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Reconnaissance geology of the Samirah quadrangle, sheet 26/42 C, Kingdom of Saudi Arabia

by

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[Plates are in pocket]

RECONNAISSANCE GEOLOGY OF THE SAMIRAH QUADRANGLE, SHEET 26/42 C, KINGDOM OF SAUDI ARABIA

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ABSTRACT

The Samirah quadrangle (26/42 C), an area of desert plains and mountain ridges and peaks, lies in the northern Arabian Shield 150 km southeast of Ha'il. Rocks are of late Precambrian age and consist of three major divisions: older plutonic and metamorphic rocks, low-grade metasedimentary rocks, and younger plutonic rocks. The older plutons represent monzogranite, quartz monzodiorite, and quartz diorite (646 Ma) magmas that intruded amphibolite, hornblende schist, and metaquartzite. The metasedimentary rocks that rest on the older metamorphic and plutonic rocks are metamorphosed in the lower greenschist facies, and consist mainly of the Murdama group, which contains the Hibshi formation, a coarse grained clastic basin-margin facies of sandstone and conglomerate, and the Hadiyah formation, a basin facies of fine-grained sandstone, siltstone, and shale, and minor marble and greenstone. Age of the Murdama group is 646-616 Ma based on radiometric ages of plutonic rocks. Metasedimentary rocks also include the Qarnayn sandstone and a limestone pebble conglomerate, which may be older than or equivalent to the Murdama, and a younger pebbly siltstone, the Jibalah group(?).

The younger plutonic rocks are mostly undeformed and consist of large plutons of peraluminous quartz monzodiorite, granodiorite, monzogranite (616 Ma), syenogranite, and alkali-feldspar granite (579 Ma), and small intrusive bodies of diorite and gabbro.

Deformation of the Murdama group and other sedimentary rocks, which began during deposition, resulted in moderately strong folding along northeast to east axes. The Hadiyah basin deposits were thrust northward and northwestward over the Hibshi coarse clastics of the basin margin. Thrusting was accompanied by development of northwesterly-trending, left-lateral transcurrent faults and local deposition of pebbly siltstone of the Jibalah formation(?).

The Hadiyah formation is host to numerous small mineral occurrences, most of which were exploited by ancient people chiefly for gold. The deposits are associated with irregular systems of quartz veins commonly in the vicinity of diorite

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plugs. Small amounts of minerals bearing copper, lead, silver, and zinc are present in zone deposits.

INTRODUCTION

The Samirah quadrangle (sheet 26/42 C) lies between lat 26°00' and 26°30' N. and long 42°00' and 42°30' E. (fig. 1) and encompasses an area of about 2775 km^2 in the northern part of the Arabian Shield. Most of the area is a flat desert plain with altitudes of 800 to 950 m, from which rise mountain ridges and peaks to altitudes of 1000 to nearly 1200 m. The area is drained mostly by wadis flowing southward and southeastward into Wadi ar Rimah, which lies south of the quadrangle boundary.

The Samirah quadrangle is located about 150 km south-southeast of Ha'il (fig. 1). Small communities exist at Samirah, Al Mahalani, Hebairiah, and An Nimriyah, but most of the population are Bedouin who occupy small encampments scattered throughout the area. Numerous unimproved dirt tracks cross the area. Paved highways are under construction between Samirah and towns to the north, and from Samirah eastward through Hebairiah and An Nimriyah to Al Fawwarah, which lies east of the map area.

The geology of the area was first studied by Bramkamp and others (1963) in the course of preparing a 1:500,000-scale geologic map of the Wadi ar Rimah quadrangle. The region is presently the focus for reconnaissance mapping and mineral resource evaluation.

Field work was done by the author during parts of April, May, and November, 1982, from a base camp located 10 km northwest of Samirah. Logistic, office, and laboratory support were supplied by the Deputy General of Mineral Resources. I thank Ahmad el Basli for modal analyses of plutonic rocks, and J. C. Cole, E. A. du Bray, R. C. Greene, K. S. Kellogg, J. S. Pallister, J. E. Quick, and D. B. Stoeser for helpful discussions of the geology. Cole and C. Thornbur provided very helpful reviews of the manuscript.

