UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Reconnaissance geology of the Al Ba'ayith quadrangle, sheet 26/41 D, Kingdom of Saudi Arabia

by

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with a Geographic map by Jack D. Turner

Open-File Report 85-617

Prepared for the Ministry of Petroleum and Mineral Resources, Deputy Ministry for Mineral Resources

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

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1985

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RECONNAISSANCE GEOLOGY OF THE AL BA'AYITH QUADRANGLE, SHEET 26/41 D, KINGDOM OF SAUDI ARABIA

By

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ABSTRACT

The Al Ba'ayith quadrangle, located in the northeastern part of the Arabian Shield, is underlain by upper Proterozoic intrusive rocks and volcanogenic layered sequences bounded by unconformities. The oldest rocks are silicic volcanic rocks of the Banana formation that is tentatively assigned to the Hulayfah group. Successively younger layered rocks are the Maraghan formation of the Murdama group, consisting of lithic graywacke, siltstone, and shale; the Hibshi formation, coarse-grained lithic sandstone and conglomerate; the Sufran formation, dacitic and andesitic lava flows and ash-flow tuffs; the Jurdhawiyah formation, andesitic flows and agglomerate, and conglomeratic sandstone; and the Hadn formation, rhyolite flows and ash-flow tuffs, conglomerate, sandstone, and andesite flows.

Plutonic rocks are of four main age groups: an early group consisting of orthogneiss of granodioritic and granitic composition, and metagabbro; a pre-Hibshi group consisting of the Murran complex (diorite and quartz diorite) and quartz monzodiorite; a post-Hibshi group, consisting of altered mafic plutonic rocks, granodiorite of the Idah suite, and monzogranite of the Shuwayman suite; and a latest Precambrian group of highly evolved granitic rocks, consisting of alkali-feldspar granite, granophyre, and syenogranite.

Structures in the orthogneiss and metagabbro trend northeast to northwest, and in the Murran complex, generally east. The Maraghan formation was folded and thrust over the Hibshi formation along the northeast-trending Raha fault. The Jurdhawiyah formation is at the northern margin of the east-trending Shuqrah basin. Northwest-trending left-lateral faults probably belong to the Najd fault system.

Quaternary surficial deposits mantle large areas of the quadrangle, and consist of sheet gravel, alluvial fan gravel, eolian and alluvial sand and silt, and sabkhah deposits.

Gold-bearing quartz veins occur associated with small plutons of the Idah suite in the southeastern part of the quadrangle, and have been mined in the past. Ironstones, near Murran in the center of the quadrangle contain trace amounts of silver and gold.

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INTRODUCTION

GEOGRAPHIC SETTING

The Al Ba'ayith quadrangle (sheet 26/41D) encompasses an area of about 2760 km^2 bounded by lat 26^0 00' and 26^0 30' N. and long 41^0 30' and 42^0 00' E., and lies in the northern part of the Arabian Shield in the Najd province, Kingdom of Saudi Arabia. The area is mostly an exceedingly flat, featureless, desert plain between 800 and 900 m in elevation above which rise isolated peaks and ridges several tens of meters high. Resistant rocks in the northwest part of the quadrangle form several groups of mountains, the largest of which is Jibal Qusayrah, a deeply dissected upland rising to more than 1200 m above sea level. (see pls. 1 and 2).

The area is drained by a branching wadi system that carries surface flow only intermittently. The trunk stream of the region, Wadi ar Rumah, flows eastward across the southern part of the quadrangle, and is joined by a large south-flowing tributary, Wadi ash Shi'bah, just south of the southeast corner. Several flowing springs occur in the mountains in the northwest part of the quadrangle.

The climate is typical of large desert areas of lower middle latitudes, with hot summers and cool winters, and marked diurnal variation in temperature during most of the year. Scant rainfall, which occurs mostly in the spring and fall, gives rise to brief periods of surface flow in the wadi channels. Natural vegetation consists of sparse desert shrubs, and grasses appear during periods of rainfall. Scattered small trees are present in places along some wadis.

The population of the Al Ba'ayith quadrangle is sparse. The inhabitants live in several small villages along the major wadis and in scattered bedouin encampments throughout the area. The largest community, Al Ba'ayith, has a population of several hundred. Other settlements are at Al Ballaziyah, Humr al Qa'asa, Ar Rufayi, Murran, Butayhan, Kutayfah and Wusayt. The economy is pastoral, based primarily on grazing of goats, sheep, and camels. Some food crops are grown in small tracts irrigated mostly by shallow wells tapping underflow in wadi channels.

In 1984, there were no paved roads in the Al Ba'ayith quadrangle, and few sections of road were graded and drained. Unimproved roads follow the major wadis and cross the area in several directions at intervals of several kilometers, and numerous tracks cross the desert plain. Communities within the Al Ba'ayith quadrangle are connected by unimproved roads with towns situated on paved highways outside the quadrangle, such as Al Mustajiddah, 20 km north of the quadrangle; Samirah, 15 km northeast; Uqlat as Suqur, 40 km southeast; Nuqrah, 45 km southwest; and As Sulaymi, 15 km west. Ha'il, the principal city in the region, lies 120 km to the north.

The Darb Zubaydah, the ancient pilgrim road connecting Baghdad with Al Madinah and Makkah, passes in a south-southwesterly direction just east of Al Ba'ayith. Ruins believed to be those of a fort or outpost dating from the period of the Ottoman empire, lie at the southern edge of Jibal al Qusayrah.

PREVIOUS INVESTIGATIONS

The area of the Al Ba'ayith quadrangle was first mapped in the early 1960's and is part of a reconnaissance geologic map of the Northwestern Hijaz quadrangle, Sheet I-205-A, scale 1:500,000 (Brown and others, 1963). The area was also covered in a regional airborne magnetometer and scintillation-counter survey (BRGM, 1966). A reconnaissance minerals survey was carried out in the Wadi ar Rimah 1:500,000-scale quadrangle directly east of the Al Ba'ayith quadrangle (Mytton, 1970). The area directly south of the quadrangle was geologically mapped in the 1970's (Delfour, 1977).

In 1980, the U.S. Geological Survey began systematic quadrangle mapping in the northeastern part of the Arabian Shield at a scale of 1:100,000; this work is virtually completed (fig. 1). Quadrangles contiguous to the Al Ba'ayith quadrangle are As Sulaymi, sheet 26/41C (Quick, 1984, unpublished data) Ar Rawdh, sheet 26/40D (O'Neill and Ferris, 1984, unpublished data); Al 'Awshaziyah, sheet 26/41B (Leo, 1984); Harrat Hutaymah, sheet 26/42A (Pallister, 1984); Samirah, sheet 26/42C (Williams, 1983); and Uqlat as Suqur, sheet 25/42A (Cole, 1984). The geology of the Al Ba'ayith quadrangle has been compiled at a scale of 1:250,000 as part of a geologic map of the Wadi ash Shubah quadrangle, sheet 26E (Quick and Doebrich, in press); 1:250,000-scale maps contiguous to the Al Ba'ayith quadrangle are the Jabal Habashi quadrangle, sheet 26F (Johnson and Williams, 1984), and the Aban al Ahmar quadrangle, sheet 25F (Cole, 1985).

PRESENT WORK

Field work for this report was done during a total of 33 days in October and November 1982, April 1983, and January 1984, and was staged from a base camp near Samirah. About two-thirds of the field work was supported by helicopter, and one-third by vehicle. The geology was mapped on 1:57,000-scale black and white aerial photographs compiled on a controlled photomosaic base at a scale of 1:100,000 (pl. 1). Mapping was substantially aided, especially in flat areas of poor exposure, by Landsat false-color imagery at 1:250,000-scale, and by the aeromagnetic contour map at 1:100,000-scale. Measurement of gamma radiation with a hand-held scintillation counter was found useful for correlating rock units. The geographic map (pl. 2) was prepared by Jack D. Turner (1984).

Supporting laboratory work included study of about 250 thin sections and 115 stained slabs, much of the preparation of which was done at camp in a mobile field laboratory. Chemical and spectrographic data were obtained from analysis of 33 samples of igneous rocks. Classification of plutonic rocks follows that of Streckeisen (1976) and is based on stained-slab modes; classification of volcanic rocks is that of Irvine and Baragar (1971) and is based on normative composition.

ACKNOWLEDGEMENTS

The authors thank J. E. Quick and J. L. Doebrich, who compiled much of the preliminary data for the Wadi ash Shi'bah report and contributed many useful ideas. J. S. Pallister was most helpful in field and office. J. C. Cole and C.E. Hedge made unpublished geochronological data available. A. H. El Bazli's careful modal analyses of stained slabs of the plutonic rocks, and his general assistance in preparation of the report are gratefully acknowledged. Technical review of the report by H. I. E. Hall greatly improved its content and presentation. The Field Services Section of the U.S. Geological Survey Mission and the helicopter crews of Saudia Special Flight Services provided excellent field support.

This report is in accordance with the work agreement between the U.S. Geological Survey and the Saudi Arabian Ministry of Petroleum and Mineral Resources.

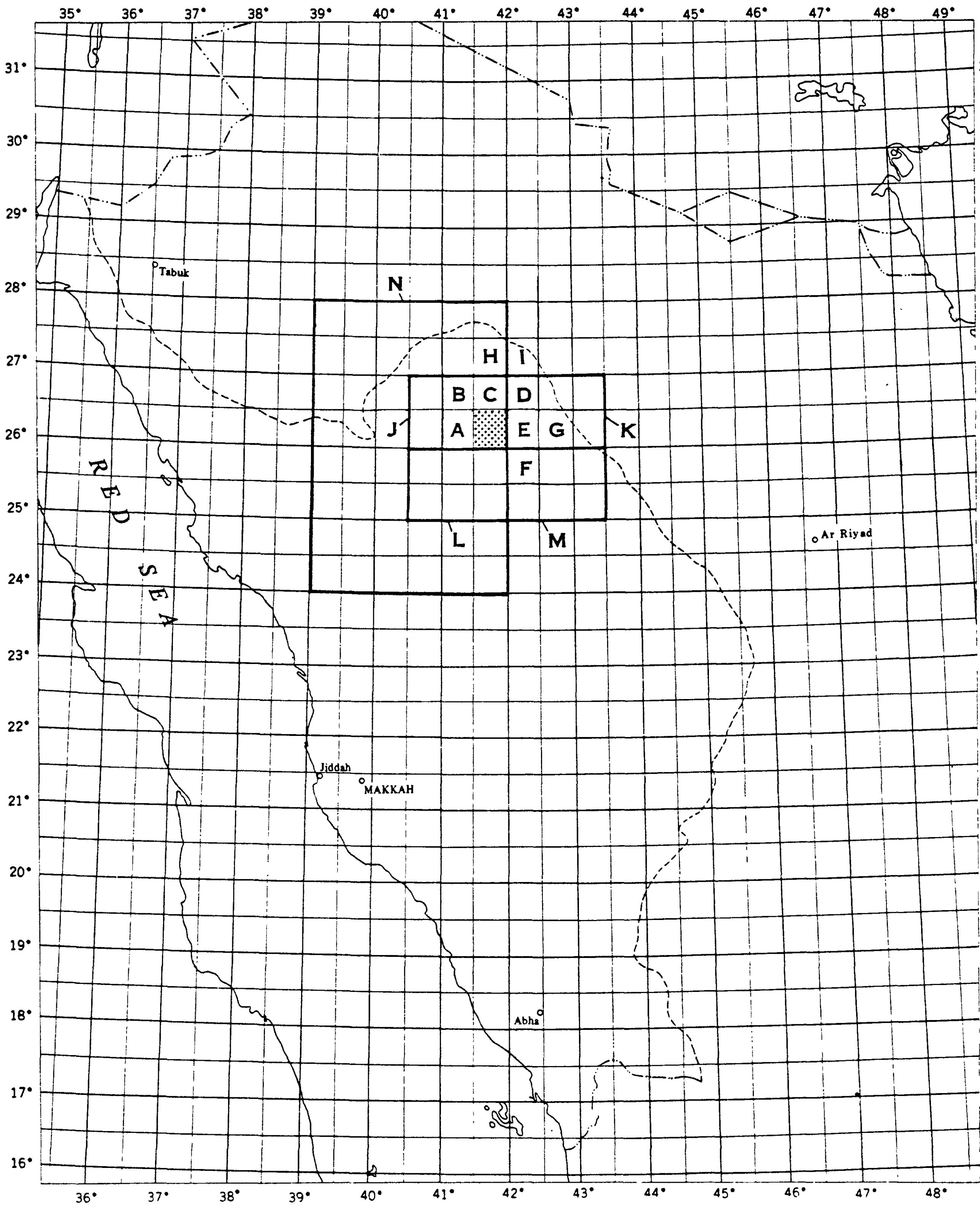

Figure 1.--*Index map of western Saudi Arabia showing location of the Al Ba'ayith quadrangle (stippled) and quadrangles referred to in the text: A, As Sulaymi (Quick, 1984, unpub. data); B, Ar Rawdh (O'Neill and Ferris, 1984, unpub. data); C, Al 'Awshaziyah (Leo, 1984); D, Harrat Hutaymah (Pallister, 1984); E, Samirah (Williams, 1983); F, Uqlat as Suqur (Cole, 1984a); G, Jabal as Silsilah (du Bray, 1983); H, Qufar (Kellogg, 1984b); I, Rak (Kellogg, 1984a); J, Wadi ash Shubah (Quick and Doebrich, in press); K, Jabal Habashi (Johnson and Williams, 1984); L, Nuqrah (Delfour, 1977); M, Aban al Ahmar (Cole, in press); N, Southeastern Hijaz (Brown and others, 1963).*

GEOLOGIC SETTING

The northeastern part of the Arabian Shield is a region of upper Proterozoic granitic rocks and genetically related metasedimentary and metavolcanic sequences, all of magmatic arc origin. Brown and others (1963) recognized four layered rock sequences bounded by major unconformities. From oldest to youngest, the sequences are: (1) the Halaban formation (later Halaban group), dominantly basic volcanics; (2) the Murdama formation (later Murdama group), coarse- to fine-grained marine volcaniclastic rocks and limestone; (3) the volcaniclastic Hibshi formation, and (4) the Shammar rhyolite. They also identified two major generations of granitic rocks: (1) pre-Halaban granite and granodiorite and (2) post-Murdama, pre-Shammar alkalic to peralkic granite forming oval to rounded plutons.

