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Reconnaissance geology of the Jibal Matalli quadrangle, sheet 27/40 D, Kingdom of Saudi Arabia

by

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RECONNAISSANCE GEOLOGY OF THE JIBAL MATALLI QUADRANGLE, SHEET 27/40 D, KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

The Jibal Matalli quadrangle lies along the northern boundary of the Arabian Shield about 90 km west-southwest of Ha'il. The quadrangle consists of about 45 percent Precambrian bedrock, 50 percent Quaternary deposits, and 5 percent sedimentary cover rocks. The Precambrian rocks include volcaniclastic and volcanic rocks that are slightly metamorphosed and various granitic plutons. The volcaniclastic and volcanic rocks are correlated with the Hulayfah group and the Hadn formation. The older Hulayfah is principally basalt of probably submarine origin that has locally been metamorphosed to greenschist facies. The Hadn is composed of submarine and subaerial deposits. These consist of volcanic-derived sandstone and siltstone and lesser amounts of chiefly rhyolite volcanic rocks. In most areas, the Hadn shows little in the way of metamorphic effects, but locally it too has been metamorphosed to greenschist facies. The volcanic rocks of the Hadn include ash-flow tuffs; some appear to be water-laid, but others are subaerial. The oldest pluton is diorite, those of intermediate age are monzogranite and syenogranite, and the youngest are alkali feldspar granites. The largest pluton, a metaluminous, low-calcium, biotite monzogranite, occupies much of the southern part of the quadrangle. The alkali feldspar granites are mostly peralkaline; the two youngest are particularly so. The latter two are located in the southwest and southeast corners of the quadrangle, and both contain arfvedsonite and kataphorite. The pluton in the southeast grades outward from a peraluminous core to a peralkaline, comenditic peripheral zone and is inferred to be genetically related to a spectacular, west-trending comendite dike swarm in the southern half of the quadrangle.

Two northeast-trending buried right-lateral faults are inferred in the quadrangle; one in the southeast and one in the northwest. The one in the northwest probably offsets the comendite dike swarm about 3 km. This fault appears to be part of a broad right-lateral fault and flexure zone that juxtaposes the Hadn formation on the west against the Hulayfah group on the east.

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INTRODUCTION

Location and access

The Jibal Matalli quadrangle, sheet 27/40 D, occupies a 2,740 km^2 area along the northern boundary of the Arabian Shield between lat 27°00' and 27°30' N., and between long 40°30' and 41°00' E. (fig. 1). The area lies about 90 km west-southwest of Ha'il and is accessible by numerous dirt roads that trend westward or northwestward from a variety of turnoffs along the Al Madinah-Ha'il Highway. Abundant dirt roads within the quadrangle allow access to most points, except for parts of the Great Nefud, locally Irq al Jumaymah (see pl. 1), which is blanketed by eolian sands.

The principal villages, all with adjoining farms, are Gariat al Fayfah, Gariat Rovh al Shuwag, and Bir Farhania. Farming areas are present also at Bir Mughayr, Bir al Qufayfah, and Gariat al Havira. Water for drinking and irrigation is derived from numerous shallow wells; there are no natural springs in the area.

Previous work and acknowledgments

The Jibal Matalli quadrangle lies within the northeastern quarter of the Northeastern Hijaz quadrangle, which was mapped in reconnaissance at a scale of 1:500,000 by Brown and others (1979). D. B. Stoeser, J. E. Elliott, and J. S. Stuckless of the U.S. Geological Survey (USGS) sampled several of the better-exposed granite masses between 1976 and 1979 as part of regional studies. Thin sections of these samples were available at the start of this present work and greatly facilitated the completion of this report. Sample localities from the past and present studies are shown on plate 1. Inquiries regarding these data can be made through the Office of the Technical Advisor, Deputy Ministry for Mineral Resources, Jiddah, Saudi Arabia.

The author wishes to thank Carl Thornber, USGS analytical laboratories, for his complete cooperation in expediting thin sections and slabs. Thanks go also to Mahdi and Ali Abdulrazzak of the thin section laboratory for their diligent and prompt work in completing the thin sections and modally analyzing 17 stained slabs. Special thanks go to Mr. Robert Fryer, helicopter pilot extraordinaire and boon companion.

The work on which this report is based was performed in accordance with a work agreement between the Saudi Arabian Deputy Ministry for Mineral Resources and the U.S. Geological Survey.

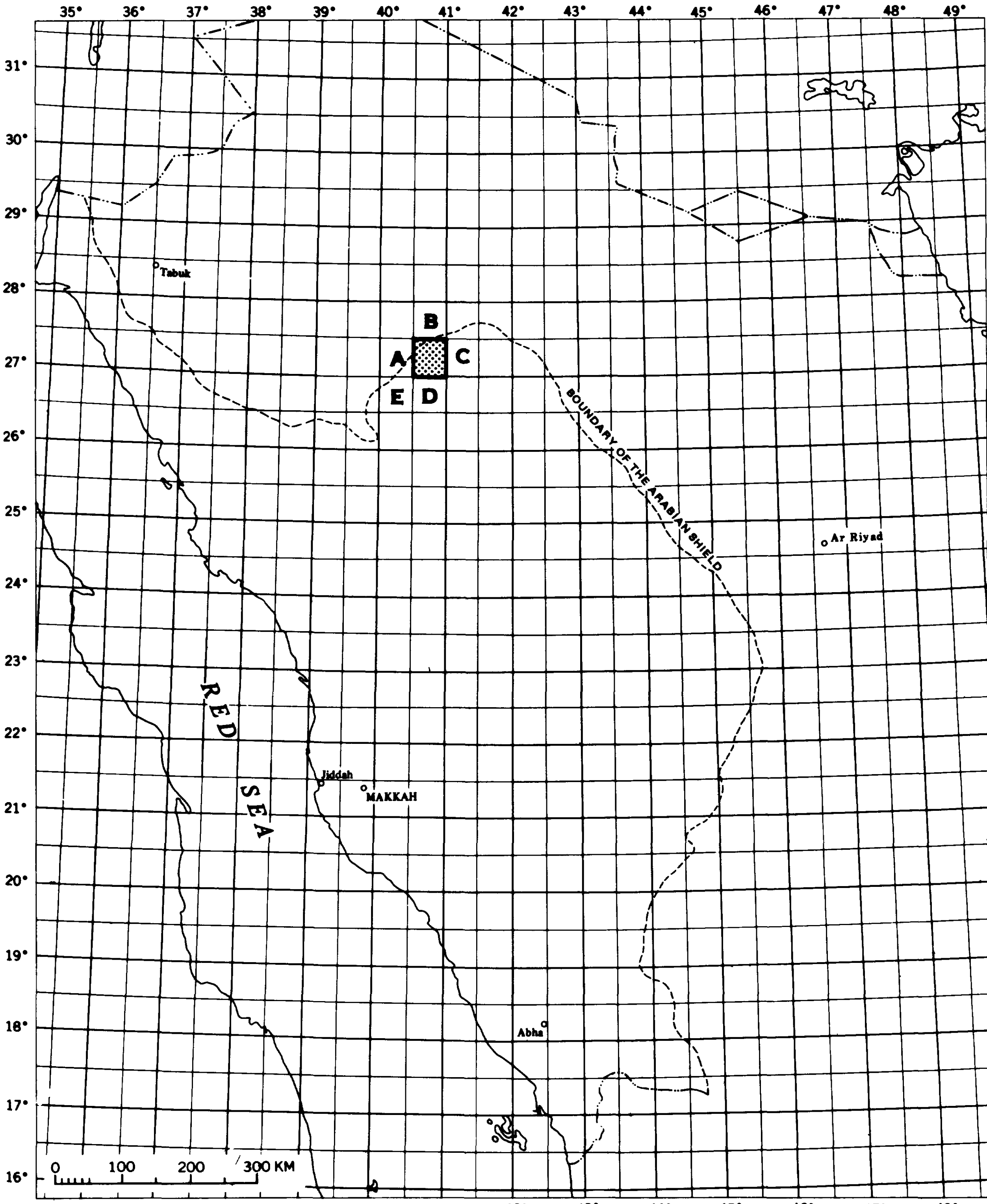

Figure 1.--Index map of the Arabian Shield showing locations of the Jibal Matalli quadrangle, 27/40 D, (shaded) and other 1:100,000 scale quadrangles referred to in this report: A, Jibal al Misma quadrangle, 27/40 C; B, Jibal Hibran quadrangle, 27/40 B; C, Al Qasr quadrangle, 27/41 C; D, Zarghat quadrangle, 26/40 B; and E, As Shamila quadrangle, 26/40 A.

