, moderate-amplitude magnetic signature characteristic of the Qarnayn lithic graywacke at Jabal al Muwashsham but metamorphic magnetite is responsible for the annular zones of negative anomalies enclosing the Qutn syenogranite, the Mahalani granodiorite, and other plutons.

SUMMARY OF GEOLOGIC HISTORY

The Precambrian rocks of Jabal Habashi quadrangle record a short period of late Proterozoic earth history, from about 740 Ma to about 565 Ma. This relatively compressed period of time is unusual for the Arabian Shield. In the southern Shield for example, layered rocks occur as old as about 950 Ma (Cater and Johnson, in press) and there is isotopic evidence that granites in the eastern Shield had middle Proterozoic precursors (Calvez and others, 1983; Stacey and Hedge, in press).

The earliest event known in the quadrangle was the formation of mafic to intermediate volcanic and volcaniclastic rocks. They were subsequently deformed and metamorphosed, and later intruded by mafic to intermediate prekinematic plutonic rocks about 645 Ma ago. By analogy with petrogenetic models used elsewhere in the Shield (Schmidt and Brown, 1982; Roobol and others, 1983), it is inferred that these early rocks are remnants of a volcanic-arc complex, possibly of the order of 740 Ma old. A growing body of evidence (Greenwood and others, 1982; Johnson and Vranas, 1984; Camp, in press.) demonstrates that the progenitor of the Arabian Shield resulted from the accretion of arc complexes and other types of precratonic, tectono-stratigraphic units. It is likely that the strong deformation and amphibolite-grade metamorphism of these early rocks in the Jabal Habashi quadrangle reflect accretionary processes which occurred prior to and soon after intrusion of prekinematic plutonic rocks in this part of the northeastern Shield.

Within a short span after this tectonometamorphic event, the deformed arc complex was unroofed by denudation. Subsequent transgression by a shallow sea, across the erosion surface, led to deposition of the Maraghan formation. The formation is part of the Murdama group and represents the northernmost extent of a large sedimentary basin over 600 km from northwest to southeast, and 100 km from southwest to northeast. A localized fault-controlled basin developed at the northern margin of the Maraghan basin about 630 Ma ago, in which volcanic and clastic rocks of the Hibshi formation accumulated, and a caldera-type volcanic center formed in the vicinity of Jabal ar Raha.

These developments were followed by a major compressive orogenic event producing widespread open to tight folds and subvertical bedding dips in the Maraghan and Hibshi formations. A probably related phase of deformation resulted in development of the Raha fault zone, disrupting the caldera volcanic center. The deformation also resulted in steep reverse or thrust faults, and the onset of Najd-type transcurrent faults. All these structures are cut by post-Murdama intrusive rocks, just over 615 Ma old. This date, and the known age of basement plutonic rocks constrain deposition of the Murdama group and associated deposits in the region to within a period of 25 Ma. The post-Murdama intrusive rocks follow a calc-alkalic trend (du Bray, in press) and the majority of the evolved plutons resemble I-type granites (White and Chappell, 1977). In their chemistry, the post-Murdama plutonic rocks are compatible with an origin as modified partial melts derived from the mantle, or subduction-related partial remelting of basal island-arc material (du Bray, in press).

A phase of hydrothermal mineralization was associated with mafic to intermediate plutons of this post-Murdama period, resulting in the formation of auriferous quartz veins in the southern part of the quadrangle. A second phase of mineralization was associated with the subsequent emplacement of postkinematic evolved granites, and the local effusion of coeval felsic volcanic rock.

The ages of the postkinematic granites in Jabal Habashi and adjacent quadrangles indicate that major compression in the region had ceased prior to 580 Ma (Stuckless and others, 1984). Syenogranite and alkali-feldspar granite are the most common postkinematic rock types, and include peraluminous, S-type granites and some peralkaline granites. Both are important sources for granitophile mineralization in the quadrangle. Such granitic rocks in the Arabian Shield reflect within-plate magmatism (Harris, 1982), and their emplacement resulted in the final cratonization of the Shield. Their geochemistry indicates that the magmas were likely generated by the melting of ensialic and ensimatic protoliths (Stuckless and others, 1984) by processes which allowed both over- and undersaturation of alumina to result. On the basis of isotopic studies, these same authors concluded that the protoliths were probably not more than 100 Ma older than the granites.