Subsequent studies in the region have established an age of about 740 Ma for the oldest metavolcanic sequence (Delfour, 1977). The Hibshi formation is dated at about 632 Ma (C. E. Hedge, written commun., 1983). Several other layered rock sequences have been defined (Cole, 1984a; duBray, in press). Plutonic rocks were emplaced during four principal magmatic episodes: (1) early intrusives, ranging from granite to gabbro, about 680-690 Ma; (2), pre-Hibshi dioritic rocks, including diorite, quartz diorite, and quartz monzodiorite, about 640-650 Ma; (3) post-Hibshi granitic rocks, of diverse but generally calc-alkaline composition, mostly monzogranite, granodiorite and quartz monzodiorite, but include syenogranite, diorite and gabbro, about 615-625 Ma; and (4), post-tectonic plutons of monzogranite, syenogranite and highly evolved alkali-feldspar granite, ranging in age from about 575-600 Ma (du Bray, 1984, unpub. data; Johnson and Williams, 1984; Aldrich and others, 1978; C. E. Hedge and J. C. Cole, written commun., 1983). Volcaniclastic sequences related to the third plutonic episode are compositionally varied and include two andesitic units, the Jurdhawiyah formation (Cole, 1980, 1984, unpub. data) and the Turmus formation (du Bray, 1984b). A third sequence, the Hibshi formation, is heterogeneous and contains basalt, andesite and dacite (du Bray, in press; Williams, 1983; Pallister, 1984). Volcanic sequences related to the post-tectonic alkali-feldspar granites, predictably, are mostly rhyolitic and can be spatially related to their plutonic eruptive centers (Chevremont, 1982: Leo, 1984: Kellogg, 1984a, 1984b, 1984c, unpub. data).

About 575 Ma ago, during early Cambrian time, magmatic activity ceased abruptly, and marine sedimentation began. Deposition of platform-facies sedimentary rocks continued over the entire Arabian Peninsula region during most of the Paleozoic and Mesozoic eras. Opening of the Red Sea rift in early Cenozoic time resulted in renewed intra-Shield deformation, forming the Ha'il arch in the northern part of the Shield (Greenwood, 1973). This structure, which appears in plan view as a salient into the Cenozoic platform sedimentary rocks, is a broad upwarp about 400 km wide. Uplift along its north-trending axis, which lies about 50 km west of the Al Ba'ayith quadrangle, has resulted in stripping of the sedimentary cover and erosion several kilometers deep into the Precambrian rocks of the Shield. The post-Precambrian rocks have been entirely removed from the Al Ba'ayith quadrangle.

PRECAMBRIAN METASEDIMENTARY AND METAVOLCANIC ROCKS

Layered volcanic and volcaniclastic rocks in the Al Ba'ayith quadrangle are divided into six formations that are demonstrably bounded by unconformities within the quadrangle or in adjacent areas of the northern part of the Shield. Two of these formations, the Banana and Sufran formations, are dominantly volcanic within the quadrangle; the Maraghan and Hibshi formations are mostly clastic; and the Hadn and Jurdhawiyah formations are interbedded clastic and volcanic rocks.

BANANA FORMATION

Silicic volcanic rocks (bsv) form the small, steep, rugged dark-colored hills of Jibal Abid along the western border of the quadrangle, and a small area of outcrop south of Biyadat al Jubu. In the adjacent As Sulaymi quadrangle, Quick (1994 unpub. data) included these rocks in the Banana formation, which he tentatively assigned to the Hulayfah group (Delfour, 1977), and which consists mostly of basalt and andesite flows metamorphosed in the greenschist facies, but includes minor intercalated silicic volcanic rocks (rhyolites and dacites) and metasediments. The Banana is equivalent to the Aqab formation (Leo, 1984) and the Nuf formation (Kellogg, 1983b). O'Neill and Ferris (1994 unpub. data) mapped equivalent rocks as informal rock units in the Hulayfah group. The Banana may also be equivalent to the Saydun formation in the Uqlat as Suqur quadrangle (Muller, 1975; Cole, 1985). The Banana formation is probably the oldest layered rock unit in the Al Ba'ayith quadrangle, although its base is not exposed.

Within the Al Ba'ayith quadrangle, the Banana formation consists mostly of dark-greenish-gray to dark-red, ledge-forming, densely welded ash-flow tuff that forms bold strike ridges. Dark-green sheared volcanic conglomerate and lithic tuff were observed at one locality. The ash-flow tuff consists of phenocrysts of embayed quartz, 0-15 percent; potassium feldspar, 0-5 percent; and sericitized plagioclase, 20-25 percent; mafic minerals are absent except for sparse pseudomorphs of secondary alteration minerals. The groundmass is a fine-grained mosaic of quartz and feldspar, and displays features typical of zoned ash-flow tuffs such as devitrification spherulites made up of radiating mineral aggregates, and eutaxitic compaction structures such as deformed glass shards and flattened, recrystallized pumice. The phenocryst suite suggests that the rocks are dacites; equivalent rocks in the As Sulaymi quadrangle are dacites and rhyolites (Quick, 1994 unpub. data). The outcrops south of Biyadat al Jubu consist of cream-colored, quartz- phyric, flow-banded rhyolite. The rock is sheared, and epidote veinlets are common.

A minimum age for the Banana formation is indicated by the age of a granodiorite that intrudes it in the Ghazzalah quadrangle. The age of the granodiorite is 735±10 Ma (C.E. Hedge, written commun. reported in Quick and Doebrich, in press). If, however, the rocks in the Al Ba'ayith quadrangle assigned to the Banana prove to be equivalent to the Saydun formation, a younger minimum age about 680-690 Ma is indicated; this age is that of the Suwaj suite that intrudes the Saydun formation in the Uqlat as Suqur quadrangle (Cole, 1985).

MARAGHAN FORMATION

The Maraghan formation (du Bray, in press; Johnson and Williams, 1984) consists of metasedimentary rocks (ma) that form poor exposures in the southeast corner of the Al Ba'ayith quadrangle. The lower part of the Maraghan is in fault contact with the Hibshi formation; in the Uqlat as Suqur quadrangle equivalent rocks lie unconformably on the Saydun formation (Cole, 1985). The Maraghan is unconformably overlain by the Jurdhawiyah formation. The Maraghan formation is considered to be a formation of the the Murdama group, and is equivalent to rocks mapped as the Hadiyah formation, also of the Murdama group (Delfour, 1977; Williams, 1983) and to the Murdama group, undivided (Cole, 1985).

The Maraghan formation consists of light-greenish-gray siltstone, shale, and fine-grained sandstone. Compositionally, the sandstones are lithic graywackes, consisting mostly of quartz, plagioclase feldspar, and volcanic rock fragments in a fine-grained matrix (du Bray, in press). The rocks are commonly weakly calcareous, and gray limestone and dolomite beds are present in places. The lowermost part of the Maraghan formation at the extreme east edge of the quadrangle consists of gray, massive to thin-bedded, dolomitic marble (mam) that forms megaboudins several hundred meters thick along the faulted Maraghan-Hibshi contact. The marble unit is tectonically eliminated in most places, although it is present elsewhere near the base of the Maraghan (Johnson and Williams, 1984; Cole, 1985). The Maraghan contains metabasalt (greenstone) in the adjacent Samirah quadrangle and, at Dilay al Rashid at the eastern edge of the Samirah quadrangle, contains a lens several hundred meters thick of remarkably well-preserved andesitic pillow lava (Williams, 1983).

The fine-grained clastics of the Maraghan formation display strong slaty cleavage that contributes to their tendency to weather to a flat plain of poor outcrop. An irregular network of thin quartz veins is commonly present in the Maraghan; in such places the outcrops are mantled by a lag of white quartz chips.

The Maraghan formation is tightly, locally isoclinally, folded along northeast-trending axes that are not mappable in the Al Ba'ayith quadrangle because of poor exposures.

Although there are no radiometric ages for the Maraghan or its correlatives, available ages on associated plutonic rocks indicate that is probably between about 640 and 680 Ma old. It rests nonconformably on the Suwaj suite, 680-690 Ma, and is intruded by the Idah suite, about 620 Ma. It is older than the Hibshi formation, dacite in the lower part of which has been dated at about 630 Ma. (J. C. Cole and C. E. Hedge, written commun., 1983). Its age relative to the Laban quartz diorite, about 650 Ma, is unknown.

HIBSHI FORMATION

The Hibshi formation (hi) forms a low strike ridge from 1 to 5 km wide in the southeastern part of the Al Ba'ayith quadrangle. The ridge is continuous about 100 km northeastward to Jabal Hibshi, the type locality for the formation (Brown and others, 1963; Pallister, 1984). The Hibshi formation in the Al Ba'ayith quadrangle rests nonconformably on the orthogneiss unit and the Samirah quartz monzodiorite, and is intruded by granodiorite of the Idah suite.

The Hibshi formation consists of black to dark-green, fine- to coarse-grained sandstone, conglomeratic sandstone, siltstone, and shale. Conglomerate occurs in channels at the base of the unit, and contains cobbles of granitic rocks as large as 20 cm. The Hibshi is thin to medium bedded, although a pervasive fracture cleavage obscures original bedding. Layers of fine-grained greenstone are intercalated with the clastic rocks in places. The most common lithology is coarse-grained lithic graywacke that commonly contains light-green shale chips, and consists of about 15 percent angular quartz, 20 percent plagioclase feldspar, and 20 percent volcanic rock fragments in a fine-grained, chloritic, and slightly calcareous matrix.

Thickness of the Hibshi is difficult to determine because of isoclinal folding. The rocks at the type locality are less strongly folded. The formation contains thick conglomerate layers and a thick succession of dacitic ash-flow tuffs, implying a nearby volcanic eruptive center. Total thickness is in excess of 3000 m. The Hibshi in the Al Ba'ayith quadrangle is a distal facies consisting of relatively fine grained clastic rocks, and is probably no more than 1000 m thick. Dacitic ash-flow tuff in the Hibshi has been dated at 632±6 Ma (C. E. Hedge and J. C. Cole, written commun., 1983); this age is concordant with radiometric ages from pre- and post-Hibshi rocks.

SUFRAN FORMATION

The Sufran formation (sv) is here named for volcanic rocks that form a range of hills in the northern part of the quadrangle from Jibal Sufran al Ballaziyah westward. The unit is continuous with rocks mapped as rhyolite and quartz latite in the adjacent Samirah quadrangle (Williams, 1983); these rocks rest unconformably on the Samirah quartz monzodiorite. Pallister (1984) used the term "Samirah volcanics" for the rhyolite and quartz latite in the Samirah quadrangle: as Samirah was used previously for the Samirah quartz monzodiorite (Williams, 1983; Johnson and Williams, 1984), a new name, Sufran formation, seems preferable. The Sufran is demonstrably older than volcanic rocks of the Hadn formation in the northwest part of the quadrangle. Quick and Doebrich (in press) include the Sufran formation in the Hulayfah group.

The Sufran formation consists of a variety of light- to dark-red, gray, and black flow rocks and subordinate welded tuffs. Flow boundaries are difficult to determine in the field, and flows are distinguished chiefly by color. Most of the flows are porphyritic, with phenocrysts of plagioclase and subordinate hornblende forming 10 to 40 percent of the rock. Phenocrysts of quartz and potassium feldspar are sparsely present in some units.

Thin-section study shows that the Sufran contains both silicic volcanics and andesites. Silicic volcanics include both flows and densely welded ash-flow tuffs, and consist of varying proportions of phenocrysts of anhedral resorbed quartz, subhedral orthoclase and plagioclase, and small amounts of fresh biotite and hornblende, in a fine-grained groundmass of quartz, feldspar and minor chlorite. Black to dark-green andesites consist of plagioclase and green hornblende phenocrysts in a groundmass of fine-grained hornblende, plagioclase, quartz, and chlorite. A small amount of olivine was observed in one sample.

Chemical analyses of four samples of the Sufran volcanics (table 1; fig. 2) indicate a dacitic composition; inadvertently andesitic rocks were not sampled. The Sufran is similar chemically to volcanic rocks in the Hibshi formation, which, on the basis of limited sampling, also contains dacites and andesites. The two formations are likely about the same age and represent two eruptive centers active during the same volcanic episode; both are younger than the Samirah quartz monzodiorite, and older than monzogranite of the Shuwayman suite (Johnson and Williams, 1984).