PHYSIOGRAPHY

Drainage, which is principally toward the northwest, was undoubtedly established before the present-day arid climatic cycle and has since been modified by the large northeast-trending mass of Irq al Jumaymah sand. Elevations (uncorrected altimeter) of the gently northwest sloping lowlands in the southeast range from about 930 to 1,050 m, whereas comparable lowlands near the northwest corner of the quadrangle are as low as about 850 m. Jabals rise as high as 250 m above the surrounding lowlands in both areas. In the southwestern part of the Jibal Hibran quadrangle just north of the map area, the highest elevations, as much as 1,290 m, are along the crest of the cover rocks forming Jibal Hibran (Ekren, 1984a). In the map area, the tops of the larger Precambrian massifs, for example, the Jibal Matalli, which rises 250 m above surrounding lowlands, show a nearly flat, albeit dissected, summit as high as 1,250 m. The correspondence of these altitudes (crests of cover rocks vis-a-vis flat tops of granite inselbergs) suggests that an ancient peneplain has been eroded forming a lower-level regional erosion surface, which was covered by Quaternary lag- and sheetflood-gravel and eolian-sand deposits and, in places in other quadrangles, by Cenozoic basalt flows. Both erosional surfaces truncate the gently northwest-dipping Ordovician and Cambrian cover rocks and underlying Precambrian rocks of different varieties and erosional resistances.

Regional studies and accurate topographic maps are required to determine which, if either, erosion surface correlates with the widespread peneplain in southern Arabia described by Overstreet and others (1977) and by Madden and others (1979). It is certain, however, that both erosion surfaces were developed at or near the temporal sea levels in order that such widespread base-leveling could have been accomplished without deep canyon-cutting. Apparently, the only period in which this base-leveling could have occurred was during early Tertiary time. According to Schmidt and others (1982, p. 43), cratonic stability during the early Tertiary in the southern Shield is indicated by a variety of data, principally, the occurrence of the peneplain in southern Arabia, which, in places, is mantled with thick lateritic deposits; these deposits are dated by lower Tertiary volcanic rocks that overlie them. Neither erosion cycle in this northern region resulted in a completely mature plain as indicated by numerous inselbergs or monadnocks that are prominent landscape features. Lateritic deposits, if they existed locally, have been removed by erosion.

GEOLOGIC SETTING

The study area lies on the western or northwestern flank of the Ha'il arch (Powers and others, 1966; Dixon, 1982), which apparently accounts for the local northwestward-flowing drainage.

On the basis of the distribution of the calc-alkaline and alkali granites, the Arabian Shield has been subdivided by Stoeser and Elliott (1979) into three regions: the Asir, the Hijas-Najd, and the Ha'il-Ad-Dawadimi. The Jibal Matalli quadrangle lies within the eastern or Ha'il-Ad-Dawadimi region which is separated from the central Hijas-Najd region on the basis of a sharp increase from west to east in the abundance of exposed granite. The Hijas-Najd and Asir (western) regions are separated from each other on the basis of the distribution of alkali granites. According to Stoeser and Elliott (1979, p. 9), the boundary between the Hijas-Najd and Ha'il-Ad-Dawadimi regions coincides, more or less, with the northern limit of the Najd fault zone (Fleck and others, 1976, 1980).

Stoeser and Elliott (1979, p. 10) point out that as a general rule the calc-alkaline granites are older and give way temporally to alkaline and peralkaline varieties. With few exceptions, this rule holds in the study area.

In addition to the granitic rocks, the study area contains two compositionally separable sequences of volcaniclastic and volcanic rocks. These consist of the Hulayfah group, the oldest; and the Hadn formation, the youngest. The Hulayfah is principally basalt; whereas, the Hadn is principally rhyolite, although it also contains minor amounts of basalt. The Hadn also contains conglomerate and lithic tuff, both of which contain variegated granitic clasts including syenogranites. Granitic clasts have not been observed in rocks assigned to the Hulayfah group, which probably predates all granitic rocks in this quadrangle.

PRECAMBRIAN METAMORPHIC ROCKS

Hulayfah group

A poorly exposed sequence of black basalt and green metabasalt in a broad north-trending belt in the western part of the quadrangle is assigned to the Hulayfah group (Halaban group of Greenwood and others, 1976; Baubron and others, 1976; Delfour, 1977) on the basis of its gross lithologic similarities with that group in nearby quadrangles (currently being mapped by G. M. Fairer and J. E. Quick, oral and written commun., 1983). These rocks are all roof pendants and sheets that are intruded by a considerable variety of plutonic rocks ranging in composition from diorite to alkali-feldspar granite. The base of the sequence was not observed in the quadrangle and its thickness is not known, however, the steep attitudes and the considerable areal extent of the Hulayfah suggest a minimum thickness of at least several hundred meters. All contacts with adjacent plutonic rocks are intrusive. The basalts, where relatively unaltered, are dense with average grain sizes less than about 0.1 mm. Hand specimens have markedly high specific gravities when compared to similar-sized granitic, rhyolitic, or intermediate-rock samples. Thin section analysis indicates approximately equal percentages of clinopyroxene and plagioclase. Quantitative chemical analyses are not available but a semiquantitative analysis of fresh basalt by energy-dispersive X-ray fluorescence spectroscopy (XRF) yielded the following percentages: FeO, 9.96; CaO, 14.72; K_2O, 0.27; TiO_2, 0.79; Zr, 62 ppm; Sr, 320 ppm; Rb, 23 ppm (E. A. du Bray, written commun., 1983). The analyzed basalt has an unusually high content of CaO.

In most places, the basalts have been extensively metamorphosed to greenstones or greenschist facies by dynamothermal and hydrothermal processes and are green or greenish gray with chlorite, actinolite, epidote, and sodic plagioclase. Foliation is steep where it has been observed.

In several exposures north of Gariat al Fayfah (specifically at sample localities 203190-191, 203182, 203171-173, and 203269), the basalt has been extensively serpentinized, sheared, crushed, and partly altered to brown carbonate. In thin section, serpentine-suite minerals surround folia of carbonate and sheared basalt. This calcareous cataclasite zone lies near the contact of the Hulayfah group and thin-bedded limestone and marble that is included in the Hadn formation. The zone is inferred to indicate that the buried contact is a major fault (see "STRUCTURE" on later pages).

In addition to basalt and metabasalt, the Hulayfah is mapped to include pink-gray aphanitic rocks that contain sparse alkali feldspar phenocrysts a few millimeters across and very sparse quartz phenocrysts that are generally less than 2 mm in diameter. None of these rocks were examined in thin section, and field relations did not clearly indicate whether they were of extrusive or intrusive origin. They are presumed to be intrusive sills and dikes, and therefore, not integral parts of the Hulayfah lava pile.

In several places, basalt alternates with dark-green, ophitic-textured diabase or gabbro. These coarser rocks are inferred also to be sills or dikes that were intruded into the lava pile.

Hadn formation

A well-stratified sequence of thin-bedded feldspathic and argillaceous sandstone, siltstone, conglomerate, and ash-flow tuff crops out over a considerable area in the southeastern and northwestern parts of the study area. This sequence is herein assigned to the Hadn formation on the basis of contiguity with rocks mapped as Hadn in the adjacent Al Qasr quadrangle (Stoeser and Elliott, unpub. data) and of rhyolitic ash-flow tuffs in both areas. The formation, however, undergoes a considerable facies change from east to west. In the adjacent Al Qasr quadrangle, the Hadn is almost entirely subaerial rhyolite welded tuff (D. B. Stoeser, oral commun., 1983). It includes boulder and cobble conglomerate along the boundary and within the quadrangle.

Rocks exposed in the northwestern part of the Jibal Matalli quadrangle are correlated with the Hadn formation on the basis of the similarity of the rhyolite ash-flow tuffs, identical intercalated conglomerate lenses and the presence of evenly stratified sandstone and siltstone beds. More siltstone, mudstone, and flows(?) of basaltic composition are present in the northwest than in the southeast.

Sandstone, siltstone, sills, and limestones

One of the most striking features of the Hadn formation is the even stratification of the beds (fig. 2) in both the southeast and northwest parts of the quadrangle. The even bedding is so pronounced that a marine origin seems inescapable. Furthermore, most of the thin-bedded sandstones show only low-angle crosslaminations indicative of gentle currents. No trough-type, cut-and-fill, fluvial cross-stratification was observed nor were any high-angle crossbeds noted that are typical of sandstones of eolian origin. The beds show poor grading. The sequence apparently was laid down in a shallow marine environment, perhaps including tidal flats. The latter conclusion seems necessary in order to account for the presence of densely welded rhyolite tuffs at several horizons throughout the sequence (see later pages).