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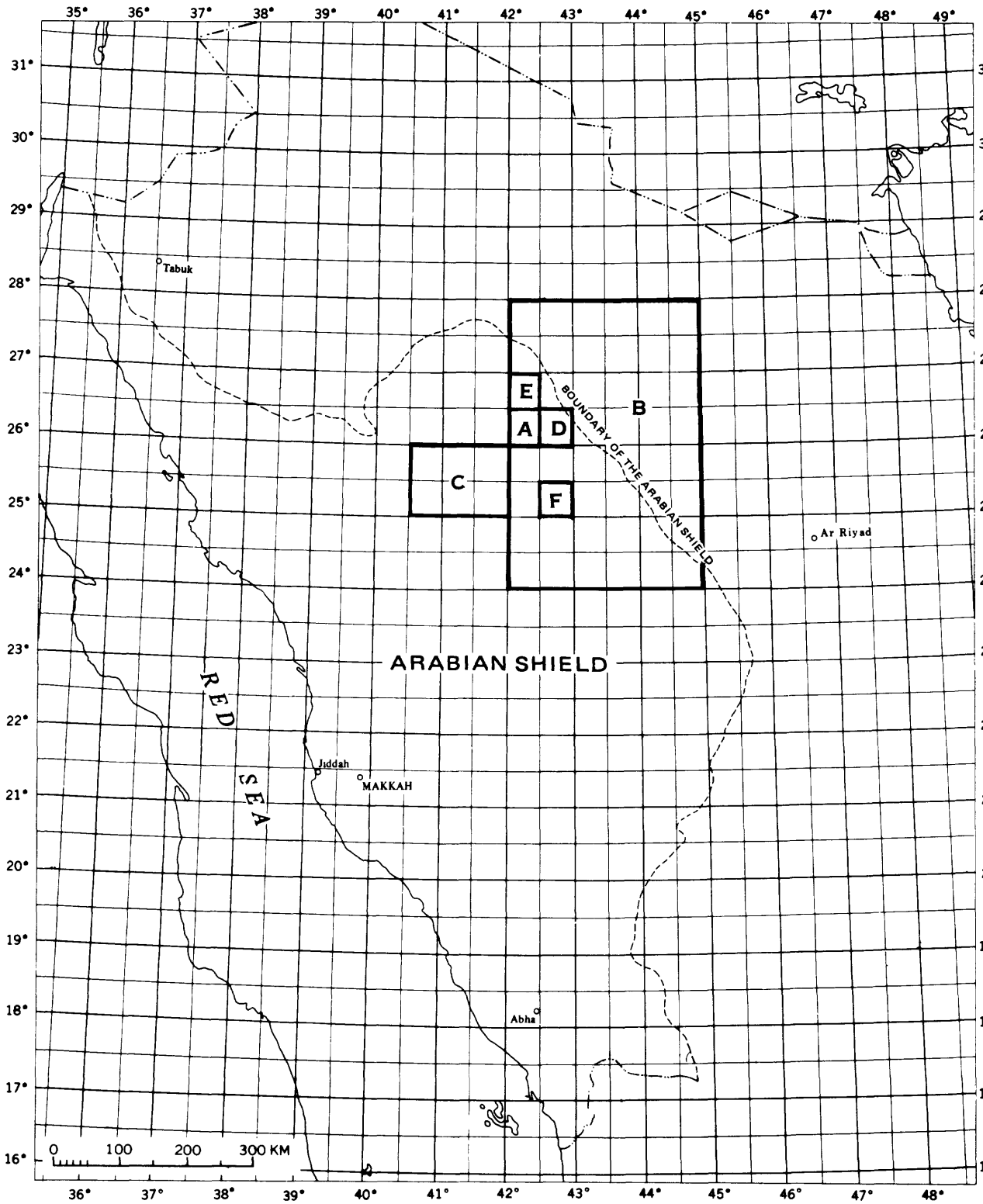