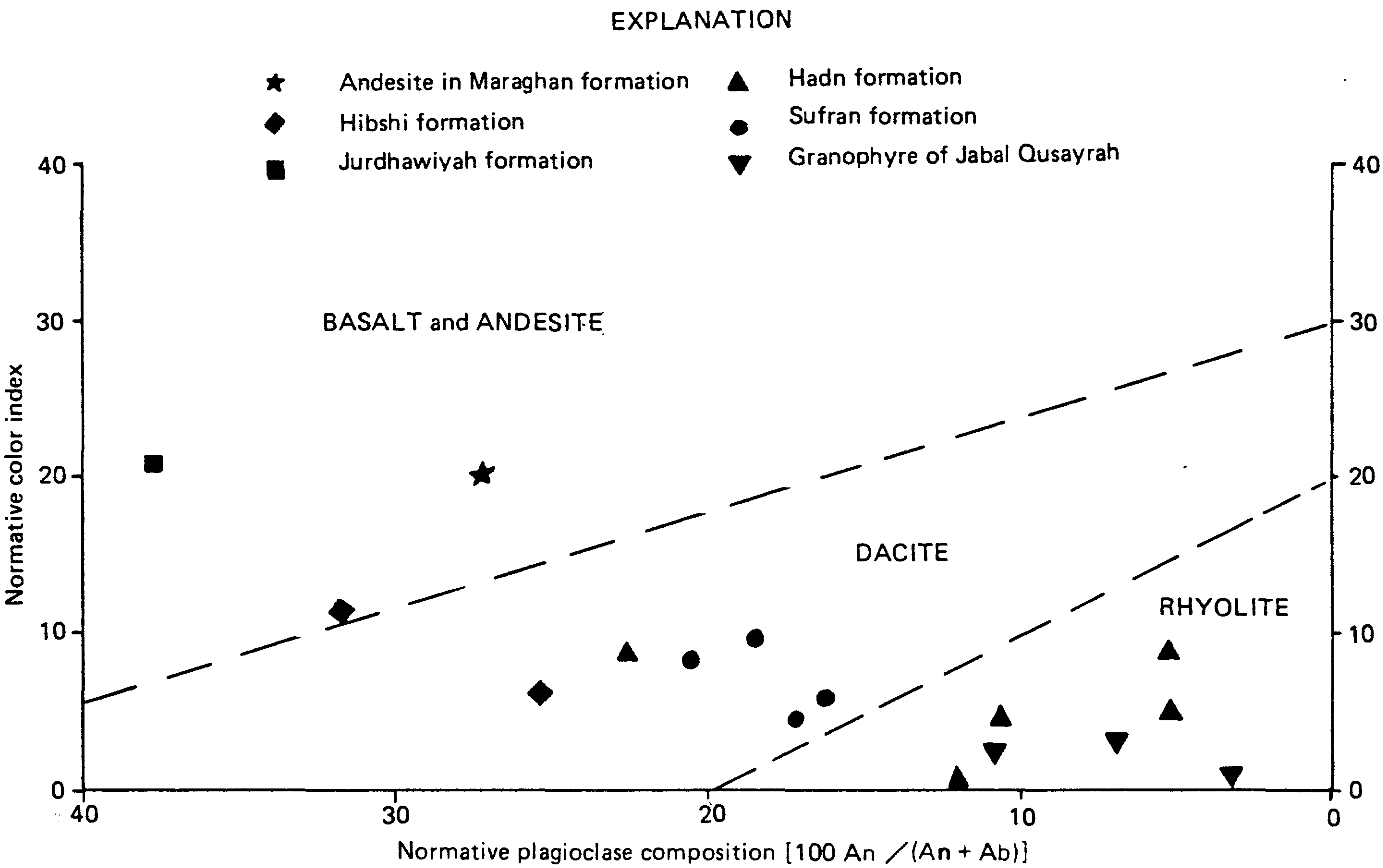

Figure 2.--*Geochemical classification of volcanic rocks in the Al Ba'ayith quadrangle and adjacent areas (Irvine and Baragar, 1971).*

JURDHAWIYAH FORMATION

Volcanic flows and clastic rocks of the Jurdhawiyah formation (ju) (Cole, 1981, 1985) crop out in low hills in the southeastern corner of the Al Ba'ayith quadrangle. These outcrops are at the western extremity of a series of east-trending tectonic basins in which a thick succession of andesite flows and agglomerate, with subordinate epiclastic rocks, accumulated. Detailed studies by Cole (in press) led him to raise the rank of the Jurdhawiyah to group status, and to subdivide it into four mappable formations. Cole's earlier (1981) designation of the unit as a formation is retained because the unit is sparsely represented in the Al Ba'ayith quadrangle.

East of Wadi ash Shi'bah the Jurdhawiyah is mostly clastic and rests unconformably on tightly folded rocks of the Maraghan formation; west of the wadi it consists mostly of lava flows and rests on the Maraghan and on post-Maraghan granodiorite of the Idah suite. At the base of the sequence east of Wadi ash Shi'bah a green, coarse-grained sandstone containing pebbles of granitic rocks lies unconformably on strongly folded rocks of the Maraghan formation. The sandstone is framework-supported, consisting almost entirely of volcanic lithic fragments, mostly andesite, with minor quartz, potassium feldspar, and plagioclase, in a scant matrix of chlorite and calcite. Above the basal sandstone lie dark-green and dark-gray, porphyritic andesite flows and agglomerate interbedded with coarse- to fine-grained, green lithic sandstone. The andesite consists of 10 to 40 percent plagioclase phenocrysts in a pilotaxitic groundmass of plagioclase, pyroxene, and amphibole. Clasts in the agglomerate are as large as 40 cm.

Table 1.—Major element analyses and CIPW norms for selected volcanic rocks in the Al Ba'ayith quadrangle

Rapid-rock analyses performed in the DGMR/USGS chemical laboratory, Jiddah, using techniques described by Shapiro and Brannock (1962). All values are weight percent

Number	1	2	3	4	5	6	7	8	9	10	11	12
Field No. 193-	256	263	654	667	668	682	416	794	795	796	797	869
Chemical analyses												
SiO_2	70.00	62.70	68.60	66.70	65.80	74.10	68.50	69.50	65.20	69.5	63.70	54.90
TiO_2	0.46	0.73	0.48	0.49	0.69	0.18	0.48	0.48	0.61	0.2	0.55	1.54
Al_2O_3	14.70	16.30	15.40	15.90	15.80	13.90	13.20	13.30	15.30	15.4	17.30	17.50
Fe_2O_3	1.55	4.05	1.64	2.06	1.86	0.75	5.41	5.20	3.18	1.7	2.94	2.31
FeO	1.25	1.27	1.36	2.15	2.15	1.57	0.94	0.36	2.36	1.4	1.81	5.37
MnO	0.04	0.08	0.11	0.10	0.07	0.04	0.44	0.08	0.25	0.0	0.17	0.16
MgO	1.04	2.40	0.77	0.88	1.09	0.27	0.06	0.09	0.40	0.2	1.20	2.82
CaO	2.60	4.45	1.88	2.45	2.86	1.53	0.84	0.98	1.43	1.1	3.20	5.71
Na_2O	4.10	4.12	5.14	4.86	5.11	4.24	4.45	3.90	6.61	5.2	5.83	3.73
K_2O	3.38	3.34	3.54	3.69	3.48	3.11	4.74	4.82	3.04	3.7	2.01	4.00
P_2O_5	0.13	0.24	0.14	0.14	0.18	0.03	0.05	0.04	0.14	0.0	0.21	0.82
H_2O	0.96	0.58	0.68	0.22	0.52	0.50	1.11	1.02	1.03	0.8	0.75	1.65
Total	100.91	100.26	99.74	99.64	99.61	100.22	100.22	99.57	99.55	99.6	99.67	100.51
CIPW norms												
Q	27.10	14.52	20.32	17.63	15.70	33.11	23.33	26.59	12.17	21.8	14.06	2.01
C	0.00	0.00	0.03	0.00	0.00	0.85	0.00	0.00	0.00	0.7	0.22	0.00
Or	19.98	19.80	21.12	21.93	20.75	18.43	28.26	28.84	18.23	22.3	12.01	23.91
Ab	34.71	34.97	43.90	41.36	43.63	35.98	37.99	33.42	56.77	45.1	49.87	31.92
An	11.73	16.17	8.49	10.73	9.99	7.41	2.06	4.61	3.15	5.3	14.66	19.42
Di	0.26	3.43	0.00	0.47	2.55	0.00	0.33	0.04	2.60	0.0	0.00	3.14
Wo	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.0	0.00	0.00
Mt	2.25	2.25	2.40	3.00	2.72	1.09	3.10	0.03	4.68	2.6	4.31	3.39
Il	0.87	1.39	0.92	0.94	1.32	0.34	0.92	0.92	1.18	0.4	1.06	2.96
Ap	0.31	0.57	0.33	0.33	0.43	0.07	0.12	0.10	0.34	0.0	0.50	1.96

No.	Rock type, formation	Location
1.	Dacite, Hibshi formation	(26°32' N., 42°19' E.)
2.	Andesite, Hibshi formation	(26°33' N., 42°20' E.)
3.	Dacite, Sufran formation	(26°25' N., 41°58' E.)
4.	" " "	(26°25' N., 41°53' E.)
5.	" " "	(26°24' N., 41°52' E.)
6.	" " "	(26°26' N., 41°43' E.)
7.	Rhyolite, Hadn formation	(26°29' N., 41°39' E.)
8.	" " "	(26°29' N., 41°40' E.)
9.	" " "	(26°30' N., 41°38' E.)
10.	" " "	(26°23' N., 41°33' E.)
11.	Dacite, " "	(26°22' N., 41°31' E.)
12.	Andesite, Jurdhawiyah formation .	(26°00' N., 41°51' E.)

West of Wadi ash Shi'bah the Jurdhawiyah consists of dark-green to black porphyritic andesite flows; the area was probably an eruptive center. Phenocrysts form 20 to 40 percent of the rock, and are dominantly plagioclase, as much as 2 cm long, and subordinate clinopyroxene and hornblende. The fine-grained groundmass consists of plagioclase laths, pyroxene, amphibole, and opaque minerals with trachytic to pilotaxitic textures. Andesite lithic fragments were observed in one flow. Alteration is intense in some flows, with most of the primary mineral constituents replaced by chlorite, epidote and sericite; other flows are virtually unaltered.

The relationship of the Jurdhawiyah to the strongly folded Maraghan formation is clearly unconformable; its relationship to the Hibshi formation is less clear. But the fact that the Hibshi is also strongly folded suggests that the Jurdhawiyah is also younger than the Hibshi. Furthermore, the Jurdhawiyah rests nonconformably on granodiorite attributed to the Idah suite that cuts both the Maraghan and Hibshi formations; if correlation of the granodiorite with the Idah suite, dated at 617 ±6 Ma, is correct, then the Jurdhawiyah, at least in this area, may be considerably younger than the Hibshi, dacite in which has been dated at 632 Ma.

HADN FORMATION

A heterogeneous succession of silicic volcanic rocks and intercalated clastic rocks (hv, hvs), in the northwest part of the Al Ba'ayith quadrangle, is mapped as the Hadn formation (Chevremont, 1982; Stoeser and Elliott, 1984; unpub. data). Equivalent rocks in the Al Awshaziyah quadrangle to the north were designated the 'Awshaziyah formation by Leo (1984). The Hadn forms prominent fault-controlled strike ridges at Jibal umm as Saham at the north edge of the quadrangle, and a terrain of rugged hills to the south at Jibal al Jabiriyah. The two outcrop areas are separated by Jibal Qusayrah.

Volcanic rocks in the Hadn formation are light-red, orange, dark-gray, and light-green porphyritic lava flows and densely welded ash-flow tuffs. Generally the ash-flow tuffs and some of the flows form prominent ledges and cliffs. Interbedded clastic rocks included bedded vitric-crystal tuff, conglomerate, sandstone, and agglomerate. The following succession, described from top to base, occurs on a ridge at the eastern end of Jibal al Jabiriyah, and although not a measured section, expresses the lithologic variety of the Hadn in this area; thicknesses are estimated:

(11) Welded ash-flow tuff, black, containing conspicuous pumice fiamme and sparse feldspar phenocrysts .... 3 m

(10) Conglomerate containing pebbles and cobbles of volcanic rocks .... 2 m

(9) Felsite flow, light-red, aphanitic .... 5 m

(8) Cobble and boulder conglomerate containing clasts of volcanic and granitic rocks .... 4 m

(7) Felsite, light-red, aphanitic .... 8 m

(6) Andesite(?) flow, black, aphanitic .... 5 m

(5) Sandstone, grayish-green, coarse-grained, with cobble conglomerate near the top; contains beds of light-gray, tuffaceous sandstone .... 30 m

(4) Flow, light-red, containing quartz and potassium feldspar phenocrysts... 5 m

(3) Sandstone, green, pebbly, coarse-grained .... 30 m

(2) Felsite flow, light-red, sparsely porphyritic .... 6 m

(1) Lithic sandstone, gray, coarse-grained .... 4+m

Petrographically, the volcanic rocks can be roughly divided into felsites and andesites, the former more abundant than the latter. The rocks classed as felsites are mostly porphyritic, and include welded ash-flow tuffs and lava flows. The ash-flow tuffs are moderately 'to densely welded and contain phenocrysts of quartz and orthoclase in a fine-grained groundmass displaying vitroclastic and crystallization textures and structures typical of silicic pyroclastic rocks. Flow rocks have a holocrystalline, generally equigranular and structureless groundmass.

Andesites are also porphyritic, mainly as plagioclase, with aphanitic to fine-grained groundmass textures. Mafic minerals are commonly altered to chlorite, and appear to be less abundant than is typical for andesites, either as phenocryst or groundmass components. Amphiboles are more abundant than pyroxenes.

Five major-element analyses for Hadn volcanic rocks in the Al Ba'ayith quadrangle are given in table 1, and classification based on rock norms are in figure 2. Four of the rocks sampled are rhyolites, and one is dacite. Andesitic rocks were not analyzed. Na_2O/K_2O ratios are higher than normal in the Hadn rocks, so that they can be classified as quartz keratophyres. Stoeser and Elliott (1984, unpub. data), noted similar high Na_2O/K_2O ratios in rhyolites and dacites of the Hadn formation in the Al Qasr quadrangle north of the Al Ba'ayith quadrangle. They also analyzed two mafic flows in the Hadn, one of which was determined to be alkali basalt, and the other, basaltic andesite.

Areas mapped as sedimentary rocks (hvs) in the Hadn formation are exposures of conglomerate and sandstone; volcanic rocks are sparse to absent. The conglomerates are dark brown, and consist of subangular to subrounded cobbles as large as 15 cm. The clasts are about 50 percent granitic rocks, the remainder consisting of aphanitic dike rocks and sandstone, in a matrix ranging in grain size from silt to coarse sand. Volcanic clasts are sparse to absent, although at one exposure the conglomerate rests on rhyolite flows. The sandstones are gray, quartzitic, are medium to coarse grained, and have black silty and shaley interbeds a few centimeters thick.

The heterogeneity of the Hadn formation, particularly the alternation of lava flows, ash-flow tuffs, and coarse-grained volcaniclastic sediments, suggests a nearby eruptive center. Jabal Qusayrah, which lies between the two main outcrop areas of the Hadn formation, consists of thick northwest-dipping sheets of red alkalic granophyre. The granophyre bears a striking resemblance to the Na'i granophyre in the the Jabal Salma area (Kellogg, 1984b), which was emplaced as successive, rapidly quenched sheets of granite magma intruded into a rhyolitic caldera fill during resurgent magmatism at the Salma volcanic center. Possibly the Hadn in the Al Ba'ayith quadrangle is itself a caldera fill, although exposed contacts between the volcanic rocks and the granophyre are faults, not intrusive.