The thin sandstone beds all appear to be argillaceous and feldspathic. None were observed that contain more than about 30 percent quartz. Grain sizes vary from coarse to fine to silt, and most beds contain granule- to pebble-sized clasts of volcanic or granitic rocks. Most beds have fine-scale, gently dipping crosslaminations; a few of the thicker beds show foreset crossbedding with laminations dipping as steeply as 30°. The sequence is colored various shades of gray; siltstone is darker than sandstone. The sombre grays of the sedimentary rocks contrast with red, fine-grained, alkali feldspar granite sills and sill-like masses and other

Figure 2.--View to the west showing north-dipping Hadn formation in southwestern part of the quadrangle. Note the even stratification of the beds. Rock on left adjacent to small wadi is probably a thick lens of conglomerate. Most of the other beds in this view are thin-bedded feldspathic sandstone and siltstone.

apophyses of brown-gray porphyry that occur at several intervals throughout the sequence.

The red sills, which range in thickness from 1 to 10 m, probably were emplaced concurrently with nearby coarser grained plutons. The brown-gray porphyry is presumably of intermediate composition because the only phenocrysts are plagioclase as large as 1 cm; these compose about 30 percent of the volume. The groundmass contains numerous tiny mafic pseudomorphs filled with chlorite and iron oxide that apparently formed from both biotite and pyribole. The red sills and the brown-gray porphyry together compose as much as 30 percent of the volume of the Hadn map unit in some places.

Thin-bedded limestone crops out in the northwestern part of the quadrangle and was placed in the Hadn formation rather than in the Hulayfah group on the basis that tuffs, conglomerates, and evenly stratified sedimentary rocks typical of the Hadn occur nearby. In addition, thin limestone beds occur sporadically within the thin-bedded Hadn in the vicinity of the syncline in the northwest corner of the map and in the adjoining Jibal Hibran quadrangle to the north (Ekren, 1984a).

The limestone is dark gray to black on fresh surface and weathers blue and gray. It is dense and fizzes readily with dilute HCl, which suggests that its dolomite content is low. Most of the limestone in the two major localities on the map has been metamorphosed to white marble. Where the marble is coarsely crystalline, the bedding is indistinct.

Conglomerate lenses

Interesting, but somewhat enigmatic, lenses of conglomerate, that range in thickness from a few meters to as much as 100 m, occur in the Hadn locally. These lenses show little stratification except within the top few meters where they grade abruptly to sandstone. The basal contacts of the conglomerate lenses are well defined or abrupt and, in places, they are scouring contacts.

The conglomerate lenses are dark gray (fig. 3) and consist of unsorted boulders, cobbles, pebbles, and granules in an unsorted, mostly coarse-grained and granule conglomeratic sandstone matrix. The boulder-sized fragments are well rounded and as long as 30 cm; pebble-sized fragments are angular to subangular; cobble-sized fragments are gradational between the two extremes. The fragments consist of about 70 percent volcanic rocks, mostly lavas ranging in composition from rhyolite to basalt; and 30 percent granitic clasts ranging in composition from tonalite to syenogranite (see fig. 4, large crosses).

Figure 3.--Conglomerate lens in the Hadn formation just west of Jibal Matalli.

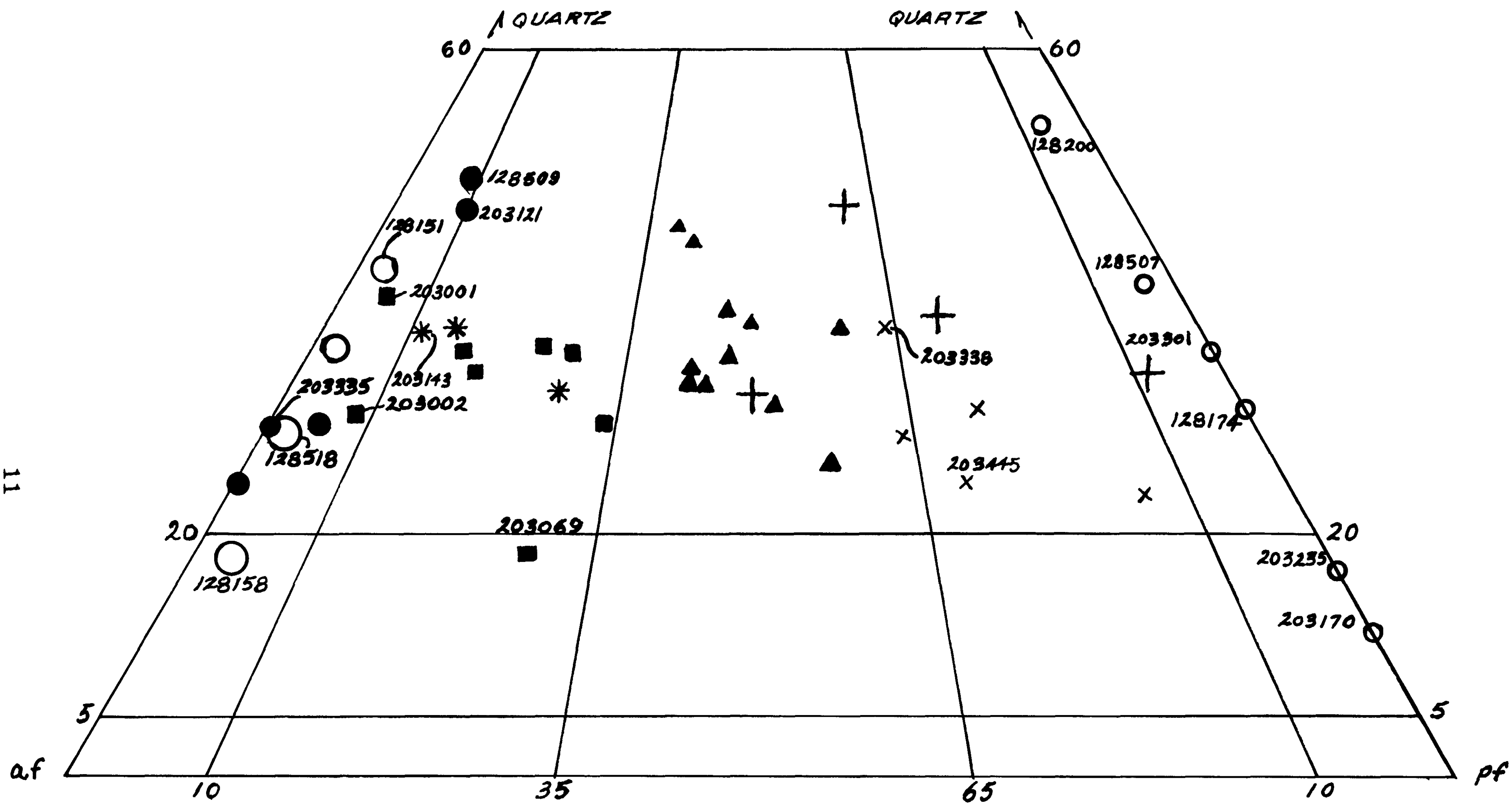

Figure 4.--Quartz-alkali feldspar-plagioclase diagram with fields of Streckeisen (1973) showing plots of principal granitic rocks in the Jibal Matalli quadrangle. Symbols: small open circles, tonalite and diorite; X's, granodiorite, princi- pally from mixed assemblage map unit; large crosses, clasts from the Hadn forma- tion conglomerates; solid triangles, pink biotite-granite; solid squares, "hornblende" granite from central part; solid circles, alkali feldspar granite (peralkaline, in part) from Jibal al Rumayh; large open circles, peralkaline granite from southwestern part; asterisks, biotite granophyre.

The depositional mechanism, source area(s), and transport history of the conglomerate lenses are difficult to deduce. The possible origins of these rocks and the associated ash-flow tuffs are presented in a section following the discussion of ash-flow tuffs.

Ash-flow tuffs

The ash-flow tuffs in the Hadn formation appear to be mostly rhyolite with flinty-fracturing matrices indicative of high-silica contents and phenocrysts indicative of rhyolite composition. A southeastern tuff with good fiamme and no brecciation contained 25 percent phenocrysts consisting of 49 percent quartz as large as 3 mm, 38 percent alkali feldspar to 2 mm, and 1.5 percent mafic pseudomorphs filled with quartz, iron oxide, and epidote. This mineralogy is apparently typical, but some tuffs contain subequal alkali feldspar and plagioclase, and only sparse quartz. Ubiquitous lithic fragments consist of intermediate lavas, granitic rocks that are very similar to those in the conglomerate lenses, and sparse dirty sandstone.