Figure 1.--Index map of western Saudi Arabia showing location of the Samirah quadrangle (A, hatched) and quadrangles referred to in the text: B, Wadi ar Rimah (Bramkamp and others, 1963); C, Nuqrah (Delfour, 1977); D, Jabal al Silsilah (du Bray, in press); E, Harrat al Hutaymah (Pallister, written comm.); F, Al Jurdhawiyah (Cole, 1981).

GEOLOGIC BACKGROUND

The Samirah quadrangle is located on a broad, late Precambrian structural upwarp in the northern Arabian Shield that has been named the Ha'il arch (Greenwood, 1973). Previous reconnaissance mapping by Bramkamp and others (1963) revealed only two types of granitic rocks and three metasedimentary units. The latter were correlated with three units that are extensive in the Arabian Shield: the Halaban, Murdama, and Hibshi formations. They recognized that the Hibshi formation rests on older granitic rocks, and that along with the Murdama formation was intruded by younger granitic magmas. No distinction was made between the two groups of granitic rocks, nor were they subdivided.

Following present-day usage, the Murdama is given group rank in this report and includes the Hibshi formation, a coarse clastic basin-margin facies, and the Hadiyah formation, a fine-grained basin deposit, which is partly younger than, and in part contemporaneous with, the Hibshi. Rocks previously mapped as Halaban are older than the Murdama group and are given local names because there is no basis for correlating them with the Halaban.

This report also describes both pre- and post-(?) Murdama metavolcanic rocks, and three intrusive units of pre-Murdama age. Seven mapped units of post-Murdama intrusive rocks range in composition from gabbro to syenogranite and comprise a number of large and small plutons. The stratigraphy and structure of the metasedimentary rocks record deformation contemporaneous with their deposition and also record continued or subsequent compressional deformation, accompanied by and followed by transcurrent (wrench) faulting.

Percentages of rock components given in the following rock-unit descriptions are volume percentages.

PRECAMBRIAN METAMORPHIC ROCKS

Metavolcanic rocks

Amphibolite and schist

The oldest rocks in the area are foliated amphibolite and schist (as) in the northwestern third of the quadrangle. In outcrop the rocks form low ridges, are generally dark green to black, and are strongly to moderately foliated and have vertical to near-vertical foliation planes, although in places they are nonfoliated. Locally there are layers a few meters thick of coarsely recrystallized vitreous quartzite. Petrographically the amphibolite layers consist of at least

50 percent green hornblende and subordinate sodic plagioclase (oligoclase), epidote, and quartz. Quartz schists commonly contain about 50 percent recrystallized quartz grains and lesser amounts of plagioclase, hornblende and epidote-clinozoisite.

The rocks of this unit represent amphibolite facies regional metamorphism of basic volcanic rocks and interbedded clastic sediments. Similar amphibolitic rocks have been described in the Nuqrah quadrangle southwest of the Samirah quadrangle and are assigned a "Middle Proterozoic" age (Delfour, 1977). No radiometric ages of these rocks are available.

Rhyolite and quartz latite

Outcrops of porphyritic rhyolite and quartz latite (rql) form low hills west of Wadi Samirah in the northwestern part of the map area. The rocks are pink, red, and gray and form irregular, apparently steeply dipping bodies in plan view. Composition is inferred from phenocryst content. One typical red unit consists of about 5 percent pink orthoclase phenocrysts, 0.1 to 0.2 mm in diameter, and 10 percent pale-pink sericitized plagioclase phenocrysts as long as 5 mm in a very fine grained groundmass mosaic of quartz and feldspar. The gray units consists of phenocrysts of quartz, about 5 percent, Carlsbad-twinned orthoclase and partly sericitized plagioclase, 10 percent each, biotite and green hornblende, about 1 percent each, in a fine-grained quartz-feldspar groundmass. The rocks are mostly silicic lava flows; one gray unit displays fragmental textures and is clearly pyroclastic. At one locality a pink unit appears to be intrusive into the adjacent older quartz monzodiorite, a relationship suggesting an hypabyssal origin in part for the unit. The relative age of the rhyolite and quartz latite is inferred only from relations at this locality; elsewhere contacts are obscured by alluvium and colluvium.