The postkinematic granites were emplaced as circular plutons or sub-caldera ring structures. Chemically, they are close to eutectic minimum compositions for a range of water vapor partial pressures equivalent to 2 and 7 km depth of emplacement (du Bray, in press). Parts of the Silsilah ring structure include fine-grained granitic rocks with quenched textures characteristic of ring-dikes (du Bray, in press). The Gusal pluton and associated felsic extrusive rocks are interpreted as resulting from activity in a resurgent caldera (Pallister, 1984, unpub data).

The latest Precambrian event in the region was the reactivation of northwest-trending Najd-type transcurrent faults, which offset postkinematic granites and earlier dikes. The faults were the loci for the latest Proterozoic mafic to felsic dikes in the region. Strongly deformed, but essentially unmetamorphosed rocks of the Jibalah (?) group outcrop alongside one of the transcurrent faults in the quadrangle, but the age of the rocks relative to the postkinematic granites is unknown.

Following a period of extensive erosion and the development of a peneplane upon the Precambrian Shield, sedimentation resumed during the Cambrian to Ordovician as the result of transgression by a shallow sea. A thick sedimentary sequence was apparently laid down, although subsequent eastward tilting and possibly slight folding by epeirogenic forces led to the removal of these Phanerozoic rocks from the western part of the quadrangle. Extension in the region of folding, in response to movement asssociated with the opening of the Red Sea, resulted in fissure eruption of alkali-olivine basalt (Greenwood, 1973) and the formation of Harrat al Hutaymah, nearly 2 Ma ago.

The present topography and erosion pattern reflect the dominance of a low-latitude arid desert climate during the Holocene. Sand-filled stream channels, aprons of coalescing alluvial fans, recently cemented gravels, and local sabkhah deposits cover large areas of the quadrangle.