Tuffs that crop out in the northwest are richer in plagioclase and in altered mafic minerals than those in the southeast. No homogeneous welded tuffs were observed. They all appear to be brecciated to some extent, but they contain the same kinds of lithic fragments, including granitic clasts as those in the ash flows to the southeast and also in conglomerate lenses.

Possible origins of the conglomerate lenses and ash-flow tuffs

Conglomerate lenses.--The principal problems posed by the conglomerate lenses are: (1) How were these conglomerate lenses deposited? (2) Where were the source areas? (3) How did the larger clasts achieve their high degree of rounding?

The lack of any well-defined stratification in the conglomerate lenses precludes a direct fluvial origin, and the lack of grading except at the very top precludes a turbidite origin. A mass-flow transport mechanism is favored in which boulders, cobbles, pebbles, and coarse to fine sand were all dumped simultaneously. There could not have been any strong through-going currents or the finer material would have been sorted out. The inferred shallow sea or seaway, in which the material was dumped, was probably troughlike and must have been partly bounded by faults and by relatively uplifted, rugged source terrains. The considerable thickness of the incomplete Hadn formation in the southeastern part of the quadrangle (at least 4,000 m, sec. A-A') suggests that the trough was rapidly subsiding. It seems possible that most of the provenance areas have simply vanished as a result of post-Hadn granitic activity, and prior to this activity, volcanic terrains with plutons very similar to the younger granites that later intruded the Hadn existed in close proximity to the Hadn seaway. Some of the pre-Hadn granitic rock is still preserved in the adjacent Zarghat quadrangle just south of the Jibal Matalli quadrangle according to J. E. Quick (oral commun., 1983).

How were the conglomerates transported? It seems possible that fluvial and alluvial-fan deposits could have accumulated nearby, especially if the region had a desert environment at that time. These deposits could have been periodically moved en masse into the sea by a combination of tectonic activity and catastrophic flooding. It seems extremely unlikely that they slid directly into the sea from adjacent mountainous outcrops because the fragments are too rounded. The rounding must have been accomplished during transport in a fluvial environment or by sheetflooding.

<u>Ash-flow tuffs</u>.--The ash-flow tuffs, in common with the conglomerate lenses, also pose a serious problem with respect to origin. If the even stratification of the sandstone and siltstone beds (fig. 2) is indicative of a marine origin; then, is it possible that the ash-flow tuffs are also marine? I think that most of the tuffs in the Hadn formation, especially in the northwestern part, probably are of marine origin and flowed out directly onto and into the sea. Those, however, that show delicate fiamme (well-flattened pumice lapilli with flaring, flamelike ends) and that are densely welded with little evidence of any extensive fumarole activity, were deposited on land.

Some of the tuffs in the southeastern part of the formation, and most of the tuffs in the northwestern part, contain pumice lapilli, tuff fragments, and various other lithic fragments showing little in the way of any eutaxitic structure. These rocks could be the products of ash-flow eruptions, in which the ash flows rode a cushion of air over the sea. Upon coming to rest, before any extensive welding could occur, the red-hot ash-flow sheet was thoroughly disaggregated by great volumes of steam penetrating upward into the frothing mass as it slowly settled to the sea floor. The final product--the material that settled on the sea floor--would have the appearance of a tuff breccia, and that is the best descriptive term for many of the tuffs in the Hadn formation.

The homogeneous, densely welded ash-flow tuffs, on the other hand, that show good eutaxitic foliation and well-flattened fiamme must have been deposited directly on land. Thus, they must indicate that the Hadn formation, in the southeast exposures, at least, accumulated in a part-marine, part-subaerial environment.

It is a well-known fact that major ash-flow tuff eruptions commonly are preceded by considerable tumescence of the crustal area overlying the magma chamber (R. L. Smith, oral commun., 1983). This tumescence, if adjacent to the Hadn seaway, could have caused temporary withdrawals of the sea, consequently allowing the ash flows to be erupted directly on land. After eruptions ceased, the seaway trough must have subsided, thus allowing the tuffs to be covered by shallow-marine deposits.

PRECAMBRIAN PLUTONIC ROCKS AND DIKES

Older plutonic rocks

Diorite

The oldest intrusive rock in the quadrangle is weakly foliated diorite that crops out in two localities in the western part of the quadrangle. The diorite is inferred to be the oldest principally because, it is the only rock, other than the basalts of the Huylayfah group, that is foliated. In addition, the diorite is intruded by biotite-alkali feldspar granite which, in turn, is intruded by late alkali feldspar peralkaline granite. These relations indicate that the diorite is at least older than two other granite plutons.

The rock is weakly propylitized, and medium gray to greenish gray in both localities. The diorite contains 8 to 13 percent quartz, 62 to 65 percent plagioclase, 20 percent hornblende, and 5 percent biotite (fig. 4).

Tonalite

The tonalite exposed in the southeastern part of the quadrangle is gray, medium grained, and rich in quartz. Three thin sections contain 35 to 52 percent quartz; 41 to 62 percent plagioclase; 3 percent biotite; and no other mafic mineral.

The tonalite in the northwestern part of the quadrangle (fig. 4, sample 128174), in contrast, was found to contain only 25 percent quartz. Furthermore, the northwestern rock contains considerably more mafic minerals--17 percent, compared to only 3 percent in the southeastern rock. The mafic minerals are all pseudomorphs and appear to be principally after hornblende. They consist of blue-green actinolite(?) and green chlorite having exceptionally deep, royal-blue interference colors.

Granodiorite

Granodiorite was observed in two small areas along the southern border. The relationship of this rock to the tonalite is unknown. The easternmost rock is intruded by an outlier of pink biotite-granite, therefore, it constitutes one of the older plutonic rocks.

The granodiorite in both areas is light pinkish gray and medium grained. In the westernmost exposures, it contains 22 percent quartz, 21 percent alkali feldspar, 47 percent plagioclase, and 10 percent biotite (fig. 4, sample 203445). The rock is well jointed and locally sheared. The easternmost rock contains the same amount of alkali feldspar, but more quartz, and consequently, less plagioclase. It plots in the monzogranite field but near the granodiorite boundary (fig. 4, sample 203338).

Younger plutonic rocks

Pink biotite-granite

Pink biotite-granite crops out over much of the southern half of the quadrangle where it constitutes the largest body of granitic rock. Isolated remnants occur far to the north, nearly to Jibal Matalli, and a few cupolas are present south of the main mass along the southern boundary of the quadrangle. Exposed rock weathers massive and forms smooth-rounded inselbergs or bornhardts (desert monadnocks) (fig. 5). The massive-weathering habit is due in large part to the general lack of strong jointing, which is characteristic of most of the younger granites.

The pink biotite-granite plots as monzogranite (fig. 4, solid triangles). Its average grain size varies from 4 to 5 mm in some areas to 8 mm in others. In most outcrops, quartz grains may be as much as 1 cm in diameter, and alkali feldspar crystals may be as long as 1.2 cm. These large grains give the rock a slightly porphyritic appearance. The alkali feldspar is commonly orthoclase that contains sparse euhedral plagioclase grains that appear to have been engulfed by the growing alkali feldspar crystal rather than having exsolved out of it by solid exsolution. Some samples contain good perthite; microcline is extremely rare. Typically, the pink biotite-granite contains 35 percent quartz, and 25 to 30 percent cloudy, slightly sericitized plagioclase. Biotite varies from 1 to 5 percent.

Chemical analyses of two samples (table 1) indicate that the rock is metaluminous (fig. 6, solid triangles).

Mixed assemblage rocks

A poorly exposed mixture of variegated granitic rocks, including irregular patches of pink biotite-granite, and of small metasedimentary and metavolcanic roof pendants was mapped in the central part of the quadrangle; contacts with

Figure 5.--Massive-weathering pink biotite-granite. Small inselberg near Gariat Rovh al Shuwag, southeastern part of quadrangle.