Metasedimentary rocks

Low-grade metasedimentary rocks are widespread in the Samirah quadrangle and are subdivided into three principal units: the Hibshi and Hadiyah formations, which compose the Murdama group, and a third unit, consisting of the Qarnayn sandstone and an overlying conglomerate containing conspicuous limestone cobbles. The third unit, which is lithologically dissimilar from the Murdama and may be unconformably older, is designated separately on the geologic map.

Qarnayn sandstone

The Qarnayn sandstone (qs) was named by du Bray (1983) for exposures at Jabal Qarnayn in the Jabal al Silsilah area.

He termed it the Qarnayn lithic graywacke and tentatively included it as a formation in the Murdama group. Jabal al Muwashsham and most of Jabal at Tin in the Samirah quadrangle are composed of this unit.

Typically the Qarnayn sandstone is a black, impure, thin-bedded sandstone containing sparse pebbles of resistant rock types, such as rhyolite. Medium- and fine-grained sandstone beds commonly alternate. The rock consists of 15-30 percent angular quartz grains, potassium and plagioclase feldspar, and abundant volcanic rock fragments. Du Bray (in press) noted that compared with other sandstones in the area the Qarnayn sandstone contains more abundant microcline. Detrital magnetite is sufficiently abundant (5 percent of the rock) that aeromagnetic anomalies over the Qarnayn sandstone are large compared with those of other sedimentary units in the area.

At Jabal al Muwashsham, lenses of gray, tan-weathering, fine- to coarse-grained, fairly pure thin-bedded marble (qm) are interbedded with the sandstone. Calc-silicate minerals are locally abundant in the marble adjacent to younger plutons and are considered to result from contact metamorphism.

Limestone-pebble conglomerate

At the east side of Jabal at Tin, the Qarnayn sandstone is overlain by a black to dark green thick-bedded limestone-pebble conglomerate (lpc). Although the conglomerate consists largely of cobbles and pebbles of medium- and fine-grained sandstone 10-20 cm in diameter, it derives its name from the 10-20 percent conspicuous white to light-gray limestone and marble cobbles. The clasts appear to be somewhat flattened parallel to the plane of foliation of the rock. This conglomerate is lithologically similar to conglomerates interbedded with the Qarnayn sandstone in the Jabal al Silsilah quadrangle (du Bray, in press) although clasts in the former are generally less flattened in the Samirah quadrangle.

The Qarnayn sandstone and limestone-pebble conglomerate are lithologically dissimilar to the rocks of the Murdama group, and therefore are mapped as separate units. Possibly they were derived from a source area to the east now concealed by Phanerozoic cover rocks.

Murdama group

Most of the clastic rocks exposed in the quadrangle are within the Murdama group (Brown and Jackson, 1960; Letalenet, 1974). In the Samirah quadrangle the Murdama consists of two subdivisions, the Hibshi formation (Brown and others, 1963; Delfour, 1976), consisting of conglomerate and coarse lithic sandstone, and the Hadiyah formation (USGS and ARAMCO, 1963;