ECONOMIC GEOLOGY

Introduction

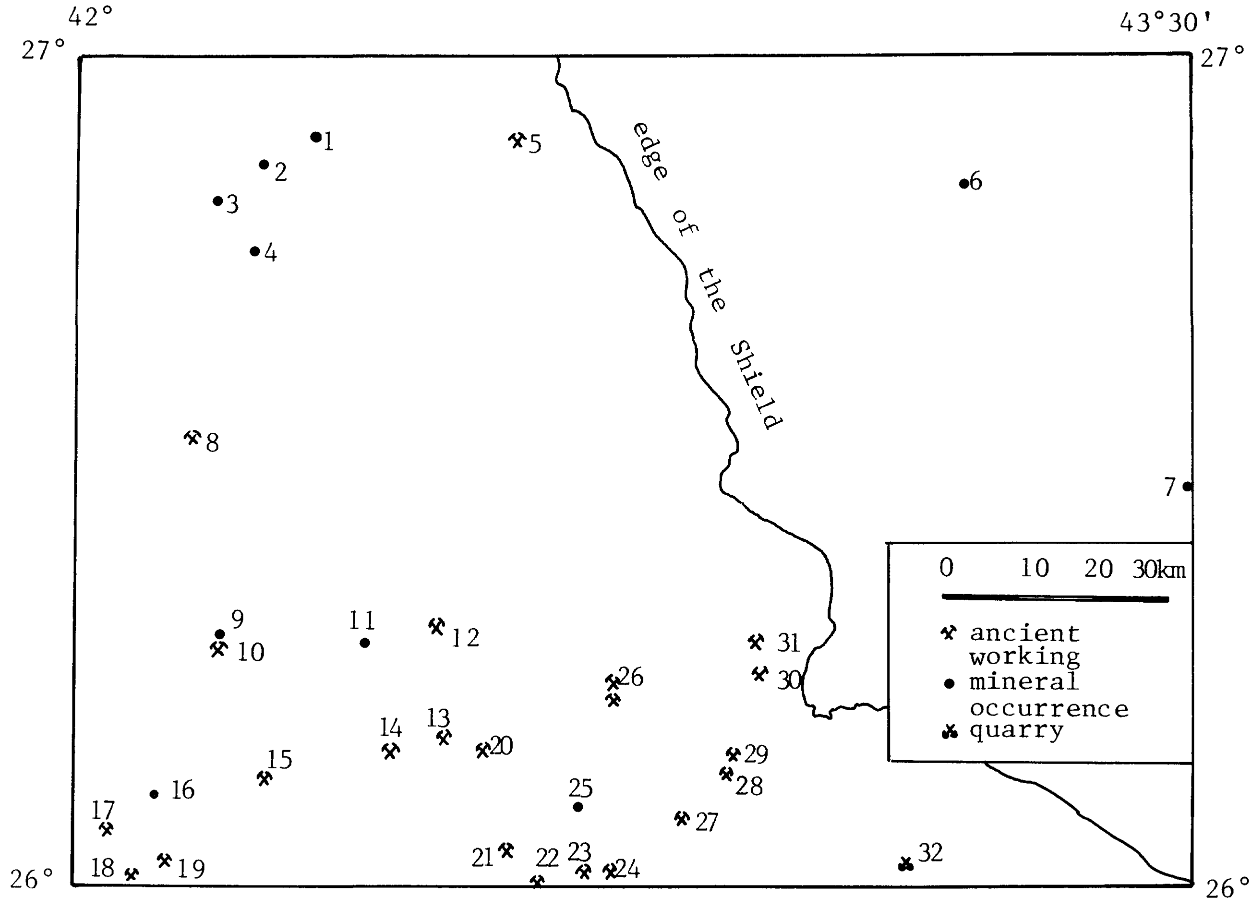
The Jabal Habashi quadrangle contains a variety of mineralization and raw materials including gold, tin, traces of rare-earth elements, roadstone and, potentially, lightweight aggregate (fig. 8). Although there is no clear evidence that the area was visited by modern prospectors until the mid-1950s, the region had aroused the interest of prospectors of the Saudi Arabian Mining Syndicate (SAMS) during the 1930s and 1940s (Fakhry, 1933; 1940; Twitchell, 1937) as a result of their encountering various references to a reputedly major ancient gold working called An Najady. Their sources were very old Arabic-language manuscripts housed in libraries in Al Madinah and Makkah. Although originally believed to lie within the Al Madinah area (Fakhry, 1933), by 1940 An Najady was listed as lying between Ha'il and Anayzah (Fakhry, 1940), spanning the Jabal Habashi quadrangle. In 1955, during the course of reconnaissance prospecting in the area, McGarry discovered the ancient excavations of Amayer al Madan (Schaffner, 1956a, c) on the southern margin of the quadrangle, which was subsequently determined to be An Najady mine. However, despite the expectations of earlier decades, and the extent of the excavations, An Najady mine, currently spelled An Najadi, was disappointing in its grade.

An Najadi is one of about twenty ancient workings, probably all for gold, within the quadrangle. A number of them, such as Agob and Niece, were first located in the 1950s during McGarry's exploration of the area (Schaffner, 1956a, d); more were examined during the 1960s (Mytton, 1970). During the preparation of the 1:100,000-scale source maps, a number of additional sites were located (du Bray, ; Smith and Samater, 1984; Smith and others, 1984).

Tin mineralization, of no known interest to ancient miners, also occurs in the quadrangle, in greisen developed in the southern part of the Silsilah ring structure (Riofinex, 1984). The secondary dispersion geochemical anomalies caused by the greisen and other areas of anomalous concentrations of metals in the quadrangle have been examined by a program of stream-sediment sampling (Allen and others, 1984).

Gold

The twenty gold occurrences in the quadrangle (Table 8) consist of one or more gold-bearing fractured quartz veins. The veins are stained by hematite and, in a number of cases, contain copper minerals, minor amounts of pyrite, and rare galena, sphalerite, and stibnite. Free gold occurs in some veins, but the more common mode of occurrence is probably in association with pyrite and stibnite. The veins are concentrated in the southern part of the quadrangle, preferentially hosted by lithic graywacke of the Maraghan formation, and close to or within diorite to granodiorite stocks of the Aydah suite. Argillic, hematitic, and silaceous alteration of the sandstone adjacent to the veins testifies to