The Hadn formation has been dated at the type section in the Al Qasr quadrangle by the Rb-Sr isochron method as 613 Ma (R. J. Fleck, written commun. reported in Stoeser and Elliott, 1984, unpub. data). Its age relative to the Jurdhawiyah formation, which is probably nearly coeval, is unknown; the two formations are nowhere in contact.

PRECAMBRIAN INTRUSIVE ROCKS

Intrusive igneous rocks of late Proterozoic age underlie most of the area of the Al Ba'ayith quadrangle. They comprise plutons ranging in size from less than 1 square km to more than 100 square km, in shape from very irregular to circular, in composition from gabbro to syenogranite and alkali-feldspar granite, and in age from about 680 Ma to 570 Ma. Most of the plutonic rocks weather recessively, although some are resistant to erosion and form mountains.

In the Jabal Habashi quadrangle, du Bray (1984a) subdivided the plutonic rocks into three broad age categories that are represented in the Al Ba'ayith quadrangle: (1) Pre-Murdama (pre-Maraghan, and also pre-Hibshi) rocks, more than 640 Ma old, largely mafic to intermediate in composition, including in the Al Ba'ayith quadrangle the Murran complex and the Samirah quartz monzodiorite; (2) post-Murdama (post-Maraghan, and also probably post-Hibshi) rocks, 600-620 Ma old, consisting of intermediate to felsic plutons that intruded the Murdama and that largely postdate its deformation, and including granodiorite of the Idah suite and numerous monzogranite plutons of the Shuwayman suite; and (3), post-tectonic rocks, about 570-580 Ma old, consisting mostly of highly evolved alkali-feldspar granites including granophyre and syenogranite. A fourth category consists of rocks older than du Bray's pre-Murdama rocks, represented in the Al Ba'ayith quadrangle by orthogneiss and metagabbro, that are probably equivalent to the Suwaj suite (Cole, in press) which is dated at about 680-690 Ma.

ORTHOGNEISS

Orthogneiss and subordinate orthoschist (gn) are the oldest intrusive rocks in the Al Ba'ayith quadrangle. This unit underlies much of the central part of the quadrangle, and is present in several places in the southwestern part. Rocks of this unit weather very recessively in most places, rarely forming outcrops and commonly mantled by incoherent grus mixed with eolian sand and silt. Contacts between the othogneiss and other units are mostly inferred, and in places rocks mapped as orthogneiss likely include gneissic rocks of the Murran complex and possibly younger weakly gneissic granitic rocks. The unit is best exposed in the east-central part of the quadrangle near Wadi ash Shi'bah.

The orthogneiss unit includes rocks with a considerable range in texture and mineral composition. The gneisses are light to dark gray or greenish gray in most exposures. Lithologies include coarse-grained leucogneiss with augen of potassium feldspar, medium-grained granite to diorite gneiss, and fine-grained gneiss and schist; some of the schist is very fine grained and resembles impure quartzite. Small pods of marble were observed in two places, suggesting that some of the unit is paragneiss. Mafic mineral content ranges from nearly none in some leucogneisses to as much as 35 percent in dioritic gneisses; mafic minerals are commonly altered to aggregates of chlorite, sericite and epidote. Biotite is the most common mafic mineral in the granitic gneisses, whereas hornblende is most abundant in dioritic gneiss. Modal composition of felsic components of the orthogneiss, shown in figure 3, ranges from quartz monzodiorite to syenogranite. More mafic rocks of the orthogneiss unit overlap in composition with the Murran complex.

Gneissic foliation is weakly to strongly developed and is in part cataclastic. The foliation nearly everywhere trends from N. 30^0 W. to N. 30^0 E., averaging north.

Age of the orthogneiss is not known with certainty. Its age relative to the Banana formation is presently indeterminable, as the two units are nowhere in contact except for the small outcrop of Banana rhyolite south of Biyadat al Jubu, where the contact, which could either be depositional or intrusive, is not exposed. Possibly it is equivalent in part to the Suwaj suite in the Uqlat as Suqur quadrangle (Cole, in press) which has been radiometrically dated at 680-690 Ma (Stuckless and others, in press; Cole and Hedge, written commun., 1984). Rocks of the Suwaj suite display a range in composition similar to that of the orthogneiss in the Al Ba'ayith quadrangle, although granophyric textures which are common in rocks of the Suwaj were not observed in the orthogneiss.

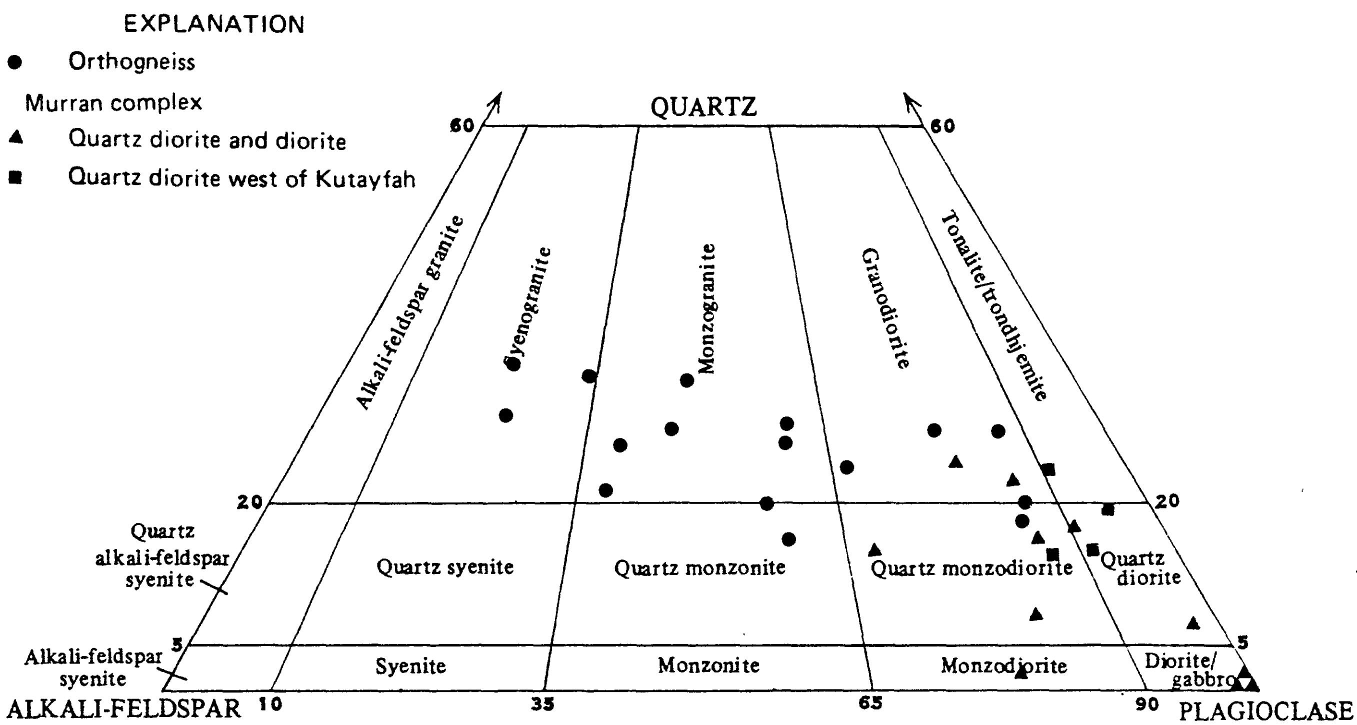

Figure 3.--*Ternary diagram showing relative modal composition of orthogneiss and the Murran complex. Composition fields are drawn according to Streckeisen (1976).*

METAGABBRO

Metagabbro (mgb) forms elongate bodies hundreds of meters to tens of kilometers long in the orthogneiss east of Biyadat al Jubu and at Kuhaylat al Ba'ayith near Wadi ar Rumah. The rock is more resistant to erosion than the enclosing orthogneiss and crops out as low, dark-gray ridges.

The rock is dark gray to black in outcrop and tends in places to weather to large black boulders. Gneissic foliation is apparent at most outcrops. The rock is seen in thin section to be mineralogically and texturally varied. Gabbro in the large pluton east of Biyadat al Jubu consists of medium-grained labradorite, with diabasic texture. The gabbro at Kuhaylat al Ba'ayith is fine grained, lacks olivine, and is strongly foliated, containing bands rich in green hornblende alternating with pyroxene-bearing bands. Sparse coarser grains of plagioclase and clinopyroxene are probably phenocrysts and are somewhat smeared out parallel to the foliation which is apparently cataclastic.

The age of the metagabbro is not known. The presence of fresh olivine in some samples suggests a relatively young age, whereas it intrudes only the orthogneiss and has well-developed foliation, suggesting an older age.

MURRAN COMPLEX

Quartz diorite and diorite (qdd) underlying much of the quadrangle from its central part southwestward is here informally named the Murran complex, after the small village of Murran north of Bidayat al Jubu. These rocks apparently intrude the orthogneiss, although no exposures of an intrusive contact were observed. It is intruded by the quartz monzodiorite at Sh'aib Rijlat and by monzogranites of the Shuwayman suite. Rocks of the Murran complex are recessive-weathering in most places and form few outcrops; boundaries are inferred from grus and scattered poor outcrops. East-trending photo lineaments in the vicinity of Murran suggest that the Murran there was injected as a dike swarm. West of the village of Wusayt, quartz diorite (qd) occurs in a pluton with mappable boundaries that contains numerous outcrops; this subunit is described separately.

Quartz diorite and diorite

Rocks of the Murran complex mapped as quartz diorite and diorite, undivided, are dark gray to dark greenish gray, are mostly medium grained, and are weakly gneissic to structureless. Plagioclase feldspar, 50-70 percent, commonly sericitized, and hornblende, 20-40 percent, are major constituents common to all rocks of the assemblage. Hornblende is altered to actinolite, chlorite, and epidote in most samples. Interstitial quartz is present in some samples in trace to minor amounts; small amounts of potassium feldspar occur in a few samples. Biotite is rare but occurs in small amounts in quartz diorite where it is greatly subordinate to hornblende and is commonly chloritized. Pyroxenes were noted in a few samples, and are mostly altered to secondary minerals. Modal composition of felsic constituents are shown in figure 3; the range in composition is from diorite to granodiorite. The rocks are mostly medium grained, and have both diabasic and ophitic textures. Fabric is varied, ranging from strongly gneissic to random.

Quartz diorite west of Wusayt

Rocks forming the pluton west of Wusayt are light gray, and are weakly gneissic. The rock is medium-grained quartz diorite and tonalite, and consists mostly of partially sericitized plagioclase. Quartz, 15-20 percent, occurs as subparallel discoid grains that impart the gneissic fabric to the rock. Potassium feldspars is present in small amounts. Mafic minerals form 5-10 percent of the rock, and consist of subequal amounts of green hornblende and chloritized biotite.

Age of the Murran complex

The rocks of the Murran complex, particularly the quartz diorite, are lithologically very similar to the Laban complex in the western part of the Jabal Habashi 1:250,000-scale quadrangle (Johnson and Williams, 1984). The Laban complex is nonconformably overlain by the Hibshi formation, and has been dated at 650±6 Ma (J.C. Cole and C.E. Hedge, written commun., 1983).

SAMIRAH QUARTZ MONZODIORITE

The Samirah quartz monzodiorite (sqm) forms a large pluton in the western part of the Samirah quadrangle (Williams, 1983; Johnson and Williams, 1984) where it intrudes amphibolite, schist and diorite, and is intruded by the Kilab monzogranite. The western border of the pluton lies in the Al Ba'ayith quadrangle generally east of, and subparallel to, Wadi ash Shi'bah. It intrudes the orthogneiss unit, is intruded by the Shuwayman monzogranite and rocks of the alkali-feldspar granite suite, and is nonconformably overlain by volcanic rocks of the Sufran formation.

The rock is medium gray, and although it weathers recessively, forms numerous outcrops. Weak gneissic structure from subparallel alinement of mafic minerals was observed in most places. Disc-shaped, fine-grained mafic inclusions 5-30 cm in long dimension form 1-2 percent of the rock in most outcrops. Texturally, the rock is medium grained but locally is fine and coarse grained, and is inequigranular, rarely porphyritic. The quartz monzodiorite consists of 40-70 percent plagioclase, 10-30 percent quartz, 5-30 percent potassium feldspar (microcline, and rarely orthoclase) and about 10 percent chloritized biotite or green hornblende; the two minerals rarely occur in the same specimen. Modal composition of the felsic constituents is given in figure 4, and shows a composition range from quartz diorite to monzogranite.

The Samirah quartz monzodiorite has not been radiometrically dated. It is nonconformably overlain at Jabal al Khidar in the Samirah quadrangle by the Hibshi formation, dacite in which is 632±6 Ma (J. C. Cole and C. E. Hedge, written commun., 1984), and is believed to be younger than the Laban complex, 646±6 Ma, although the two units are nowhere in contact.