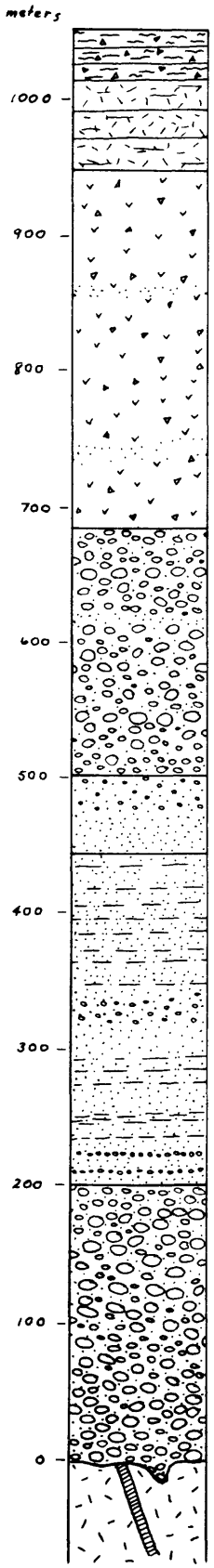
Delfour, 1977), which consists of fine-grained clastics and minor amounts of marble and greenstone. The Hadiyah formation in the Samirah quadrangle differs from the same unit in the Nuqrah quadrangle by absence of conglomerate and purplish shales (Delfour, 1977). In the Samirah quadrangle, the Hibshi formation is considered to be a coarse, clastic basin-margin facies of the finer-grained Hadiyah, and it is probable that deposition of the two units was partly contemporaneous.

Hibshi formation.--The Hibshi formation (hbc, hc, hi) forms a northeast-trending strike ridge across the Samirah quadrangle from the south end of Jabal Hibshi, through Jabal al Khidar and Jabal Witidah. It also underlies Jabal al Musawdayyah.

A stratigraphic section of the lower part of the Hibshi formation was measured at Jabal Hibshi 5 km north of the northern boundary of the Samirah quadrangle (fig. 2). Units from the base upward are: a boulder conglomerate (100-200 m); gray, very coarse grained arkosic sandstone interbedded with thin, dark-red siltstone (240 m); green, compact, platy, coarse-grained sandstone (60 m); boulder and cobble conglomerate (180 m); massive lithic tuff (260 m), and dacitic (?) lava flows and ash-flow tuff (about 110 m). East of the measured section, dark-green, pebbly, coarse-grained sandstone 2000 m or more thick apparently overlies the volcanic rocks, but the contact between volcanic rocks and sandstone is a thrust fault, one of several such faults in the Harrat al Hutaymah quadrangle east of Jabal Hibshi (J. Pallister, oral commun., 1983).

In the Samirah quadrangle, the Hibshi formation consists mostly of conglomerate and sandstone. Volcanic rocks, not differentiated on the geologic map, consist only of layers of lithic tuff a few meters thick and a single ash-flow tuff 2 to 3 m thick intercalated with green, coarse-grained sandstone in Jabal al Khidar. The thick volcanic succession of Jabal Hibshi apparently is eliminated in part by much faulting and in part by attenuation southward from the eruptive source in the Harrat al Hutaymah quadrangle.

Total thickness of the Hibshi Formation is unknown. A section measured at Jabal Hibshi is 1050 m thick. At the north end of Jabal al Khidar a minimum thickness of about 2000 m was calculated from measured dips and width of outcrop. Projection to the axis of the syncline along the valley of Wadi al Jufrah suggests a possible total thickness of about 5000 m, although poor exposures do not permit direct measurement. The Hibshi formation is progressively finer grained southwestward from Jabal al Khidar through Jabal Witidah, and probably is thinner as well, although thrust faulting precludes determination of actual thickness.



LAVA FLOWS AND ASH-FLOW TUFF--Black, purple, and dark red porphyritic lava flows and densely welded ash-flow tuff. Tuff is well zoned, strongly eutaxitic, and contains 1-5 percent angular lithic fragments as large as 1 cm. Feldspar phenocrysts compose 2-10 percent of both lava flows and tuff; absence of quartz phenocrysts suggests intermediate composition. Approximate thickness, 110 m

LITHIC TUFF--Light green to yellowish-green, dark-brown-weathering massive lithic tuff with sparse layers several meters thick of green tuffaceous sandstone. Massive; weathers to large (0.5-1m) irregular slabs and plates. Contains 2-5 percent, locally as much as 10 percent, black porphyritic and green aphanitic angular volcanic rock fragments 0.5-5 cm long. Approximate thickness, 260 m