Mineral occurrences in the Jabal Habashi quadrangle, sheet 26F

No.	MODS#	name of occurrence	commodities reported	status	year first reported
1	2770	Harrat al Hutaymah (ZAN52)	lightweight	occ.*	1979
2	3492	Harrat al Hutaymah	pozzolan	occ.	1984
3	3488	Samra as Safra	pozzolan	occ.	1984
4	2775	Harrat al Hutaymah (ZAN284)	lightweight	occ.	1979
5	none	unnamed quartz vein		a.w.**	1983
6	3281	Jabal at Tiraq	phosphorite	occ.	1983
7	2206	Buraydah-northwest	Zr (Th)	occ.	1978
8	1264	Samirah	Au	a.w.	1966
9	3271	Jufrah	Fe	occ.	1983
10	3270	Khidar	Au-Cu	a.w.	1983
11	3274	An Nimriyah south	Cu-Pb	occ.	1983
12	1265	Hebairiah	Au	a.w.	1966
13	3275	Asha north	Au	a.w.	1983
14	1266	Meshaheed	Au	a.w.	1966
15	1599	Niece	Au	a.w.	1956
16	3273	Wuday (Wudayy)	Au	occ.	1983
17	3272	Ar Rahail	Au	a.w.	1983
18	1272	Amayer al Madan (An Najadi)	Au	a.w.	1956
19	1271	Agob	Au	a.w.	1956
20	3269	Jurayyir north	Au	a.w.	1983
21	3268	Jurayyir south	Au	a.w.	1983
22	3267	Al Jurayyir	Au	a.w.	1983
23	3264	Fawwarah	Au	a.w.	1983
24	3263	Hadhir	Au	a.w.	1983
25	3262	Silsilah	Sn	occ.	1983
26	1383	Shialla (Ghinaymawat)	Au	a.w.	1978
27	1269	Waqt (Wagt)	Au	a.w.	1966
28	1268	Jerayer	Au	a.w.	1966
29	3265	Amudah	Au	a.w.	1983
30	3266	Raha	Au	a.w.	1983
31	3155	Bu'qara jasperoid	Cr-Ni-Zn-Sb-Fe	a.w.	1983
32	none	unnamed quarry	aggregate	quarry	1983

* occurrence

** ancient working

Figure 8.--Mineral occurrences and ancient workings in the Jabal Habashi quadrangle, sheet 26F.