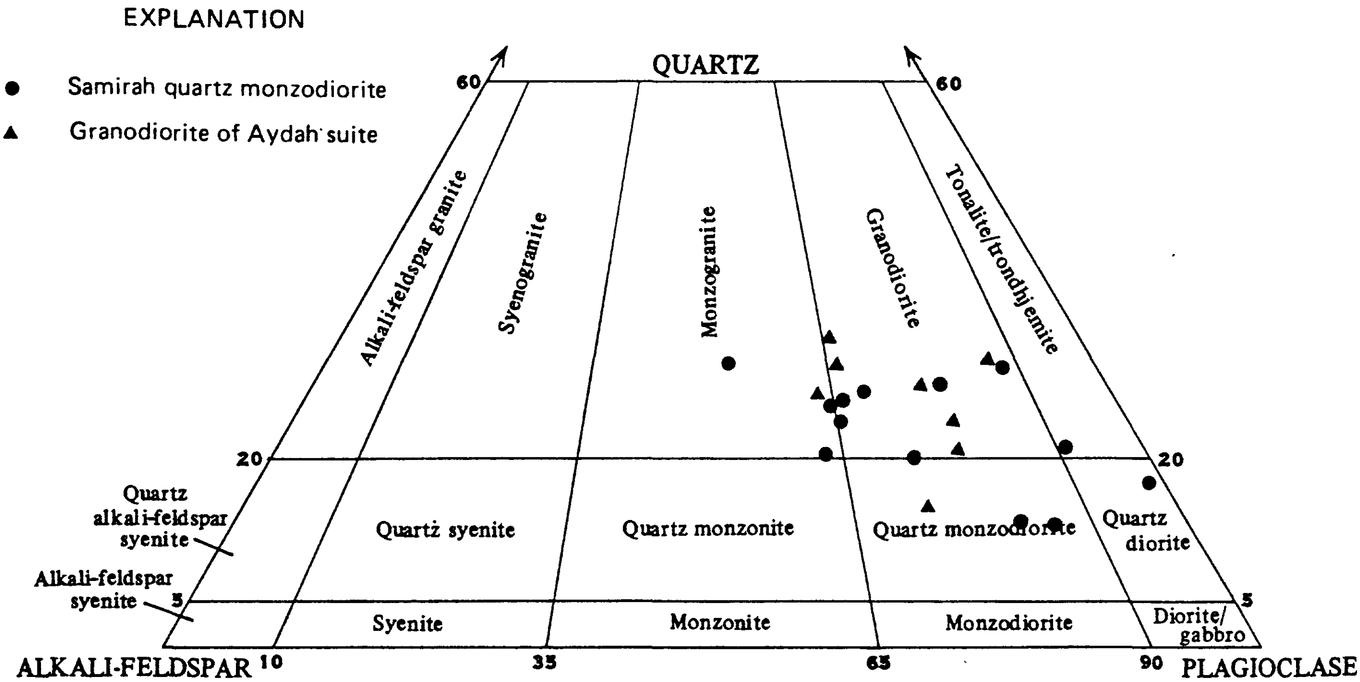

Figure 4.--*Ternary diagram showing relative modal composition in granodiorite of the Aydah suite and in the Samirah quartz monzodiorite. Composition fields are drawn according to Streckeisen (1976).*

QUARTZ MONZODIORITE AT SHA'IB RIJLAT

A single outcrop of quartz monzodiorite (qmd) occurs in an area of poor rock exposure near Sha'ib Rijlat at the west edge of the quadrangle. An oval pluton about 5 by 8 km is inferred from Landsat imagery, and from a roughly coincident anomaly on the aeromagnetic map. The rock is pinkish gray, medium grained, inequigranular and sparsely porphyritic, and consists of 12 percent quartz, 25 percent orthoclase, 55 percent plagioclase, and about 4 percent each biotite and hornblende. Much of the quartz and feldspar is fine grained and intergranular.

Age of the quartz monzodiorite is unknown, except that it is apparently younger than the Murran complex, which it intrudes.

PORPHYRITIC MONZONITE

Porphyritic rocks of probable monzonitic composition (mz) were mapped at three places in the quadrangle. At Usayfrat Murran are two small plugs of gray, porphyritic monzonite with conspicuous hornblende phenocrysts. The rock consists of 50 percent medium-grained, euhedral, equant to elongate, zoned plagioclase and 10 percent columnar green hornblende phenocrysts in a fine-grained groundmass of orthoclase and quartz (35 and 5 percent of the rock, respectively). East of Al Ballaziyah is an area containing several poor outcrops of very similar pinkish-gray rock; granophyric texture was noted in the groundmass. The third area is at Dil al Humaymah, where two small outcrops consist of gray porphyritic rock containing about 20 percent coarse plagioclase phenocrysts in a fine-grained groundmass of potassium feldspar, plagioclase and minor quartz.

Age of the monzonite is unknown, except that at two of its outcrop localities it is younger than the orthogneiss, which it intrudes, and at Al Ballaziyah it is intruded by the Gusl granite. Possibly the plugs are feeder conduits to the Sufran volcanic rocks that crop out near all three occurrences of the monzonite.

GABBRO

Small elongate pods of gabbro (gb) were mapped in three places in the Al Ba'ayith quadrangle: 2 km northeast of Jabal ath Thilbut al Asfar, where it intrudes granophyre associated with the Sufran volcanic rocks; 4 km southeast of Murran, intruding the orthogneiss; and 2 km north of Jibal Faghghanat, intruding quartz diorite of the Murran complex and the red granodiorite of uncertain age. Rock of the three pods is quite similar, consisting of dark-green to black gabbro that weathers to black boulders. Mineral composition is about 50 percent euhedral calcic plagioclase, 15 percent clinopyroxene, 5 percent olivine, and 5 percent opaque minerals poikilitically enclosed by megacrysts of hornblende, 25 percent of the rock. The gabbro is somewhat altered, olivine being partly transformed to fine-grained aggregates of secondary minerals, and hornblende and clinopyroxene to fibrous amphibole (actinolite?).

A post-Sufran age is established for the gabbro pod near Jabal ath Thilbut al Asfar, and is inferred for the other two occurrences.

MAFIC PLUTONIC ROCKS

Pods of dark-green, sheared, and somewhat altered mafic plutonic rocks (mpr) lie along the Raha fault north of Wadi ar Rumah in the southern part of the quadrangle. Gamma radioactivity is very low, about 20-30 counts per second. The rock consists entirely of secondary minerals, mainly chlorite, epidote, tremolite-actinolite, quartz, and possibly serpentine. Irregular polygonal patterns in coarse altered mineral grains suggest the fracture pattern characteristic of olivine. Porphyritic texture was observed in one sample; textures are generally obscured by a contorted shear fabric. Similar rocks occur commonly along the Raha fault zone farther east (duBray, in press; Williams, 1983; Johnson and Williams, 1984) and contain serpentine, spinels, and altered carbonates in addition to common secondary minerals named above. No chemical analyses were made of the unit in the Al Ba'ayith quadrangle, but a sample of mafic plutonic rock from the Raha fault zone at Jabal at Tin in the Samirah quadrangle (table 2) suggests that the protolith was a tholeiitic gabbro.

The emplacement of the mafic plutonic rock is essentially coeval with movement on the Raha fault zone; apparently gabbro was injected along the zone and deformed during continued faulting. Age of faulting is demonstrably post-Hibshi and occurred largely if not entirely prior to emplacement of the Idah suite granodiorite.

GRANODIORITE OF THE IDAH SUITE

Granodiorite (gd) crops out near Wadi ash Shi'bah in the southeastern part of the quadrangle. Bedrock exposures are poor and much of the area is mantled with Quaternary gravels, but two positive magnetic anomalies, one strong and one weak, suggest that the granodiorite occurs in two ovoid plutons separated by a thin septum of the Hibshi formation. The granodiorite intruded the Hibshi and Murdama formations, and is in turn intruded by monzogranite of the Shuwayman suite; it is also nonconformably overlain by andesite flows of the Jurdhawiyah formation. It is accordingly considered to belong to the Idah suite, which consists largely of medium-sized, post-Hibshi, granodiorite and quartz monzodiorite plutons in the Uqlat as Suqur and Jabal Habashi quadrangles (Cole, in press; Johnson and Williams, 1984).

Granodiorite in both plutons is light gray and weathers recessively. The mineral compositions are similar (fig. 4): both contain quartz, about 25 percent; weakly perthitic orthoclase, 15-25 percent; plagioclase, 45-55 percent; and variable amounts of biotite and hornblende, averaging about 3 percent each. Texturally, however, the rocks of the two plutons are quite dissimilar. Granodiorite in the northern pluton is medium grained and equigranular with sparse orthoclase phenocrysts; that in the southern pluton is distinctly porphyritic, being composed of euhedral medium-grained plagioclase and mafic minerals set in a fine-grained groundmass mosaic of quartz and orthoclase Modal composition of the granodiorite of the Idah suite is shown in figure 4.

Altered granitic rock that is considered to be part of the Idah suite forms two very small plutons in the southeastern part of the quadrangle at and near its eastern margin. The plutons form somewhat irregular bodies several hundred meters across that intruded the Maraghan formation. Both plutons consist of light brown medium-grained porphyritic rock of quartz dioritic to granodioritic composition. Felsic components are 15-25 percent glomercrystalline quartz, 10-20 percent potassium feldspar, and about 50 percent plagioclase, some of which forms sparse phenocrysts as large as 1 cm. The feldspars are strongly sericitized, so that distinguishing of feldspar type in thin section is difficult. Biotite was the only original mafic component and makes up 10-15 percent of the rock. Biotite was altered to white mica in most places, with release of iron to form minerals that oxidized to produce the brown color of the rock. The rocks of both plutons and the altered Maraghan formation are cut by quartz veins and pods that are gold-bearing and were extensively mined in the past.

A radiometric age of 617±5 Ma was obtained for granodiorite of the Idah suite from the Dhibiyah pluton in the southeastern part of the Jabal Habashi quadrangle (J. C. Cole and C. E. Hedge, unpub. data, 1983). This age is in accordance with ages obtained for the pre-Idah Hibshi formation and for monzogranite of the post-Idah Shuwayman suite.

GRANITE

Scattered outcrops of red granite (gr) north of Jibal Faghghanat appear to define a small pluton that is older than the Faghghanat monzogranite but younger than the orthogneiss and the Murran complex, both of which it intrudes. The rock consists of medium-grained, inequigranular granite, containing about 35 percent quartz, 35 percent perthitic orthoclase, 28 percent plagioclase, and 2 percent chloritized biotite.

Table 2.—Major element analyses and CIPW norms for selected plutonic rocks in the Al Ba'ayith quadrangle.

Rapid-rock analyses performed in the DGMR/USGS chemical laboratory, Jiddah, using techniques described by Shapiro and Brannock (1962). All values are weight percent.

Number	1	2	3	4	5	6	7	8	9	10	11
Field no. 193-	704	776	772	093	651	517	619	515	458	481	659
					Chemical analyses						
SiO2	71.0	61.2	64.9	67.60	70.60	49.80	69.30	73.90	75.20	71.50	72.60
TiO2	0.3	0.5	0.45	0.33	0.23	0.11	0.32	0.18	0.23	0.30	0.17
Al2O3	15.00	16.60	18.10	17.80	15.20	15.80	14.80	13.80	12.40	14.80	15.20
Fe2O3	1.34	4.20	1.32	1.09	1.24	0.46	0.99	0.79	1.49	0.95	0.77
FeO	1.22	2.83	1.81	1.19	0.95	3.64	1.32	0.64	0.48	1.34	0.62
MnO	0.05	0.12	0.08	0.05	0.07	0.15	0.05	0.08	0.13	0.08	0.03
MgO	0.46	1.53	1.06	0.63	0.43	12.60	1.35	0.33	0.23	0.71	0.29
CaO	1.83	4.27	3.52	3.52	1.89	13.20	2.44	0.85	0.49	2.40	1.29
Na2O	4.55	3.25	5.58	5.87	4.35	1.63	4.86	4.72	4.77	4.86	4.87
K2O	3.61	3.89	1.57	1.73	3.80	0.41	3.64	4.00	4.39	2.07	3.80
P2O5	0.06	0.33	0.19	0.12	0.08	0.02	0.10	0.06	0.03	0.11	0.06
H2O	0.84	0.82	1.00	0.53	0.88	0.81	0.52	0.42	0.38	0.72	0.64
Total	100.23	99.51	99.58	100.46	99.72	99.63	99.69	99.77	100.22	99.8	100.34
					CIPW norms						
Q	26.09	16.6	17.35	18.33	26.39	0.00	20.57	29.02	30.11	29.0	26.66
C	0.43	0.07	1.29	0.16	0.69	0.00	0.00	0.31	0.00	0.4	0.88
Or	21.46	23.29	9.41	10.23	22.72	2.48	21.69	23.79	25.98	12.3	22.52
Ab	38.73	27.86	47.89	49.70	37.24	14.10	41.47	40.20	39.40	41.4	41.33
An	8.74	19.28	16.45	16.69	8.96	35.35	7.88	3.85	0.00	11.2	6.03
Di	0.00	0.00	0.00	0.00	0.00	24.96	2.94	0.00	1.24	0.0	0.00
Wo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.0	0.00
Mt	1.95	6.17	1.94	1.58	1.82	0.00	1.45	1.15	1.31	1.3	1.12
Il	0.52	0.90	0.87	0.63	0.44	0.21	0.61	0.34	0.44	0.5	0.32
Ap	0.14	0.79	0.46	0.28	0.19	0.05	0.24	0.14	0.07	0.2	0.14

No.	Rock type, formation	Location
1.	Orthogneiss	(26°19' N., 41°48' E.)
2.	"	(26°18' N., 41°39' E.)
3.	Quartz diorite	(26°16' N., 41°50' E.)
4.	Samirah quartz monzodiorite	(26°22' N., 42°04' E.)
5.	" " "	(26°24' N., 41°54' E.)
6.	Mafic plutonic rock	(26°17' N., 42°19' E.)
7.	Granodiorite of Aydah suite	(26°12' N., 41°57' E.)
8.	Monzogranite of Shuwayman suite	(26°23' N., 42°23' E.)
9.	Kilab monzogranite	(26°21' N., 41°31' E.)
10.	" "	(26°27' N., 41°45' E.)
11.	" "	(26°29' N., 42°00' E.)

Table 2.—Major element analyses and CIPW norms for selected plutonic rocks in the Al Ba'ayith quadrangle — continued.