CONGLOMERATE--Dark-brown-weathering boulder and cobble conglomerate. Moderately well sorted; subangular to subrounded clasts average 20-25 cm (maximum 60 cm) in diameter and consist of about 20 percent green calcareous sandstone and siltstone, 40 percent granitic rocks, and 40 percent volcanic rocks, in a coarse-grained sandstone matrix. Contains several beds of coarse-grained green sandstsone. Thickness, 183 m

SANDSTONE--Green, compact, coarse-grained, slabby to platy ledge-forming sandstone; contains scattered round pebbles of resistant rock types, 2-7 cm in diameter, in upper half. Thickness, 58 m

SANDSTONE AND SILTSTONE--Light purplish-gray, coarse-grained friable arkosic sandstone, weathers buff to yellowish-gray; medium- to thick-bedded (15-25 cm), mostly horizontally-bedded, rarely cross-bedded; contains calcareous cement in upper half. Sandstone layers are interbedded with dark dusky red, locally green, platy to fissile, very thin bedded shaly siltstone with raindrop imprints and oscillation ripple-marks on some bedding surfaces. Siltstone forms layers as thick as 10 m in lower part and layers 0.1-2 m thick in upper part of unit. Cobble conglomerate in beds 1-2 m thick near base of unit, and scattered pebbles in middle part. Thickness, 241 m

CONGLOMERATE--Dark-brown weathering, massive, poorly to moderately well sorted boulder conglomerate. Boulders are 20-90 cm in diameter, subrounded to rounded, in a matrix of coarse-grained arkosic sandstone and grit. Composition of boulders is 98 percent gray biotite quartz diorite and 2 percent dark porphyritic dike rocks, and a trace of aplite. Unit becomes slightly finer-grained in upper part, where maximum clast diameter is about 60 cm. Occurs in channels as large as 1 km wide and 100 m deep cut into underlying quartz diorite. Approximate thickness, 100-200 m

(BIOTITE QUARTZ DIORITE)

Figure 2.--Stratigraphic section of the Hibshi formation measured at Jabal Hibshi.

Within the Samirah quadrangle, a basal conglomerate (hbc) nearly 1000 m thick is well exposed at the north end of Jabal al Khidar. The conglomerate lies unconformably on quartz diorite, amphibolite, and schist along most of Jabal al Khidar; in one place it lies conformably on a reddish ash-flow tuff containing pumice lapilli and dark rock fragments that in turn lies on quartz diorite; in places it lies conformably on arkosic sandstone. Generally the unit forms rugged hills.

At the north end of Jabal al Khidar, the conglomerate in its lower part is crudely bedded and consists of boulders and cobbles of quartz diorite, dark-colored diorites, porphyritic dike rocks and minor amounts of siliceous to intermediate volcanic rocks. Clasts have a maximum diameter of 50 cm, averaging 10-15 cm, and are subrounded to rounded. The matrix is coarse, gritty pebbly sandstone. Lenses of coarse, green pebbly sandstone a meter or two thick are interbedded with the conglomerate at intervals of several tens of meters. In places there are thin beds of rip-up conglomerate, in which the clasts are coarse- to medium-grained sandstone.

Farther south along Jabal al Khidar, the conglomerate is thinner and discontinuous, forming channel-filling lenses in the older crystalline rock; south of Wadi Safaq the conglomerate is apparently absent and coarse-grained sandstone layers at the base of the unit contain grit and small pebbles.

The boulder conglomerate is tentatively correlated with the basal conglomerate at the Jabal Hibshi measured section, which locally exceeds 1,000 m in thickness. The boulder conglomerate may also correlate with the much thinner upper conglomerate. Recent mapping of Jabal Hibishi (J. Pallister, oral commun., 1983) shows facies changes so abrupt in the intercalated volcanic and clastic rocks that correlation of units across unexposed areas is uncertain.