Table 8:--Summary of gold occurrences in the Jabal Habashi quadrangle, sheet 26F

LOCATION AND MODS NUMBERS		NAME AND STATUS	COMMENTS
8	1264	SAMIRAH, ancient workings	Quartz veins in cataclastically deformed and altered Laban complex; the veins strike N. 55°E.; they consist of fractured quartz, stained gray, brown and red, calcite and ankerite, and contain abundant malachite, lesser azurite, chalcocite and a trace of free gold. Grab samples assay 7 g/t Au [source: Mytton, 1970].
10	3270	KHIDAR, ancient workings	Quartz veins in marble and calcareous shale of Maraghan formation. Grab samples assay less than 0.5 g/t Au [source MODS file].
12	1265	HEBAIRIAH, ancient workings	Quartz veins in calcareous graywacke of Maraghan formation, immediately south of a diorite plug; the veins strike N. 50°E.; and consist of fractured quartz stained with hematite. Grab samples assay 6 g/t Au; 28 g/t Ag [source: Mytton, 1970].
13	3275	ASHA NORTH, ancient workings	Quartz vein adjacent to an altered porphyry sill in calcareous shale and siltstone of Maraghan formation; the veins strike N. 55°W. Grab samples assay 1 g/t Au. [source: MODS file]
14	1266	MESHAHEED, extensive ancient workings	Numerous quartz veins in hydrothermally altered sandstone, siltstone, and greenstone of the Maraghan formation, adjacent to northwest-trending zone of small diorite and quartz monzonite plutons. Overall the workings trend N. 25° W. Individual veins are some 50 cm thick, and contain pyrite, stibnite, and gold. Rock chips assay 1 g/t Au; 13 g/t Ag. [sources: Mytton, 1970; Williams, 1983; Smith and Samater, 1984]
15	1599	NIECE, ancient workings	Hematite-stained quartz veins in Maraghan formation. Grab samples assay 1 g/t Au [source: Schaffner, 1956a, d]
16	3273	WUDAY (WUDAYY) mineral occurrence	Quartz veins at contact between Mahalani granodiorite and Maraghan formation; the veins contain pyrite. Grab samples assay 18 g/t Au. [source: Smith and others, 1984, unpub data.
17	3272	AR RAHAIL, ancient workings	Quartz veins in graywacke of Maraghan formation adjacent to a poorly exposed aplite dike; wall rocks are hydrothermally altered and silicified. Grab samples assay at less than 1 g/t Au [source: MODS file]
18	1272	AMAYER AL MADAN (AN NAJADI), extensive ancient workings	North-trending complex network of quartz veins in silty limestone of the Maraghan formation; the veins consist of fractured quartz, stained with hematite; they contain pyrite, and small amounts of galena, sphalerite, and chalcopyrite. Grab samples assay 2.5 g/t Au. [sources: Schaffner, 1956a, c; Mytton, 1970; Williams, 1983]
19	1271	AGOB, extensive ancient workings	North-trending quartz veins in Maraghan formation. Grab samples assay 10 g/t Au. [sources: Schaffner 1956a, b; MODS file
20	3269	JURAYYIR NORTH, ancient workings	Quartz veins in calcareous sandstone of Maraghan formation. Grab samples assay 18 g/t Au. [source: MODS file]
21	3268	JURAYYIR SOUTH, ancient workings	Quartz veins in calcareous sandstone of Maraghan formation adjacent to plug of hornblende quartz diorite. Grab samples assay 16 g/t Au. [sources: MODS file; du Bray, in press.
22	3267	AL JURAYYIR, ancient working	Quartz vein in calcareous sandstone of Maraghan formation. Grab samples assay less than 0.5 g/t Au. [source: MODS file]
23	3264	FAWWARAH, ancient working	Quartz vein in calcareous sandstone of Maraghan formation. Grab samples assay 1 g/t Au. [source: MODS file]
24	3263	HADHIR, ancient working	Quartz vein in calcareous sandstone of Maraghan formation. Grab samples assay 25 g/t Au. [source: MODS file]
26	1383	SHIAILA (GHINAYMAWAT), extensive ancient workings	Quartz veins trending N. 15°E. in graywacke and limestone breccia of Maraghan formation. Grab samples assay 2 g/t Au. [source: MODS file]
27	1269	WAQT (WAGT), ancient workings	Quartz vein in graywacke of Maraghan formation; the vein consists of fractured quartz stained by hematite; it contains a trace of stibnite. Grab samples assay 84 g/t Au. [source: MODS file]
28	1268	JERAYER, ancient workings	Quartz vein in quartz diorite intruding the Maraghan formation; the vein consists of fractured quartz, stained by hematite, and contains pyrite. No assay data is available. [source: MODS file]
29	3265	AMDAH, ancient working	Quartz vein in calcareous sandstone of Maraghan formation. Grab samples assay less than 0.5 g/t Au. [source: MODS file]
30	3266	RAHA, ancient working	Quartz vein in calcareous sandstone of Maraghan formation. Grab sample assays 1 g/t Au. [source: MODS file]

their hydrothermal origin.

Gold-stibnite-quartz mineralization at Meshaheed [MODS 1266] has recently been studied (Smith and Samater, 1984). Clusters of ancient workings occur within an area about 3 by 5 km, exploring quartz veins in Maraghan formation metasedimentary rocks, basalt, diorite, and plagioclase porphyry. The principal mineralized vein system fills fractures in the metasedimentary rocks. Here the veins appear to be lenticular and average less than 1 m thick; a less-distinct vein system, consisting of quartz-stibnite-pyrite stockwork, occurs in the intrusive basalt, and trenches occur locally along veins in the diorite. Both the gold-stibnite-quartz mineralization, and the molybdenite-quartz-vein system in the vicinity of Meshaheed, described below, result from hydrothermal alteration, the effects of which are clearly evident in alteration of the country rocks and are coincident with resistivity anomalies caused by the increased clay content of the altered rocks (Flanigan and Zablocki, 1984). The alteration includes moderate to intense silicification, kaolinization, carbonatization, and the introduction of pyrite and pyrrhotite.