Table 1.--Chemical analyses and CIPW norms of rocks from the Jibal Matalli quadrangle

[Analyses by X-ray fluorescence and wet-chemical methods, X-ray Laboratories, Don Mills, Ontario, Canada. All results in weight percent]

Sample no.	203010	203024	203026	203044	203115	203119	203120	203121	203122
Map symbol	cod	pbg	ag	cod	pbg	bgr	cod	agl	cod
Lat N. 27°	11'25"	06'40"	05'50"	14'45"	10'35"	09'10"	09'00"	08'35"	08'20"
Long E. 40°	45'18"	38'35"	35'25"	39'55"	53'20"	52'00"	51'40"	51'45"	51'40"
SiO_2	74.40	75.40	76.20	74.20	73.80	72.40	74.50	75.80	76.30
Al_2O_3	10.90	13.20	12.40	10.70	13.80	13.90	10.40	11.00	10.60
Fe_2O_3	1.77	1.06	.88	1.77	.97	1.46	1.64	1.66	1.70
FeO	2.04	.10	.10	2.20	.50	.40	2.40	1.31	1.56
MgO	.21	.31	.19	.17	.43	.41	.16	.17	.15
CaO	.43	.48	.31	.48	.94	.66	.27	.27	.40
Na_2O	4.34	4.60	4.97	4.51	4.75	4.29	4.80	4.43	3.61
K_2O	4.65	4.41	4.18	4.69	4.00	5.03	4.03	4.53	4.39
TiO_2	.27	.15	.14	.27	.20	.24	.14	.16	.20
P_2O_5	.02	.04	.17	.02	.06	.04	.02	.02	.02
MnO	.07	.04	.09	.08	.06	.06	.08	.06	.11
F	.03	.09	.02	.06	.09	.09	.10	.07	.01
CO_2	.30	.10	.10	.10	.10	.00	.00	.00	.20
H_2O+	.40	.30	.20	.30	.00	.60	.30	.30	.40
Total	99.43	99.98	99.75	99.25	99.70	98.98	98.54	99.48	99.25
Normative minerals									
Q	31.03	30.67	31.36	31.20	28.73	26.84	32.95	33.07	37.62
C	.00	.31	.00	.00	.32	.53	.00	.00	.00
Or	27.63	26.06	24.76	27.92	23.71	30.03	24.17	26.91	26.14
Ab	30.35	38.93	40.61	29.14	40.31	36.67	31.52	31.52	30.31
An	.00	1.49	.00	.00	3.66	2.40	.00	.00	.00
Ac	5.15	.00	1.36	5.16	.00	.00	4.81	4.83	.41
Ns	.17	.00	.00	.80	.00	.00	.99	.16	.00
Di	1.58	.00	.31	1.61	.00	.00	.44	.62	1.56
Hy	3.15	.77	.33	3.35	1.07	1.03	4.56	2.37	1.03
Mt	.00	.02	.21	.00	1.23	.80	.00	.00	2.28
Il	.52	.28	.27	.52	.38	.46	.27	.31	.38
Ap	.05	.09	.40	.05	.14	.10	.05	.05	.05
Fr	.06	.18	.01	.12	.17	.18	.20	.14	.02
Total	99.69	98.80	99.62	99.87	99.72	99.04	99.96	99.98	99.80
SALIC	89.01	97.46	96.73	88.26	96.73	96.47	88.64	91.50	94.07
FEMIC	10.68	1.44	2.89	11.61	2.99	2.67	11.32	7.48	5.73
$Al_2O_3/(K_2O+Na_2+CaO)$	.840	.998	.934	.780	.995	1.013	.815	.866	.927
$Al_2O_3/(K_2O+Na_2O)$	.894	1.069	.975	.855	1.135	1.111	.848	.901	.990

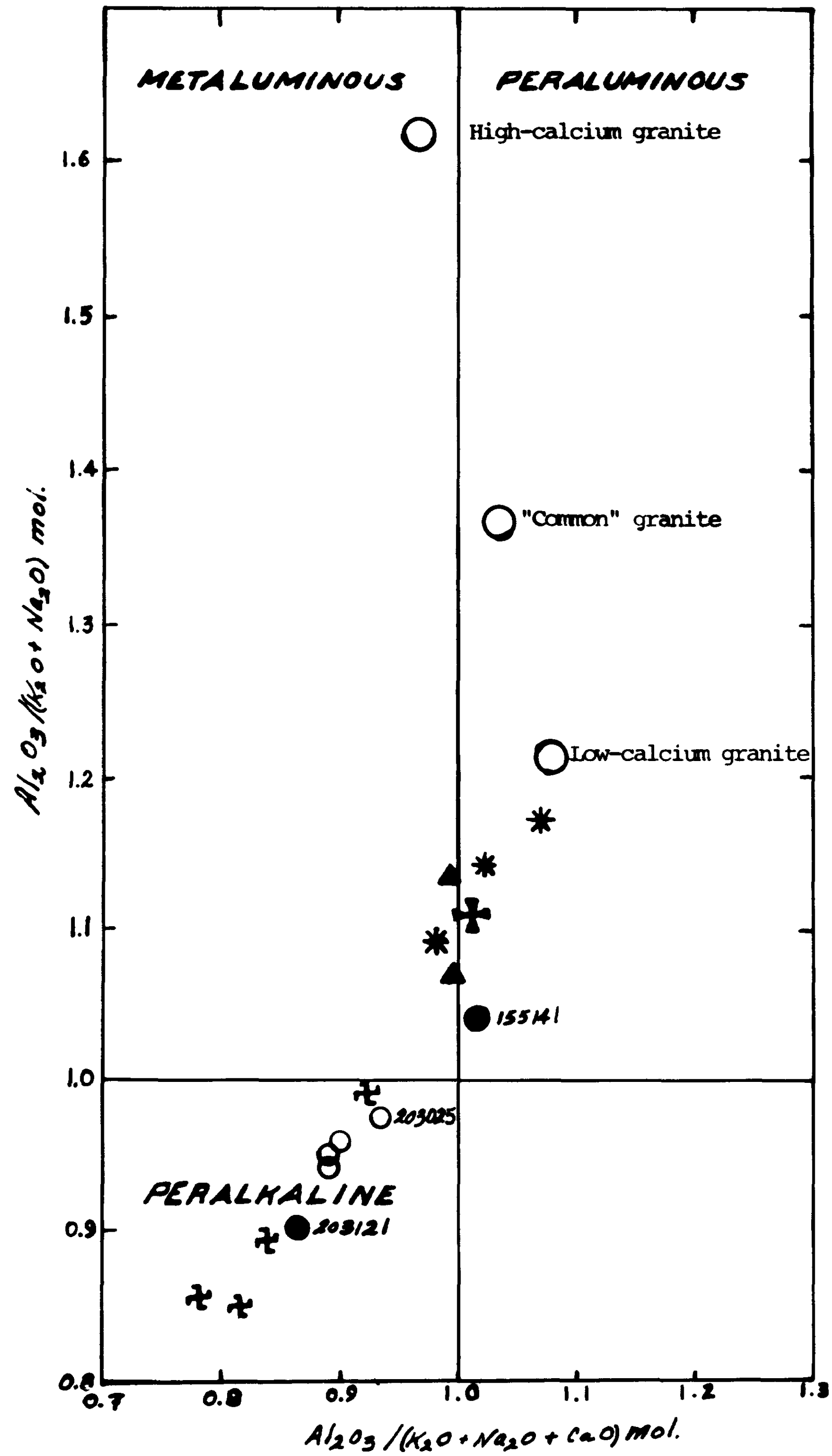

Figure 6.--Comparison of the granitic rocks of the Jibal Matalli quadrangle with worldwide averages of "common" granites and high- and low-calcium granites. Classification is based on peralkaline-peraluminous-metaluminous divisions of Shand (1947). Diagram devised by Pallister (1982). Symbols: open circles, worldwide averages from Cox and others (1979) and Turekian and Wedepohl (1961); asterisks, biotite granophyre from Jibal Matalli massif; open squares, biotite granophyre dike, from north flank Jibal al Rumayh; solid triangles, pink biotite-granite; solid circles, alkali feldspar granite from Jibal al Rumayh; open circles, alkali feldspar granites from southwestern part; solid squares, comendite from Jibal Rughayghith.

adjacent granitic rocks, especially with the hornblende granite, are arbitrarily drawn in most places.

The principal plutonic rock of the mixed assemblage is fine- to medium-grained, gray to dark-medium-gray (depending on the abundance of mafic minerals) biotite-hornblende granodiorite. Two thin sections show that the rock is composed of 16 to 27 percent quartz, 7 to 17 percent alkali feldspar, and 45 percent plagioclase. One sample contained 16 percent biotite and 14 percent hornblende, the other has more quartz and contained 7 percent biotite and only 2.5 percent hornblende (fig. 4, unnumbered x's). The relative age of this granodiorite is not known with certainty. It may be younger or older than the pink biotite-granite.