Number	12	13	14	15	16	17	18	19	20	21	22
Field no. 193-	362	359	605	427	435	789	632	472	484	471	642
					Chemical analyses						
SiO2	72.20	72.50	72.60	73.50	74.90	73.70	71.50	74.90	74.00	75.30	68.50
TiO2	0.27	0.20	0.25	0.26	0.11	0.24	0.31	0.17	0.14	0.12	0.54
Al2O3	14.20	13.80	13.50	13.40	13.10	14.10	14.90	13.00	13.50	12.70	15.20
Fe2O3	1.13	0.81	1.23	1.34	1.29	1.36	0.96	0.44	0.70	1.01	1.94
FeO	0.90	1.02	0.84	0.62	0.22	0.35	1.17	0.86	0.70	0.28	1.31
MnO	0.06	0.05	0.10	0.11	0.07	0.10	0.08	0.06	0.06	0.06	0.06
MgO	0.58	0.47	0.59	0.36	0.09	0.35	0.40	0.20	0.14	0.16	1.34
CaO	1.51	1.82	1.09	0.75	0.30	0.93	1.15	0.68	0.45	0.54	2.50
Na2O	4.66	4.04	4.50	4.77	4.75	4.74	4.44	4.45	4.38	4.35	4.16
K2O	3.84	4.18	4.15	4.12	4.38	4.16	4.70	4.71	5.16	4.77	3.92
P2O5	0.09	0.06	0.20	0.06	0.02	0.05	0.07	0.03	0.05	0.03	0.19
H2O	0.77	0.94	0.61	0.86	0.34	0.31	0.46	0.38	0.52	0.28	0.45
Total	100.21	99.89	99.66	100.15	99.57	100.39	100.14	99.88	99.80	99.60	100.11
					CIPW norms						
Q	26.62	28.75	28.03	28.29	30.02	27.82	24.45	29.34	27.6	30.96	22.55
C	0.00	0.00	0.10	0.00	0.05	0.23	0.59	0.00	0.0	0.00	0.02
Or	22.82	24.96	24.76	24.52	26.08	24.56	27.86	27.97	30.7	28.38	23.24
Ab	39.65	34.55	38.44	40.65	40.50	40.07	37.69	37.84	37.3	37.06	35.32
An	6.52	7.25	4.14	3.01	1.37	4.28	5.26	1.59	1.9	1.05	11.20
Di	0.33	1.21	0.00	0.27	0.00	0.00	0.00	1.36	0.0	0.87	0.00
Wo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.14	0.00
Mt	1.65	1.19	1.80	1.62	0.62	0.76	1.40	0.64	1.0	0.76	2.82
Il	0.52	0.38	0.48	0.50	0.21	0.46	0.59	0.32	0.2	0.23	1.03
Ap	0.21	0.14	0.48	0.14	0.05	0.12	0.17	0.07	0.1	0.07	0.45

No.	Rock type, formation	Location
12.	Monzogranite of Faghghanat pluton	(26°10' N., 41°49' E.)
13.	Monzogranite of Jubu pluton	(26°16' N., 41°45' E.)
14.	Monzogranite of Humaymah pluton	(26°19' N., 41°39' E.)
15.	Granophyre of Jibal Qusayrah	(26°25' N., 41°38' E.)
16.	" " "	(26°28' N., 41°33' E.)
17.	" " "	(26°24' N., 41°40' E.)
18.	Syenogranite of Ballaziyah pluton	(26°31' N., 41°56' E.)
19.	Syenogranite " "	(26°25' N., 41°48' E.)
20.	" " "	(26°28' N., 41°53' E.)
21.	" " "	(26°28' N., 41°46' E.)
22.	Younger monzogranite	(26°28' N., 41°55' E.)

SHUWAYMAN SUITE

Widespread monzogranites in the northeastern part of the Arabian Shield that largely postdate deformation of the Maraghan and Hibshi formations but that may in part predate it were grouped as the Shuwayman suite (Johnson and Williams, 1984). The name is taken from the Shuwayman monzogranite, named by du Bray(in press) for a large pluton exposed near the village of Shuwayman in the Jabal as Silsilah quadrangle.

The Shuwayman suite is represented in the Al Ba'ayith quadrangle by the Kilab monzogranite (Pallister, 1984; Johnson and Williams, 1984) which underlies large areas in the northern part of the quadrangle, and by four small and one large pluton in the central and southern part. The rocks of this suite weather very recessively in general so that pluton boundaries are largely inferred and were partly drawn from Landsat imagery. A descriptive summary of rocks of the Shuwayman suite is given in table 3; composition of the felsic constituents is shown in figure 5.

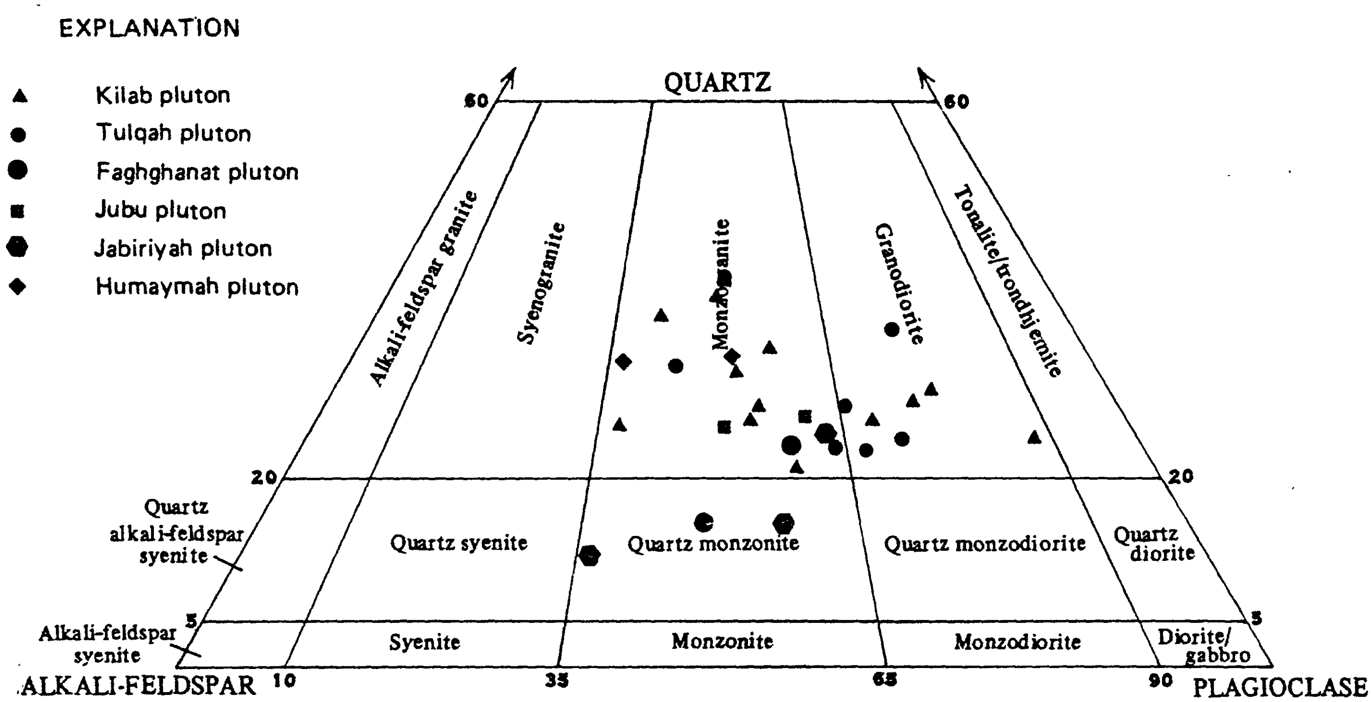

Figure 5.--*Ternary diagram showing relative modal composition in the Shuwayman monzogranite suite. Composition fields are drawn according to Streckeisen (1976).*

Table 3: Descriptive summary of monzogranite of the Shuwayman suite in the Al Ba'ayith quadrangle

R, gamma radioactivity, counts per second

Pluton name	Outcrop features	Textures	Mineral composition (Percents are average)	Rock name
Kilab	Large complex pluton; medium-gray, very recessive-weathering R=56-80	Coarse- to medium-grained, hypidiomorphic equigranular to sub-equigranular	Plagioclase, 40%; euhedral to subhedral, partly sericitized K-feldspar, 28%; subhedral perthitic microcline and orthoclase Quartz, 27%; anhedral, locally poikilitic Biotite, 4%, fresh to strongly chloritized	Biotite monzogranite and granodiorite
Humaymah	Small oval pluton 5 x 3 km; light red, recessive-weathering R=70	Coarse-grained hypidiomorphic sub-equigranular	Plagioclase, 31% K-feldspar, 37%; perthitic microcline Quartz, 31% Biotite, 2%; unaltered	Biotite monzogranite and syenogranite
Jabiriyah	Small oval pluton, 6 x 9 km; gray to light red, very recessive-weathering R=80-90	Coarse- to medium-grained, subporphyritic	Plagioclase, 40%; albite-oligoclase, coarse-grained K-feldspar, 35%; perthitic orthoclase Quartz, 20%; anhedral, interstitial Biotite, 2%, partly chloritized Hornblende, 2%	Biotite-hornblende monzogranite and syenogranite
Jubu	Small oval pluton, 6 x 11 km light reddish gray, very recessive-weathering R=70-80	Medium- to coarse-grained, subporphyritic	Plagioclase, 29%; coarse-grained, euhedral, elongate K-feldspar, 37%; subhedral, perthitic orthoclase Quartz, 30%, anhedral Biotite, 3%; unaltered Hornblende, 2%	Biotite-hornblende monzogranite
Tulqah	Large, complex elongate pluton, 8 x 22 km; gray and light red, recessive-weathering, commonly weakly gneissic R=60-120	Medium- to very coarse-grained, inequigranular to sub-porphyritic, hypidiomorphic-granular	Plagioclase, 37%; euhedral to subhedral, partly sericitized K-feldspar, 24%, subhedral, perthitic orthoclase Quartz, 24%; anhedral, compound grains Biotite, 5%; strongly chloritized Hornblende, 2%	Biotite-hornblende monzogranite and granodiorite
Faghghanat	Small oval pluton 5 x 11 km; light red recessive-weathering with some inselbergs R=70-80	Medium-grained plagioclase-porphyritic, hypidiomorphic-granular	Plagioclase, 40%; medium-grained, with sparse phenocrysts to 1 cm K-feldspar, 35%; perthitic orthoclase Quartz, 18%; anhedral Biotite, 5%, partly chloritized	Biotite quartz monzonite and monzogranite

Kilab monzogranite

The Kilab monzogranite (kmg) apparently forms a large, composite batholith which spans the northern boundary (Leo, 1984) and western boundary (Quick, 1984 unpub. data) of the Al Ba'ayith quadrangle. The intrusive contact of the Kilab with older rocks is generally convex outward in plan, in such a manner as to suggest that the pluton consists of several lobes. The rock weathers to low relief, forming few outcrops; it is medium gray, non-gneissic, and consists of medium- to coarse-grained biotite monzogranite and granodiorite, with an average composition of about 40 percent euhedral, partly sericitized plagioclase, 28 percent subhedral perthitic microcline and orthoclase, and 27 percent anhedral quartz. Biotite, about 4 percent, is the only mafic mineral. Texturally, the Kilab monzogranite is hypidiomorphic equigranular to subequigranular.

Monzogranite of other plutons

The smaller, isolated plutons are composed of monzogranite (mg) that is generally similar to the Kilab monzogranite. Humaymah pluton lies south of Jibal Qusayrah and consists of light-red, coarse-grained biotite monzogranite and syenogranite. To the west of it lies the Jabiriyah pluton which consists of gray and light-red, coarse- to medium-grained, subporphyritic, biotite-hornblende monzogranite and syenogranite. The Jubu pluton lies at the center of the quadrangle and consists of medium- to coarse-grained, subporphyritic, biotite-hornblende monzogranite. Three kilometers west of the Jubu pluton an outcrop of biotite-hornblende monzogranite resembling the rock of the Jubu pluton, but somewhat finer grained, probably indicates a small plug the size and shape of which is indeterminable due to poor exposures.

The Tulqah pluton is a large, apparently lobate pluton that is elongated in a generally easterly direction. The rock is gray and light red, and is weakly gneissic; it consists of medium- to coarse-grained, subporphyritic, biotite-hornblende monzogranite and granodiorite. The Faghghanat pluton lies northeast of the Tulqah pluton and consists of biotite quartz monzonite and monzogranite. Unlike the other plutons, the rock only locally weathers recessively, and forms bold inselbergs in places; it is distinctly porphyritic, containing sparse plagioclase phenocrysts as large as 1 cm in an otherwise medium-grained equigranular rock.

Age of the Shuwayman suite

Plutons of the Shuwayman suite in the Al Ba'ayith quadrangle are clearly intrusive into granodiorite of the Idah suite and into rocks older than the Idah suite. The Kilab monzogranite is intruded by rocks of the alkali-feldspar granite suite. Exposures north of the quadrangle demonstrate that Hadn formation lies nonconformably on the Kilab monzogranite, and monzogranite clasts are common constituents in Hadn conglomerates (Quick and Doebrich, in press); contacts between the two units are not exposed within the quadrangle.

The Nimriyah monzogranite, part of the Shuwayman suite that forms an isolated pluton intrusive into the Hibshi formation in the Jabal Habashi quadrangle (Johnson and Williams, 1984), has been dated at 617 ±10 Ma (J. C. Cole and C. E. Hedge, unpublished data, 1983). However, monzogranite in a pluton in the Qufar quadrangle (Kellogg, 1984b) and the Harrat Hutaymah quadrangle (Pallister, 1984) has been dated at 651 ±5 Ma (J.C. Cole and C.E. Hedge, written commun., 1984); although monzogranite in this pluton cannot be genetically tied to the Shuwayman suite, it suggests that granitic magma was emplaced over a fairly long time span that also included emplacement of more mafic magma.

ALKALI-FELDSPAR GRANITE SUITE

Alkali-feldspar granite occurs both as granophyre that is associated with volcanic rocks of the Sufran and Hadn formations, and as texturally diverse granite that includes the Gusl alkali-feldspar granite (Pallister, 1984). The granophyre map unit includes rocks of more than one age, whereas the Gusl granite belongs to the late Precambrian alkali-feldspar granite suite (Johnson and Williams, 1984). Modal composition of rocks of the alkali-feldspar granite suite and of the younger monzogranite and syenogranite are shown in figure 6.