Structurally controlled gold- and silver-bearing quartz veins are common in the Arabian Shield, related to second- and third-order shears in major faults (Moore and Al-Shanti, 1979; Worl, 1980). The mineralized quartz veins in the Jabal Habashi quadrangle are no exception. For example, the major vein system at Meshaheed is part of a northeast-trending fault set, whereas the veins at Asha North [MODS 3275] are quartz-filled fractures spatially related to a younger set of Najd-type west-northwest-striking faults. As noted by du Bray (in press) in the vicinity of Jabal as Silsilah, and by Kleinkopf and Cole (1983) in the Al Jurdhawiyah area south of the quadrangle, the gold-quartz vein deposits also tend to occur adjacent to dioritic, quartz dioritic, or granodioritic intrusions of the Aydah suite, many of which are too small to be shown at the scale of the compilation or do not crop out. Local concentrations of quartz veins and hornfelsed lithic graywacke for example, in the southern part of the quadrangle (du Bray, in press), and clusters of small negative aeromagnetic anomalies in an area underlain by the Maraghan formation, northeast of Jabal Qutn, are believed to indicate the presence of subsurface intrusions. Emplacement of the mafic to intermediate intrusive rocks probably induced fracturing in the Maraghan formation, providing heat to drive convecting fluids that precipitated quartz gold and sulfide minerals. The source of the gold, and the controls on precipitation are unknown; a lithostratigraphic control may be present (Riofinex, 1984), and carbonate in the lithic graywacke and limestone horizons present at some mineral occurrences probably had significant precipitating effect on the metal-bearing solutions.

Molybdenum

In addition to gold-stibnite-quartz veins, the Meshaheed area includes a molybdenite-quartz stockwork in diorite, a small molybdenum-bismuth-silver-quartz stockwork in other diorites, and large areas of moderately hydrothermally altered sediments bearing erratic, low-molybdenum contents (Smith and Samater, 1984). Most rock samples from the area contain less than 100 ppm molybdenum, but a few contain between 100 and 500 ppm, and in rare instances more than 2000 ppm. The quartz stockworks contain molybdenite flakes as great as 3 mm in diameter, and finely disseminated molybdenite locally imparts a spotted, blue-gray, texture to the quartz. Pyrite is very sparse, or is absent from the stockwork.

The results of a stream-sediment sampling program indicate that the Meshaheed mineral occurrences may be part of a larger area affected by hydrothermal mineralization. Gold and silver were not directly sampled, but a cluster of positive anomalous values of lead, copper, tin, boron, and molybdenum was detected south of Meshaheed coincident with small intrusions of granodiorite and zones of pyritic alteration (Allen and others, 1984).

Tin

The Silsilah tin prospect [MODS 3262] comprises several small areas of greisenized and hydrothermally altered Fawwarah alkali-feldspar granite locally containing cassiterite. The greisen occurs on the inside of the southwestern segment of the Silsilah ring structure. The ring, near circular, and about 12 km in diameter, is principally composed of Silsilah soda-pyribole-bearing alkali-feldspar granite (afgs), but in its southwestern segment, multiple intrusions of additional phases of granitic rock led to the emplacement of the Hadhir aplite (ap) and Fawwarah muscovite-bearing alkali-feldspar granite (afgm). The center of the structure consists mainly of folded metasiltstones and metagraywackes of the Maraghan formation, intruded by Fawwarah granite.

The Fawwarah alkali-feldspar granite is a muscovite- and topaz-bearing, weakly peraluminous rock (du Bray, 1984b, unpub. data). It is petrographically similar to the muscovite-bearing granites exposed in the eastern and southeastern Arabian Shield (du Bray, in press), such as those at the Baid al Jimalah tungsten prospect south of the Jabal Habashi quadrangle (Cole and others, 1981), and to metallogenically specialized granitoids hosting deposits of tin, tungsten, and other rare metals elsewhere in the world (Chappell and White, 1974; Tischendorf, 1977; Ishihara and others, 1980). The highly evolved nature of the alkali-feldspar granite at Jabal as Silsilah is evidenced by the 1.2 percent fluorine and 30 ppm tin contents of a granite sample (du Bray,).