In addition to the biotite-hornblende granodiorite and irregular masses of pink biotite-granite, the mixed assemblage contains xenoliths and small roof pendants of variegated hornfels that probably were derived from the Hadn formation. None of this material was examined in thin section. It apparently comprises both volcaniclastic and volcanic rocks.

The mixed assemblage also includes many sills and dikes of aplite and numerous thin veins of white quartz. The quartz veins are rarely more than about 1 m wide. They, nevertheless, weather to cover broad areas with quartz fragments.

Biotite aplite

Pink biotite-aplite is an important fraction of the mixed assemblage rocks and it is the principal rock type in several other areas especially in the east where it is shown as a separate map unit. The rock is pink or pinkish gray, and it mostly weathers pale brown. It commonly contains as much as several percent biotite. In many areas, it is porphyritic, with as much as 10 percent euhedral alkali-feldspar phenocrysts, as long as 6 mm, and lesser amounts of quartz phenocrysts, as long as 3 mm.

The biotite aplite is characterized everywhere by a distinctive sugary textured groundmass in which the quartz and feldspar grains are equal in size and less than 1 mm in diameter. The rock in most areas, and in particular where it is not porphyritic, more closely resembles a well-sorted arkosic sandstone than it does an igneous rock. Most of the aplite, based on quick scans with the microscope, is probably monzogranite in composition with alkali feldspar considerably in excess of plagioclase.

Biotite granophyre

Biotite granophyre crops out in three plutons: Jibal Matalli (the largest), Jabal Naffs, and along the western boundary extending into the adjacent Jibal al Misma quadrangle (Ekren, 1984b). In all three localities, it is pink on a fresh surface, weathers brown, and is distinctly porphyritic. Glomerophenocrysts of alkali feldspar and phenocrysts of plagioclase are as long as 1 cm, and slightly resorbed ("worm-eaten") quartz is 4 or 6 mm; the groundmass is mostly micrographically intergrown quartz and alkali feldspar. Biotite is the principal mafic mineral in all three localities; it is mostly oxidized and slightly chloritized. Sparse altered amphibole is also present, and the rock along the western border contains sparse late-phase kataphorite(?). The rock probably was intruded as a crystal mush with about 40 percent residual liquid and the liquid crystallized rapidly to form micrographic granite.

The biotite granophyre plots in the syenogranite field (fig. 4, asterisks), and chemical analyses of three samples from Jibal Matalli (table 2, samples 155161-163) show that the rock straddles the metaluminous-peraluminous boundary (fig. 6, asterisks).

Biotite-alkali feldspar granite

Biotite-alkali feldspar granite crops out in the southwestern corner and northwestern part of the quadrangle. It is pink, but weathers to brown apparently because of the presence of strongly oxidized biotite, which weathers readily and stains the rock with brown splotches. In both localities the granite contains about 25 to 31 percent quartz, 59 percent microcline and perthite, 1 to 4 percent late interstitial albite, 2 to 4 percent mostly oxidized biotite, and sparse altered amphibole(?).

The relative age of the biotite-alkali feldspar granite is problematical. It and the adjacent biotite granophyre and the hornblende granite (see below) probably are closely related in time as well as in space.

Hornblende granite

A distinctive coral-pink granite that weathers pink-brown and red-brown crops out over a considerable area in the central part of the quadrangle. Calling this rock hornblende granite is somewhat of a misnomer because, in several localities, the amphibole is not common hornblende but katophorite. Where kataphorite is present, the rock apparently has changed composition gradually from a syenogranite (fig. 4, solid squares) to an alkali granite. Locally, the rock contains sparse quartz and plots as quartz syenite (fig. 4). The

Table 2.--Chemical analyses and CIPW norms of certain granitic rocks from the Jibal Matalli quadrangle reported by Stuckless and others (1982)

[Leaders (--) indicate no data. Note that these analyses report LOI (loss on ignition at 900°C) and the analyses on table 1 report F, CO_2, and H_2O+]

Sample no.	155141	155142	155143	155144	155160	155161	155162
Map symbol	ragl	agl	agl	agl	bgr	bgr	bgr
Lat N. 27°	07'22"	02'53"	02'04"	01'11"	26'11"	25'35"	24'56"
Long E. 40°	56'21"	33'17"	32'42"	31'44"	53'16"	51'40"	50'37"
SiO_2	77.09	74.50	75.59	74.84	74.85	75.68	75.54
Al_2O_3	11.84	11.30	11.44	11.58	12.54	12.17	12.80
Fe_2O_3	1.40	1.44	1.47	1.14	1.03	1.78	.99
FeO	.14	1.44	1.47	1.14	1.28	.18	.99
MgO	.10	.20	.20	.10	.10	.20	.20
CaO	.16	.37	.43	.41	.71	.68	.56
Na_2O	3.69	4.13	4.22	4.16	4.43	3.82	4.03
K_2O	4.90	4.78	4.69	4.82	3.88	4.05	3.97
LOI	.26	.20	.30	.45	.41	.60	.49
TiO_2	.10	.19	.19	.16	.17	.13	.16
P_2O_5	.10	.05	.05	.05	.05	.05	.05
MnO	.01	.04	.03	.02	.07	.06	.11
Total	99.79	98.64	100.08	98.87	99.52	99.60	99.89
Normative minerals							
Q	36.742	31.834	32.164	31.902	32.315	36.567	35.159
C	.415	--	--	--	--	.388	.976
Or	29.016	28.636	27.692	28.808	23.039	24.077	24.486
Ab	31.289	31.946	32.707	33.103	37.666	32.519	34.138
An	.141	--	--	--	2.886	3.065	2.454
Ac	--	3.068	2.619	2.202	--	--	--
Ns	--	--	--	--	--	--	--
Wo	--	.639	.754	.721	.136	--	--
En	.250	.505	.498	.252	.250	.501	.499
Fs	--	2.108	1.974	1.564	1.355	--	.941
Mt	.194	.579	.817	.568	1.501	.402	1.437
Hm	1.269	--	--	--	-	1.514	--
Il	.190	.366	.361	.307	.324	.248	.304
Tn	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Ap	.237	.120	.118	.120	.119	.119	.119
Total	99.745	99.800	99.703	99.548	99.591	99.400	99.513
SALIC	97.604	92.416	92.563	93.813	95.906	96.616	96.214
FEMIC	2.141	7.385	7.141	5.734	3.685	2.784	3.300
Al_2O_3/ (Na_2O+K_2O+CaO)	1.015	.894	.894	.904	.981	1.022	1.072
Al_2O_3/ (Na_2O+K_2O)	1.041	.944	.952	.960	1.092	1.141	1.71

identification of the amphibole throughout this mass is greatly hampered by the fact that it is oxidized in most localities.

The rock contains 17 to 37 percent quartz, 45 to 60 percent alkali feldspar (entirely perthite in some thin sections, minor microcline in a few), 2 to 24 percent plagioclase, and 2 to 5.5 percent amphibole. Where the plagioclase is less than 10 percent it is late interstitial albite; where it is more than 10 percent it includes euhedral crystals that are estimated to be oligoclase in composition.

Alkali feldspar granite and early alkali feldspar granite

Brown-weathering, orange-pink alkali feldspar granite crops out along the eastern border of the quadrangle and in several small areas along the western and southern borders. This rock contains sodic amphibole (either arfvedsonite or kataphorite) and presumably, therefore, is peralkaline in composition. In all localities, the granite (ag) is lithologically indistinguishable from the "late alkali feldspar granites" (agl) described below, but the late granites (agl) form more compact bodies. Furthermore, chemical analysis of a sample from map unit ag (table 1 and fig. 6, sample 203026) shows that it is not quite as peralkaline as map unit agl (fig. 6, cluster of open circles) and, therefore, may be slightly older; also the late alkali feldspar granite (agl) contains elpidite, an accessory zirconium mineral whose presence is a good indicator of the degree of peralkalinity of a granite rock according to D. B. Stoeser (oral commun., 1983). As far as is known, no elpidite is present in map unit ag.

Late alkali feldspar granite

Pink-gray, orange-pink, red-weathering, amphibole-rich granite crops out at Jibal al Rumayh and in the extreme southwestern part of the quadrangle. At both localities the granite contains elpidite [$H_6Na_2Zr(SiO_3)_6$], which was first observed and identified by D. B. Stoeser (oral commun., 1983) using X-ray and microprobe analysis techniques.

At Jibal al Rumayh the granite is zoned; it becomes generally more peralkaline from the interior outward toward the peripheries. Samples 203121 and 128509 from the periphery contained 42 to 44 percent quartz, 40 to 42 percent perthite, 4 percent interstitial albite, and 10 to 11 percent amphibole. The amphibole for the most part is weakly zoned; most crystals are pleochroic from dark green to total black and have virtually zero axial angles (2 V's). The outer hulls are pleochroic from yellow green to dark green to dark blue green, and they also have very low axial angles.