Granophyre

Granophyric alkali-feldspar granite (gph) crops out in several places in the northern and eastern part of the Al Ba'ayith quadrangle. It forms the massif of Jibals Qusayrah and Ghurur in the northwest, Jibal ath Thilbut al Asfar and several small hills in the northeast, and an isolated mountain, Jibal Kutayfah, in the southeast.

The granophyre at Jibal Qusayrah crops out in an area roughly in the form of a northwest-oriented oval that measures about 20 km long and 10 km across. Most of the area is mountainous, deeply dissected upland, consisting of ridges with roughly accordant summits separated by narrow rocky valleys that are controlled by dominant north- and east-trending and subordinate northeast-trending faults and joints. The granophyre is light red to brick red, and forms generally parallel sheets each several tens of meters thick that dip about 25° to the northwest. It is medium to coarse grained and equigranular, and weathers to a coarse grussic sand. A small outcrop of flow-banded, quartz-phyric rhyolite capped with red rhyolite forms a small butte several hundred meters across in the southeast part of Jabal Qusayrah.

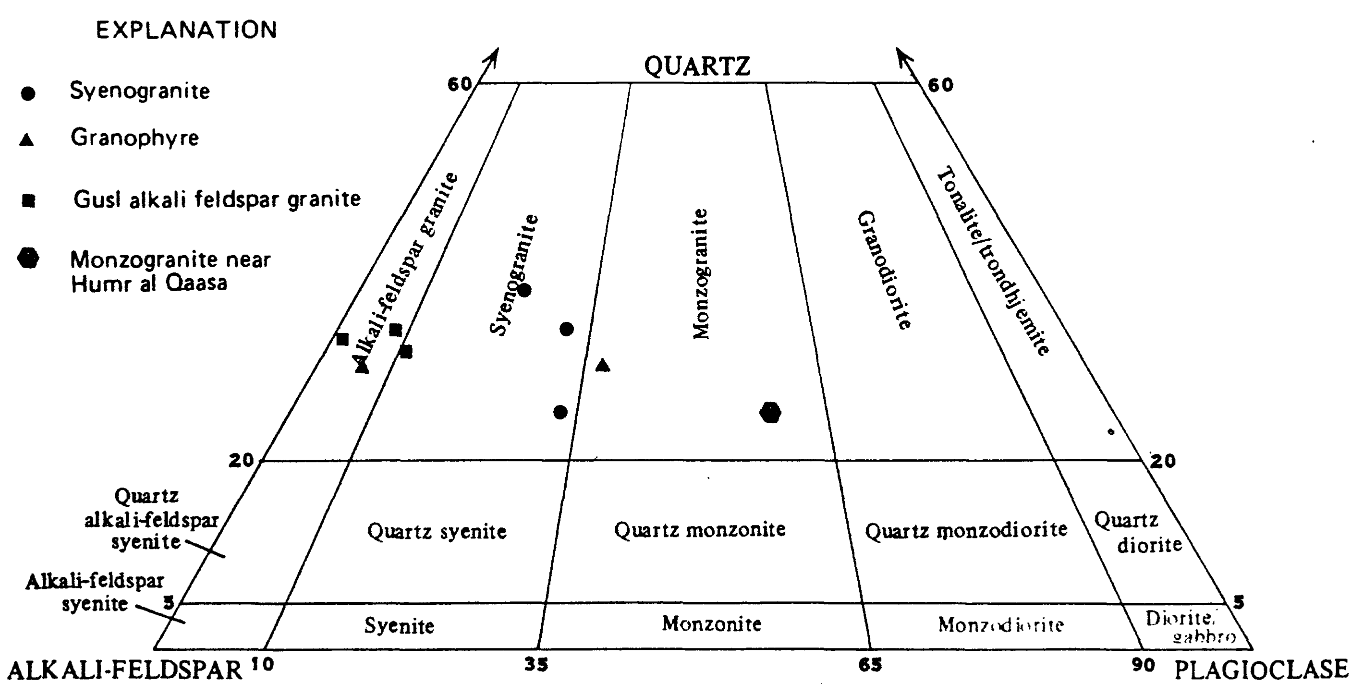

Figure 6.--*Ternary diagram showing relative modal composition in syenogranite, alkali-feldspar granite, granophyre, and younger monzogranite. Composition fields are drawn according to Streckeisen (1976).*

The granophyre consists almost entirely of alkali-feldspar and quartz. The alkali-feldspar is strongly perthitic and forms on the average 60 percent of the rock, and is best described as orthoclase grains that are one-third to one-half albite, some of which is finely twinned. In some samples the rock is equigranular in that quartz and alkali-feldspar form a granular mosaic; in others the quartz is myrmekitically and graphically intergrown with the alkali-feldspar. Mafic minerals are entirely absent, although sparse small clots of fine-grained, altered material may represent former biotite or hornblende grains. Rock textures generally suggest rapid crystallization that may have resulted from sudden volatile loss and consequent pressure quenching. Absence of fresh mafic minerals may be the result of vapor-phase alteration of existing mafic minerals.

The rhyolite in the southeast part of Jibal Qusayrah contains phenocrysts of quartz and sanidine(?), and granite lithic fragments, in a very fine grained, tightly banded groundmass. The rhyolite is considered to represent the venting of a small amount of residual liquid magma from the granophyre sheet which it intrudes.

Granophyre in the northeastern part of the quadrangle is generally similar in outcrop appearance to the rock at Jibal Qusayrah, but is probably granodiorite, as it contains sparse plagioclase phenocrysts. The granophyre at Jibal Kutayfah is a porphyritic granodiorite, consisting of 40 percent medium-grained anhedral quartz intergrown with a fine-grained groundmass of subhedral plagioclase and orthoclase which comprise about 20 and 40 percent of the rock, respectively. The rock also contains about 2 percent muscovite.

The probable genetic association of the Qusayrah granophyre with the Hadn volcanics has been described above. Similarly, the granophyre occurring with the Sufran volcanics in the northeastern part of the quadrangle is believed to be genetically related to them. The granodiorite granophyre at Jibal Kutayfah is not associated with volcanic rocks but, on the basis of similarity of composition to the Idah granodiorite and its location at the margin of one of the Idah plutons, a genetic relationship is suggested.

Gusl alkali-feldspar granite

Outcrops of alkali-feldspar granite (afg) in the northeast corner of the Al Ba'ayith quadrangle are nearly contiguous with similar rocks at Jabal Gusl in the northwest corner of the Samirah quadrangle (Pallister, 1984; Johnson and Williams, 1984), and are named for Jabal Gusl in the northwest part of the Samirah quadrangle. In the Al Ba'ayith quadrangle, the Gusl granite intrudes monzonite, the Samirah quartz monzodiorite, and the Kilab monzogranite, and is intruded by the small pluton of younger monzogranite and by syenogranite of the Ballaziyah pluton. At the west edge of the quadrangle, a mountain south of Jibal al Jabiriyah consists of biotite, alkali-feldspar granite and is part of a pluton that spans the boundary with the As Sulaymi quadrangle (Quick, 1984, unpub data).

The Gusl granite forms an irregularly shaped, lithologically heterogeneous, elongate body that that underlies Jibal al Qa'asa and low, hilly terrain to the south. Two dominant lithologies occur: medium-grained alkali-feldspar granite; and porphyritic aplite. The aplitic granite is mostly gray, strongly flow-banded, siliceous rock consisting of phenocrysts of quartz and alkali-feldspar and rare plagioclase in a fine-grained groundmass mosaic of quartz and feldspar. It resembles some rhyolites and is probably an hypabyssal rock; it likely represents the root zone of a caldera complex (Pallister, 1984) the volcanic edifice of which has been removed by erosion. The alkali-feldspar granite is orange and light red, is hypidiomorphic equigranular, and consists of 30-35 percent each of quartz, perthitic orthoclase and somewhat antiperthitic albite; modally the rock is a monzogranite. Biotite forms 4-8 percent of the rock and green hornblende is present in trace to minor amounts.

The alkali-feldspar granite pluton south of Jibal al Jabiriyah cuts the Hadn formation and is composed of red, medium- to coarse-grained, hypidiomorphic, inequigranular intergrowths of perthitic alkali-feldspar and quartz; biotite forms less than one percent of the rock (Quick, 1984, unpub. data).

Chemical composition

Chemical analyses of rocks of the alkali-feldspar granite suite are shown in table 2. Rocks of the suite are peraluminous and have roughly equal amounts of K_2O and Na_2O, which is characteristic of the highly evolved granitic rocks of the northern Shield region, including the Shuwayman suite and equivalent monzogranites, and the Hadn volcanic rocks (Stoeser and Elliott, 1984 unpub. data). For purposes of comparison, normative color index and normative plagioclase composition of the granophyre at Jibal al Qusayrah are plotted in figure 2; data points for the granophyre and for rhyolites of the Hadn volcanics are coincident, supporting the apparent genetic relationship between the two rock units.

YOUNGER MONZOGRANITE NEAR HUMR AL QA'ASA

Monzogranite (mgy) south of Al Qa'asa forms a small, oval pluton about 2.5 x 3.5 km in size. The rock weathers very recessively and is light gray and medium grained. It is equigranular and consists of about 40 percent partly sericitized plagioclase, 30 percent perthitic microcline, 20 percent quartz, and 5 percent each of biotite and green hornblende. It closely resembles some of the monzogranites of the Shuwayman suite, but is clearly younger, as it intrudes the Gusl alkali-feldspar granite; its age relative to the Ballaziyah syenogranite is not known.

SYENOGRANITE

Syenogranite forms a large, nearly circular pluton near Ballaziyah that spans the northern boundary of the quadrangle. The syenogranite clearly intrudes the Gusl alkali-feldspar granite and older rocks. South of Kuhaylat al Ba'ayith in the southern part of the quadrangle outcrops of syenogranite define a small intrusive body that may be an offshoot of the Ar Rahadah granite pluton mapped in the Nuqrah quadrangle (Delfour, 1977) and that probably underlies the area of poor exposure south of Wadi ar Rumah.

Granite in the Ballaziyah pluton generally weathers recessively, except for several small inselbergs near the south and west margins. In outcrop the rock is light red to buff and medium to coarse grained. It consists of 45-50 percent strongly perthitic orthoclase, 25-35 percent quartz, 15-25 percent plagioclase, albite to calcic oligoclase, 3 percent biotite, and trace amounts of hornblende. The rock is slightly glomerocrystalline, a texture that gives the impression of coarse phenocrysts, although it is mostly equigranular to subporphyritic.

The syenogranite south of Kuhaylat al Ba'ayith is orange, coarse grained, somewhat porphyritic, and is mineralogically similar to the Ballaziyah syenogranite. Its gamma radioactivity, about 220 counts per second, is about twice that of the Ballaziyah granite, and the same as that of the syenogranite in the Ar Rahadah pluton, as determined by field reconnaissance.

Syenogranite in the Al Ba'ayith quadrangle is similar to the Qutn syenogranite (Williams, 1983; Johnson and Williams, 1984; Cole, 1985) and other young syenogranite plutons in the region which are generally circular in plan, are coarse grained, chemically peraluminous, and have a radioactive signature 2 to 4 times background. The Qutn syenogranite has been dated at 579±4 Ma.

DIKES

Dikes are numerous in the Al Ba'ayith quadrangle, particularly in plutonic rocks. Dikes were mapped mainly from aerial photographs, but were not studied in detail. Dikes observed on outcrop were crudely classified as felsic or mafic according to their general aspect, principally color and visible mineralogy. Felsic dikes are mostly pink and orange, fine-grained aplites (ap), some of which contain phenocrysts of potash feldspar and (or) quartz, and include gray dikes of probable dacitic composition. Mafic dikes are dark gray to black, and contain phenocrysts of plagioclase, hornblende, and pyroxene.

Wide aplite dikes were mapped in two places: north of Jibal Kutayfah and west of Sha'ib Khiniqat. The aplite dike near Jibal Kutayfah trends northerly, and is 4 km long and about 200-300 m wide. It lies along the intrusive contact of the granodiorite with the orthogneiss, and is probably, like the granophyre, an intrusive phase of the granodiorite. It consists of a mosaic of quartz, orthoclase and plagioclase, and has sparse phenocrysts of pink potash feldspar and muscovite. The dike west of Sha'ib Khiniqat crops out for about 6 km along a sinuous trace, and is 50-100 km wide. It is red and consists of fine-grained, nonporphyritic aplite.

QUARTZ

Quartz pods and veins were mapped in several places in the Al Ba'ayith quadrangle. An irregular vein of milky to clear megacrystalline quartz several meters wide intrudes alkali-feldspar granite at the extreme western edge of the quadrangle north of Jibal Abid. The vein is actually a pegmatite, as it contains megacrysts of light-red potassium feldspar a meter or more in diameter. The vein was examined throughout its extent, but no mineralized rock was found.

An irregularly shaped area containing abundant float of white quartz chips was mapped near the southeast corner of the quadrangle 4 km west of Mishash ar Rafi'. The country rock, which is probably granodiorite of the Idah suite, is not exposed. No mineralization was found associated with the quartz.

Gold-bearing quartz veins trending east-northeast were mapped in the northerly of two areas of ancient mining in the southeastern part of the quadrangle.

IRONSTONE

Several small outcrops of ironstone (fe), dark purplish-red rock consisting mainly of silica and iron oxide, were observed 4 km west-northwest of Murran during reconnaissance mapping. Subsequently, numerous areas underlain by similar ironstones were mapped 3 km southwest of Murran in the course of regional geochemical studies (W. R. Miller, unpub. data, 1984). Together the occurrences define a north-trending zone about 6 km long and 2.5 km wide.

The ironstones occur within the dioritic rocks of the Murran complex. Inferred outcrop areas are round to oval in plan, ranging in diameter from several meters to several tens of meters. Some ironstones are inferred from distribution of surface lag material; others crop out. The rock is somewhat varied in character, ranging from pods and veins of nearly pure milky quartz, to quartz seamed with dark reddish brown iron oxides, to nearly pure ironstone. A pit in one area of poor outcrop excavated to a depth of half a meter displayed purplish-red iron oxides in the uppermost few centimeters and yellowish-brown iron oxides impregnated with gypsum beneath.