Prospect mapping (Riofinex, 1984) divides the greisenized granite into "southern" and "main" outcrop areas. Preliminary sampling indicates a maximum tin value over the south greisen of 6100 ppm, whereas the main greisen outcrop is surrounded by an anomalous halo of between 100 and 500 ppm tin; anomalous tungsten values of as much as 145 ppm are associated with the high tin values (Riofinex, 1984). Three types of greisen have been identified:

(1)-White greisen, consisting predominantly of quartz and variable amounts of topaz, cassiterite and mica; this type represents the most intense alteration of the Fawwarah granite, and generally contains the greatest concentrations of cassiterite.

(2)-Red-green greisen, consisting of red feldspar and green mica with quartz, topaz, and variable amounts of cassiterite.

(3)-Gray-green greisen, consisting of quartz, feldspar, topaz, muscovite, and green mica; this type represents the least-greisenized phase of granite and passes progressively into barely altered Fawwarah granite.

Geologic features controlling the greisenization have not yet been determined. On a local scale the Hadhir aplite may have functioned as a cap rock limiting the upward movement of hydrothermal solutions (E. A. du Bray, oral commun. 1984), whereas regionally, the emplacement of the ring structure itself, may have been be controlled by west-northwest-trending structures present in the southern part of the Jabal Habashi quadrangle. These are conspicuous as aeromagnetic lineaments, the westernmost coinciding with a Najd-type transcurrent fault. The easternmost lineament is, as yet, unexplained. The Silsilah ring structure is located in an area where the two lineaments are offset with respect to each other, by some 10 km.

Other metallic mineralization

Samples of jasper from the Bu'qaya ancient mining site [MODS 3155] contain as much as 3000 ppm chromium, 1000 ppm nickel, and 1500 ppm antimony (du Bray,). The site consists of pits, trenches, and working faces located in jasper, carbonate rock, and quartz. These rocks occur along the southern margin of the Raha fault zone and are the product of alteration of gabbro emplaced within the zone. The commodities exploited by the ancient miners are unknown.

Postkinematic granites in the quadrangle are potential sites for rare-earth element mineralization. Anomalous concentrations of yttrium, niobium, and lanthanum have been detected in stream sediment derived from the Hudub, Salma, and Usba plutons of alkali-feldspar granite. A similar cluster of anomalies occurs on the margin of the peraluminous Qutn syenogranite complex and over the Bu'qaya formation between the Dhibiyah and Waqt plutons. In addition, the Qutn pluton, like many postkinematic granites elsewhere in the Shield, is strongly radioactive. Although it contains anomalously high uranium values, no uranium minerals have been identified and its potential for secondary uranium mineralization is judged to be low (Stuckless and others, in press). The elevated total count scintillation readings probably result mainly from the abundance of potassium-rich feldspars in the granite (Williams, 1983).

On the eastern margin of the quadrangle a radioactive anomaly of six-times background is present in the Tabuk formation [Buraydah-northwest, MODS 2206]. The anomaly is caused by thorium. Initially detected by an airborne gamma-spectrometer survey, ground follow-up revealed the presence of radioactive detrital minerals in a bed of siltstone and sandstone, 50 cm to 1 m thick. The minerals, identified as zircon, monazite, xenotime, huttonite, and sphene, account for the thorium anomaly; uranium and potassium-bearing minerals contribute only slightly to the overall spectrometer response (Matzko and others, 1978). Because the uranium concentrations are so low, and the radioactive zones so thin, this occurrence is not of economic interest.

Pozzolan

Several Quaternary volcanic cones in the Harrat al Hutaymah lava field contain tuffs and scoria interbedded with alkali-olivine basalt flow rocks. Samples of agglomerate and scoria cinder from ten sites were tested for pozzolanic activity, but relatively few samples yielded positive results (Laurent and Al Nakhebi, 1979); three sites are recorded in the Mineral Occurrence Documentation System (fig. 8).

DATA STORAGE

No entries or updates have been made to the Mineral Occurrence Documentation System (MODS) data bank during the course of this compilation. Draft versions of the diagrams and map used in the report are stored in base data file USGS-DF-04-3.

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