Probably, the outermost parts of the amphibole phenocrysts are true arfvedsonite and the interiors are kataphorite. These crystals in outcrop are as large as 2.5 cm by 4 or 5 mm. Sample 203121 (table 1) from the periphery is comendite (fig. 7) and plots well into the peralkaline field (fig. 6, solid circle). In contrast, the interior of the pluton (red granite, ragl, sample 155141) is peraluminous (table 2, fig. 6). The red granite contains amphibole that has the optical properties of common hornblende. Sample 203335 (pink granite from the interior of the pluton) contains yellow-brown, zoned allanite as an accessory. According to D. B. Stoeser, allanite is never present in the peralkaline phases. The interior granite at sample 203335 (agl) and the interior red granite (ragl) contain considerably less quartz than the peripheral rock, 27 percent compared to more than 40 percent; and the two interior granites contain less amphibole, 5 percent compared to 10 percent.

The late alkali feldspar granite in the southwestern part of the quadrangle is strikingly similar to that in the southeastern part, but the southwestern pluton is not zoned and has no comendite. Samples 155142, 155143, and 155144 (table 2) are all peralkaline (fig. 6, open circles in cluster), but they fall in the "low-Ca rhyolite" field of Noble (1968; not plotted in fig. 7).

Modal analyses of rocks from the southwestern pluton show considerable variation in the abundance of quartz (fig. 4, large open circles). For example, sample 128158 with a quartz content of only 16 percent, plots as a quartz alkali-feldspar syenite, whereas sample 128151 containing 38 percent quartz plots as an alkali-feldspar granite.

The rocks contain from 7 to 10 percent amphibole, which is zoned. Microprobe analysis by D. B. Stoeser (oral commun., 1983) shows that the interiors of some of the crystals are ferroedenite, the intermediate zones are kataphorite, and the outermost zones are arfvedsonite. Zircon is an ubiquitous and abundant accessory, and elpidite, although less abundant than zircon, is apparently also ubiquitous.

Comendite dikes of the Jibal Rughayghith dike swarm

The most spectacular geologic and topographic feature in the Jibal Matalli quadrangle is the comendite dike swarm that extends west-northwest from the western flank of Jibal al Rumayh to the western boundary of the quadrangle. The dikes are as wide as 60 m near Jibal al Rumayh and they thin gradually westward to a few meters wide or less at the far western end of the swarm. They probably were fed by vertically rising comendite magma related to the Al Rumayh pluton from which they spread laterally westward. The dikes dip northward at an average angle of about 70°.

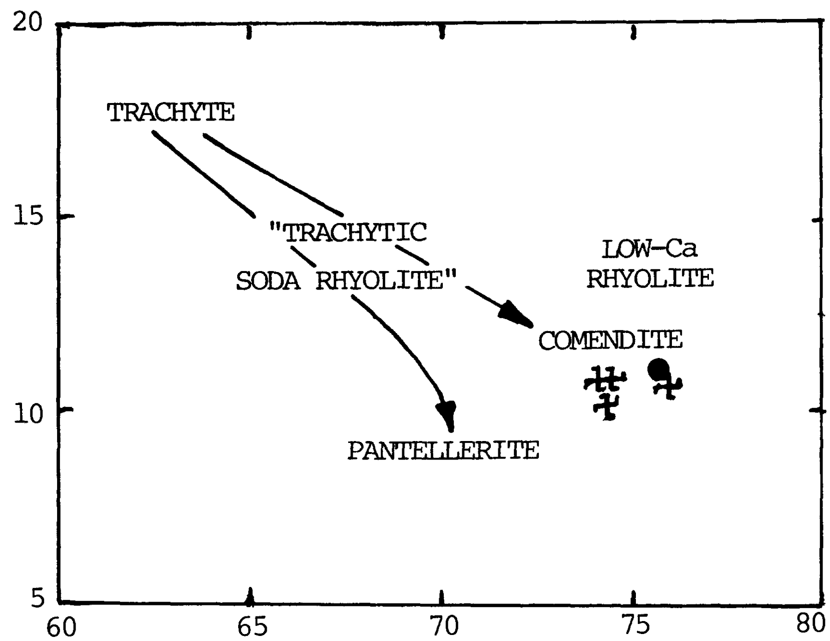

Figure 7.--Plot of Al_2O_3 versus SiO_2 of four rocks from the Jibal Matalli quadrangle. This diagram, showing approximate fields for various peralkaline silicic rock types and for low-calcium rhyolite together with the heavy lines showing quantitatively two possible lines of liquid descent, is from Noble (1968).

The dikes are gray and pink gray and contain 5 percent or less small phenocrysts of alkali feldspar and quartz in a microgranular and micrographic groundmass composed of quartz and alkali feldspar, and 10 percent or more aegerine-augite less than 1 mm long or arfvedsonite, more or less oxidized, also less than about 1 mm long. Some dikes contain both mafic minerals and, in addition, contain abundant spherules about 3 mm in diameter formed of radiating crystallite needles of pyroxene. Fresh rock without spherules has a distinctive salt and pepper appearance.

Chemical analyses (table 1, samples 203010, 044, 120, and 122) show that the dikes are all comendites (fig. 6, solid squares; fig. 7). These dikes were recognized several years ago as probable comendites on the basis of mineralogy by D. B. Stoeser (oral commun., 1983), who postulated further that they probably were related genetically to the Jibal al Rumayh pluton. The dikes, nevertheless, were emplaced after the pluton solidified as evidenced by clear-cut relations of some dikes intruding the granite. Most of the dikes, however, end abruptly at the contact of the pink biotite-granite with the Al Rumayh pluton. The fractured pink granite obviously was penetrated with ease by the comendite magma, but the Al Rumayh pluton, probably by virtue of it having just solidified, was not intruded.

Rhyolite dikes and sills

Rhyolite dikes and sills are abundant throughout the southern half of the quadrangle. Only a few of these dikes and none of the sills were mapped because they are all too thin to show at a map scale of 1:100,000. The sills are quite spectacular, however, because they are flat lying and cut across steep contacts of plutonic rocks and Hadn formation; some of these flat-lying sills are connected to vertical dike feeders (fig. 8). The rhyolite is mostly gray, green gray, or brown gray and contains less than 5 percent phenocrysts of alkali feldspar (5 mm) and quartz (3 mm) in an aphanitic, very flinty, groundmass. The rock is very resistant and is commonly covered with black desert varnish. The sills and dikes are commonly conspicuously laminated adjacent to contacts with country rocks.

In the southeastern part of the quadrangle, near Gariat Goormah, a sill-like body of rhyolite or quartz latite was mapped. This rock contains 10 to 25 percent phenocrysts consisting of plagioclase to 1 cm, sparse quartz to 2 mm, and abundant tiny flakes of biotite in a silicic, flinty-fracturing groundmass.

In the southwestern corner, three wide rhyolite dikes are present. These rocks are dark brownish gray and contain sparse quartz to 3 mm and sparse alkali feldspar to 4 mm in a

Figure 8.--View to east showing vertical rhyolite feeder dike and adjoining sills. Rhyolite is medium gray on fresh surface and weathers black; country rock is pink biotite-granite in inselberg in southeastern part of the quadrangle.

holocrystalline groundmass that apparently includes abundant tiny amphiboles. These rocks are probably closely related to the peralkaline granite that they intrude.

Granophyre and associated mafic dikes

Deeply weathered east-west-trending granophyre dikes that, in places, are as wide as 60 m, cut across the central part of the quadrangle and occur also just north of Jibal al Rumayh. They are composite masses consisting mostly of granophyre but commonly with mafic dikes along the sides or in the center. Where the mafic dikes are absent, the granophyre weathers readily and forms trenches that resemble sunken roads. The granophyre is red or purple and most of it contains glomerophenocrysts of alkali feldspar to 1 cm and quartz to 6 mm in a micrographically intergrown groundmass of quartz and alkali feldspar. Most of the rock examined in thin section contains chloritized biotite as the sole mafic mineral but some contains kataphorite or arfvedsonite and minor aegerine-augite and may be comenditic in composition.

A granophyre dike from just north of Jibal al Rumayh, which contains fresh biotite as the sole mafic mineral, was analyzed chemically (table 1, sample 203119) and was found to be peraluminous in composition (fig. 6, open square). The chemistry of this biotite granophyre is obviously very close to that of the biotite granophyre in the Jibal Matalli pluton (fig. 6, asterisks).