Two ironstone areas contain small outcrops of light purplish-red fine-grained somewhat banded siliceous rock that rings musically under the hammer, and that resembles quartzose sandstone. In thin section, this rock is seen to consist of fine-grained well-sorted silica grains in which original grain boundaries, overgrown by quartz, are commonly defined by stringers of very small iron oxide grains. Silica, iron oxide, and minor carbonate are the cementing materials. The rock is probably a form of jasperoid; despite its strong resemblance to quartz sandstone, normal detrital minerals such as feldspars and opaque ferromagnesian minerals are entirely lacking, and sedimentary textures or structures were not observed on the outcrop.

A comparison of the Murran ironstones with gossans and ironstones elsewhere in the Arabian Shield (Ryall and Taylor, 1981) suggests either that the Murran occurrences are gossans virtually barren of metals other than iron, or that they are not true gossans. Spectrographic data from 33 samples taken during mapping and by W. R. Miller and W. H. White (written commun., 1984) do not indicate anomalous concentrations of target and pathfinder elements Cu, Pb, Zn, and As, which are common in gossans in the Shield. The association of the ironstones with jasperoid suggests a related origin.

QUATERNARY DEPOSITS

Large areas in the Al Ba'ayith quadrangle are mantled with unconsolidated surficial deposits of Quaternary age that commonly conceal geologic relations between bedrock units. On the geologic map, Quaternary deposits are divided into sheet gravels, alluvial fan gravels, alluvium, sabkhah deposits, and mixed eolian-alluvial deposits.

SHEET GRAVELS

Extensive deposits of gravel mixed with coarse sand (Qg) flank the alluvial channels of Wadi ar Rumah and Wadi ash Shi'bah, and underlie large areas of the western part of the desert plain along tributaries to Wadi ar Rumah. Brown and others (1963) mapped these deposits along Wadi ash Shi'bah and Wadi ar Rumah as terrace gravels; in places their upper surfaces lie several meters above the present wadi channels. More commonly, however, the wadi channels are incised one meter or less into the gravels, so the term sheet gravels seems more appropriate.

The gravel deposits have a dark-gray tone on aerial photographs, and consist largely of pebble- to cobble-sized angular to subangular clasts of resistant rock types recognizable as belonging to rock units mapped within the quadrangle. Most of the clasts consist of volcanic and dike rocks. Plutonic rocks, because of their tendency to weather to grus, are represented in the coarse sand fraction.

The angularity of clasts in the gravels and their largely local provenance argues that they were not extensively reworked, nor transported for a long distance. An isolated fan-shaped gravel deposit heads at a gap in a dike-supported ridge west of the gravel-mantled valley of Wadi ash Shi'bah, near Wusayt, suggesting that the fan is the deposit of a single episode of flooding that spilled gravel from a large mass of detritus in transport down Wadi ash Shubah. The sheet gravels are proposed to be the products of major floods that occurred during periods of intense rainfall, perhaps during one or more pluvial episodes of the Pleistocene.

ALLUVIAL FAN GRAVELS

Mountain areas underlain by resistant rocks are flanked by alluvial surfaces that slope gently down toward adjacent wadis and that merge downslope with sheet gravels in places. The surfaces are underlain by alluvial fan gravels (Qf) of cobble to pebble size clasts, most of which are subangular and mixed with small amounts of coarse sand. The base of the gravel is rarely exposed; trenching of the fans by erosion has exposed in places as much as 15 m of gravel, and many of the deposits are likely considerably thicker. Deposition of the gravels apparently takes place during floods that result from infrequent but torrential rains characteristic of desert regions; the fans are periodically regraded, trenched and reworked by subsequent floods.

ALLUVIUM

Drainage in the quadrangle is a branching network of intermittent stream channels, or wadis. The channels are commonly floored with thin alluvium deposits (Qa) consisting of light-brown mixtures of sand, silt, clay and, in somewhat larger wadis, fine gravel, that are generally no thicker than 1 or 2 m. Major trunk drainages such as Wadi ar Rumah and Wadi ash Shubah have distributary channels that are floored with thicker deposits that include coarse gravel; the gravel in most places is mantled with channel sand, silt, and clay, the last sediment to be deposited after a period of flood.

SABKHAH DEPOSITS

Numerous small dry playa lakes occur in the Al Ba'ayith quadrangle. They are particularly abundant in temporarily abandoned distributary channels of Wadi ar Rumah and Wadi ash Shi'bah. The lake beds are floored by light-brown silt, clay, and sand (Qsb) that is commonly mixed with saline minerals. In places, the upper layer consists of white salts formed from evaporation of salt water that accumulates during rainfall and resulting periods of flooding.

ELUVIAL AND ALLUVIAL DEPOSITS, UNDIVIDED

Generally flat areas where the bedrock is covered by a thin mantle of silt and sand of eolian and colluvial (slopewash) origin are designated as eolian and alluvial deposits, undivided (Qs). The map unit also includes small areas of wadi alluvium. Deposits of this map unit are common in areas where the bedrock consists of recessively weathering plutonic rocks, which underlie most of the quadrangle. In places where the deposits are largely discontinuous, they are not mapped, and the area is mapped as the underlying bedrock unit.

METAMORPHISM

Metamorphism of rocks in the Al Ba'ayith quadrangle is both progressive and retrogressive, and is low grade, entirely within the greenschist facies. The degree of metamorphism increases roughly with age, although exceptions occur where hydrothermal activity has locally affected younger rocks.

Silicic volcanic rocks of the Banana formation display few metamorphic effects beyond formation of chlorite in the groundmass and as replacement of mafic minerals, and partial sericitization of feldspars. Basic volcanic rocks, which make up most of the Banana in adjacent quadrangles, are metamorphosed in the upper greenschist facies, with actinolite, chlorite and epidote replacing primary mineral assemblages (Quick and Doebrich, in press).

The orthogneiss and metagabbro units and the rocks of the Murran complex commonly show retrogressive metamorphism of primary mafic minerals to actinolite, chlorite, epidote, and iron oxides, although relicts of the pyrogenic minerals, including olivine, are commonly observed. Both plagioclase and potassium feldspars commonly are partly sericitized.

The Samirah quartz monzodiorite, granodiorite of the Idah suite and the monzogranites of the Shuwayman suite show retrogressive metamorphic effects, such as chloritization of biotite and sericitization of feldspars, although commonly the minerals are unaltered. Younger granitic rocks are virtually unaltered, except for deuteric alteration in the granophyres indicated by destruction of mafic minerals, and minor chloritization of biotite.

The mafic plutonic rock that forms small intrusions along the Raha fault are strongly retrogressively metamorphosed in the Al Ba'ayith quadrangle as elsewhere in the region. Mafic minerals are altered to serpentine, actinolite, epidote, and chlorite. The rock is also extensively sheared parallel to the trend of the fault.

The Maraghan and Hibshi formations contain chlorite in most places, which accounts for the greenish-gray color of the rock (du Bray, in press; Williams, 1983); the Hibshi in the Al Ba'ayith quadrangle is mostly dark gray to black, however. In thin section the matrix is seen to consist largely of fine-grained biotite, which was evidently formed from chlorite by weak thermal metamorphism associated with intrusion of the Idah suite granodiorite; similar biotitization of chlorite was noted in the Hibshi in the Samirah quadrangle near intrusions (Williams, 1983). No other contact metamorphic effects were noted in the Hibshi in the Al Ba'ayith quadrangle.

Low-grade metamorphism is variable in volcanic rocks of the Sufran, Hadn and Jurdhawiyah formations, and is probably the result of local hydrothermal activity. The volcanic rocks in all three formations contain fresh mafic minerals in places; in other samples mafic minerals are partly to completely altered. Clastic rocks in the Hadn and Jurdhawiyah formations contain chlorite in most samples, and detrital mafic mineral grains are largely chloritized but commonly are cored with relicts of the original mineral.

STRUCTURE

The dominant types of structural units in the Al Ba'ayith quadrangle are (1) plutons, which occur throughout the quadrangle and are of widely differing sizes, shapes and ages; (2) a volcanotectonic structure, or caldera, at Jabal Qusayrah; and (3) tectonic units consisting of volcanic and volcaniclastic sequences deformed by folding and faulting, which occur in the northern and southeastern parts of the quadrangle. Several periods of deformation are recorded and can generally be approximately dated or at least temporally constrained by available radiometric age dates of the rocks involved.

Structural trends in the oldest rocks in the quadrangle range from northwest to northeast, and are defined by compositional layering and fracture cleavage in the Banana formation, and gneissic and schistose cataclastic foliation in the orthogneiss and metagabbro units. This period of deformation appears to predate the emplacement of the Murran complex which by analogy with the Laban complex in the Samirah quadrangle is about 650 Ma old.

Foliation trends in the quartz diorite and diorite unit of the Murran complex are generally easterly in the central part of the quadrangle and coincide with photolineaments suggesting that the unit was emplaced in part as a dike swarm. Trends in the southwest part of the quadrangle and the weak gneissic structure in the quartz diorite pluton west of Kutayfah, however, are generally northerly.

The northeast-trending Raha fault in the southeast part of the quadrangle is a thrust fault along which the Maraghan formation was thrust over the Hibshi formation (Williams, 1983; Johnson and Williams, 1984). The Raha fault is a regional east-trending structure more than 100 km in extent characterized by complex and varied senses of movement. The fault zone is intruded in several places by small plutons of mafic and ultramafic rock which suggests that the fault penetrates the crust to considerable depth and is a major structural boundary (du Bray, in press; Johnson and Williams, 1984). Age of the faulting is between about 632 Ma, the age of the Hibshi formation, and about 616 Ma, the age of the granodiorite of the Idah suite that post-dates the thrusting.

The Jurdhawiyah formation, deposited unconformably on the Maraghan formation, lies at the northern margin of the Shuqrah basin, one of several east-trending tectonic basins that are in part fault-bounded (Cole, 1985).

Two northwest-trending transcurrent faults offset the Raha thrust fault and and the Hibshi formation in a left-lateral sense. Possibly the faults formed as tear faults concurrent with overthrust movement on the Raha fault; it is more likely, however, that the faults are part of the Najd system of latest Precambrian transcurrent faults (Moore, 1979), which trend northwesterly and generally have left-lateral offset. Young faults with similar trends occur farther west in the Wadi ash Shubah quadrangle, where they offset the Hadn formation (Quick and Doebrich, in press). It is possible to connect these faults with those in the Al Ba'ayith quadrangle, but in the absence of any field evidence it appears inadvisable to do so.

Structures involving young volcanic rocks are dominant in the northern part of the quadrangle. The Sufran formation is an east-trending belt of volcanic rocks in which details of internal structure are little known. The Hadn formation is well exposed; the rocks strike generally 30-60^0 east of north and dip moderately to steeply northwest. Outcrops of the Hadn are arrayed north and south of their eruptive source, an oval volcanotectonic structure, or caldera. Following eruption of rhyolite ash-flow tuffs and minor andesite lava flows, resurgent magmatism produced successive sheets of intrusive granophyre that form Jibals Aharir, Qusayrah and Ghurur. Present outcrops of the granophyre outline the limits of the caldera. Linear faults occur within the granophyre and separate it from the volcanic rocks on the southwest side of the caldera. An arcuate fault is inferred from scattered outcrops on the east side of the structure.

ECONOMIC GEOLOGY

Prior to 1984, no mineral occurrences were reported from the Al Ba'ayith quadrangle. In 1984, Riofinex Ltd. discovered two gold occurrences in the southeastern part of the quadrangle (J. Grotenboer, written communication, 1984), and ironstones resembling gossans in some respects were discovered near Murran in the central part of the quadrangle. These occurrences are described below. In addition, geochemical reconnaissance in the quadrangle has found anomalous amounts of molybdenum in the Banana formation at the extreme west edge of the quadrangle (W. R. Miller, unpubl. data, 1984).

GOLD ASSOCIATED WITH ROCKS OF THE IDAH SUITE

Gold-bearing quartz veins occur at Shi'bah Northeast (MODS 04234 and Shi'bah East (MODS 04235) where small granitoid plutons of the Idah suite intruded the Maraghan formation. Ancient workings occur at both localities, and mostly follow irregular quartz veins and pods that trend east-northeast. The quartz contains segregations of iron oxides, and free gold was observed. Two samples of quartz from Wadi Shi'bah Northeast contained 0.46 and 2.2 ppm gold, and 0.32 and 2.4 ppm silver. A sample of the altered granitic rock from Shi'bah East contained 2.1 ppm gold and 1.0 ppm silver. Extensive sampling of both deposits by Riofinex Ltd. indicate significant amounts of gold in country rock of the Maraghan formation as well as in quartz veins and intrusive rock (J. Grootenboer, written commun. 1985).

The association of gold-bearing quartz veins with small quartz dioritic to granodioritic plutons of the Idah suite cutting the Maraghan formation is common in the region. Other nearby deposits of this association, also worked by ancient miners, are at Ar Rahail; at An Najady and Agob (Smith and others, 1984a); and at Al Habla (Smith and others, 1984b).

IRONSTONE AT MURRAN

Occurrences of ironstone associated with quartz veins and with jasperoid near Murran (MODS 04260) described above, were sampled for trace and minor element content. Spectrographic analysis of 33 samples showed no anomalous amounts of the base metals. Seven samples analyzed by the atomic absorption method contained trace amounts of silver (0.16 to 0.42 parts per million) and gold (8 to 16 parts per billion).

DATA STORAGE

Field and laboratory data contributing to this report, including field notes and maps, thin sections, and petrographic and geochemical data, are stored in Data File USGS-DF-03-13, which is in the Jeddah office of the U.S. Geological Survey Saudi Arabian Mission.

Data on mineral occurrences in the Al Ba'ayith quadrangle have been updated and entered for the following MODS numbers:

04234	Shi'bah NE	Au	Updated 2/85
04235	Shi'bah E	Au	Updated 2/85
04260	Murran	Ag	New input 2/85

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