The associated mafic dikes contain as much as 50 percent partly altered clinopyroxene and hornblende. The remainder of the rock consists of unoriented plagioclase and sparse quartz. The quartz occurs as interstitial grains and as scattered phenocrysts to 3 mm that have reaction rims of epidote, possibly after pyroxene. Some rocks contain interstitial micrographic quartz and alkali feldspar. The pyroxene is commonly altered to actinolite, chlorite, and epidote.

PALEOZOIC ROCKS

Ram and Um Sahm sandstones, undivided

The lower part of the Ram-Um Sahm sandstone covers a small area in the northwestern part of the quadrangle where it consists of poorly sorted fine- to coarse-grained, mostly crossbedded sandstone with some crossbedded conglomeratic lenses which contain subangular to subrounded pebbles and granules of white quartz. The sandstone occurs principally as tabular-planar crossbedded cosets (0.5-3 m thick). The crossbedded cosets are commonly bounded and truncated by laterally continuous, nearly horizontally stratified cosets or horizontal erosional planes (fig. 9). Crossbedded cosets

Figure 9.--Basal part of Ram and Um Sahm sandstones, undivided. Note horizontal parting just above top of hammer handle.

thicker than about 3 m are rare, and no sets of cross-strata with dips greater than about 20° were noted. They are present, however, higher in the section west and north of this quadrangle.

The sandstone is varicolored brown, pale yellow brown, chocolate brown, buff, and white. Some thin beds with abundant ferruginous cement are dark red brown and weather nearly black. Two thin sections show that brown sandstone is cemented with iron oxide plus minor amounts of calcite and clay and, friable white sandstone has relatively little cement of any kind. The brown sandstone contains 67 percent subrounded and subangular quartz 0.1 to 0.7 mm in diameter, 29 percent iron-oxide cement, and 4 percent epoxy-filled pore space. The white sandstone contains 66 percent subrounded and subangular quartz 0.2 to 0.6 mm, a trace of alkali feldspar, 10 percent iron-oxide cement, and 24 percent epoxy-filled pore space. The volume of pore space that is filled with epoxy is a fair measure of porosity in these sandstones; the Ram and Um Sahm sandstones potentially are excellent aquifers.

Heavy minerals consist of a single grain of tourmaline in one thin section of the brown sandstone, and a large flake of muscovite, two grains of hypersthene, and two grains of zircon in a thin section of the white sandstone.

The Ram-Um Sahm sandstone was deposited on a peneplain developed on a considerable variety of Precambrian rocks with differing erosional characteristics. In places, according to Brown and others (1979) and Powers and others (1966), a basal conglomerate is present, particularly, at the base of the Saq sandstone, which is equivalent in part to the Ram and Um Sahm sandstones. No basal conglomerate was noted in this or the adjacent Jibal Hibran and Jibal al Misma quadrangles (Ekren, 1984a, 1984b, but the actual base is covered in most areas. The relief at this contact is generally low, but in the Jibal al Misma quadrangle, an erosional window shows as much as 20 m of local relief on the Precambrian surface. The erosional remnant of the basal part of the Ram-Um Sahm sandstone in this quadrangle is on the order of 50 m thick.

QUATERNARY DEPOSITS

Eolian sand of Irq al Jumaymah (Great Nefud)

An arm of the Irq al Jumaymah, also called the Great Nefud or Great Sand Sea, extends into the quadrangle from the north. The dunes are not as high nor as well defined as in the main Nefud farther to the north; for example, in the Jibal Hibran quadrangle (Ekren, 1984a); however, there is no difference in composition of the quartz sand from south to north. According to D. J. Faulkender (oral commun., 1983), the dunes of the Nefud are composed of fine- to medium-grained quartz sand, mostly 0.25 to 0.50 mm, and the grains have high sphericity. Feldspars are not present in any of the samples collected by Faulkender and the sands contain only about 1 percent heavy minerals, chiefly tourmalines and minor diopside.

According to Faulkender the dunes comprise barchanoidal, transverse, ridge, and linear types. Because no topographic maps are available for this quadrangle, estimates of dune heights and total thickness of the sand are exceedingly rough. Some dunes have at least 50 m of relief and the thickness of the sand is estimated to be at least 100 m.

Undifferentiated alluvium

The quadrangle contains broad areas mantled by a mixture of windblown sand and cobble and pebble gravels; these areas were mapped as undifferentiated alluvium. Some of the gravels in this mixture have been transported at least several kilometers to the site where they now repose. This movement apparently was accomplished by periodic sheetflooding. For example, in several areas where all the bedrock beneath the thin alluvium is granitic rock of one kind or another, the gravels contain an abundance of very hard basaltic rock or silicified rhyolite derived from the Hadn formation or the Hulayfah group. In places, the nearest outcrops of these rocks lie several kilometers beyond the granite outcrops.

The undifferentiated alluvium in this quadrangle probably locally exceeds 100 m in thickness.

STRUCTURE

Rocks of the Hadn formation are moderately folded and form a generally north-dipping homocline in the southern part of the quadrangle. In the northwestern part, they are folded into a west- to northwest-trending syncline. Minor folds were not mapped but they do occur in local areas. In the Zarghat quadrangle to the south, the Hadn formation is moderately to strongly folded (J. E. Quick, oral commun., 1983).

There are two inferred northeast-trending buried right-lateral strike-slip or oblique-slip faults in the quadrangle. The fault in the southeast corner of the quadrangle is a projection of a fault mapped in the Zarghat quadrangle by J. E. Quick. There, relative movement has been down to the north, and drag features suggest an important component of right-lateral slip (J. E. Quick, oral commun., 1983). The only evidence for the continuation of that fault into this quadrangle is the presence of an extremely straight alluvial valley. The buried fault in the northwestern part of the quadrangle is based on the presence of shearing in basalt of the Hulayfah group. The shearing is especially prevalent in the contact zone between basalt and thin-bedded limestone of the Hadn. In addition to this zone, sheared rocks were observed northeast of the limestone outcrops just west of Jibal Matalli at station 203350 and to the southwest of the limestone outcrops at 203190-191 and stations 203267 and 203269. In several of the outcrops along the strike of this inferred fault, the sheared basalt has been partly converted to carbonate. The amount of shearing together with the alteration of basalt to carbonate suggests a strike-slip or thrust fault rather than a simple dip-slip normal fault. The only evidence supporting a thrust-fault interpretation is the abrupt bend or change of position of the inferred buried fault between the two limestone outcrops. I feel that this change of position is best explained by a complementary northwest-trending fault having left slip.

The evidence that the displacement along the buried northeast-trending fault is right lateral is the apparent offset of the Jibal Rughayghith dike swarm. This right-slip displacement appears to be on the order of 3 km. Furthermore, the western extremities of the dike swarm are dragged from a west strike to northwest strikes along the western border of this quadrangle, and in the adjacent Jibal al Misma quadrangle (Ekren, 1984b). This drag, however, cannot be caused by movement along the strike-slip fault itself. It is best explained as being caused by a broad zone of right-lateral flexing of which the strike-slip fault is a part.

Inasmuch as the comendite dikes are one of the youngest Precambrian rock units in the quadrangle, it is noteworthy that the inferred fault and flexure zone postdates these rocks.

ECONOMIC GEOLOGY

No metallic ore minerals were found during the course of this reconnaissance study. Furthermore, no rocks showing the effects of strong hydrothermal alteration were observed other than the calcareous basalts in the vicinity of the strike-slip fault. Some rocks show the effects of mild or weak alteration especially in the older plutons and in the volcanic rocks of the Hulayfah group and the Hadn formation, but these effects are not the kind that generally signal the proximity of a metallic-mineral ore body of hydrothermal origin. The possibility of completely concealed stratabound massive sulfide deposits in the Hulayfah and Hadn formations, which are both in part, at least, of submarine origin, must be considered. These deposits would not necessarily show any surface traces.

The possibility cannot be precluded that some greisen-type tin deposits or tungsten deposits could occur locally in this quadrangle. The presence of such a wide variety of granitic rocks suggests that such deposits are in the realm of possibility. Several of the granites and, in particular, the gabbros just north of this quadrangle are potentially valuable for building and decorative stone.

DATA STORAGE

No Mineral Occurrence Documentation System (MODS) localities were identified in the quadrangle.

Work materials related to the Jibal Matalli quadrangle, and for the Jibal Hibran quadrangle (27/40 B) and the Jibal al Misma quadrangle (27/40 C) are archived as USGS-DF-04-01 (Ekren, 1984c).

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