Most of the Hibshi formation is composed of the Hibshi formation undivided (hi), a dark-green lithic sandstone that weathers to a light greenish gray color where not coated with dark desert varnish. The sandstone is generally medium to coarse grained and forms resistant-weathering beds several meters thick. Sparse floating pebbles and pebble-rich layers 1-2 cm thick are common; most pebbles are of well-rounded porphyry consisting both of dike and volcanic rocks. Shale and siltstone interbeds are rare, although angular, green intraformational shale clasts are fairly common.

Microscopic analysis of 17 Hibshi sandstone samples shows that the unit is a lithic sandstone, containing on the average about 18 percent angular quartz, 4 percent potassium feldspar, 18 percent plagioclase feldspar, 45 percent rock

fragments, and 15 percent fine-grained chloritic to sericitic matrix. The rock fragments are overwhelmingly of volcanic origin, reflecting the dominantly volcanic provenance of the Hibshi formation; in several thin sections, a dozen or so types of volcanic fragments were identified, ranging from basalt to rhyolite. Shard structure indicates that some of the fragments are welded tuff. There are, in addition, sparse fragments of sedimentary, metamorphic, and plutonic rocks. The low percentage of silt and clay matrix in the Hibshi sandstones (15 percent) is believed to indicate a high-energy, near-source environment of deposition. The matrix is commonly recrystallized. It consists of quartz, sericite, chlorite, epidote, and calcite. In metamorphosed sandstone near post-Hibshi plutons, fine-grained biotite is a common matrix constituent.

The Hibshi formation also contains a second major conglomerate unit (hc) that makes up much of Jabal al Musawdayyah, where it forms black, rugged, craggy hills. The conglomerate is at least 2 km thick; it is faulted against the Qarnayn sandstone on the east but clearly conformably underlies green coarse-grained sandstone of the Hibshi formation in the western part of Jabal al Musawdayyah, where the rocks form a west-dipping homocline.

The composition of the conglomerate at Jabal al Musawdayyah is very different from that of the boulder conglomerate at Jabal al Khidar. The conglomerate at Jabal al Musawdayyah is green and its clasts consist almost entirely of fine sandstone, siltstone, and shale of the Hadiyah formation in a matrix of coarse to fine sand. Pebbles of marble, igneous rocks, and chloritic vein quartz are rare. Clasts are subangular to subrounded and range from 1-2 cm to a maximum observed diameter of 22 cm. Upward-fining cycles within the conglomerate are each several meters thick.

The presence of abundant Hadiyah clasts in a conglomerate within the Hibshi formation indicates that the Hadiyah in part predates the Hibshi. This age relationship is the basis for postulating that the Hibshi is a basin-margin facies of the deeper-basin Hadiyah, an interpretation that requires local uplift within the basin, probably along faults; detritus shed from the uplift would be deposited as the conglomerate.

Hadiyah formation.--Fine-grained sandstone, siltstone, and shale form a surface of low relief in the southern half of the Samirah quadrangle; these rocks are referred to as the Hadiyah formation (ha). Similar rocks in the Jabal al Silsilah quadrangle were named the Maraghan lithic graywacke (du Bray, in press). Particularly along Wadi al Mahalani, the rocks are covered by a lag of quartz chips weathered from small quartz veins in the rock; elsewhere the beds form low strike ridges and are generally poorly exposed.

Total thickness of the Hadiyah formation is unknown, and is not determinable because of strong folding and absence of distinctive, continuous marker units. In the Nuqrah quadrangle a succession of Hadiyah formation 2,000 m thick is exposed (Delfour, 1977). A section probably two or three times as thick is intermittently exposed in the Samirah quadrangle.

The Hadiyah formation is atypically well exposed in low hills about 8 km north of Jabal Qutn. There the rock is mostly green to olive-gray, thin-bedded siltstone interbedded with minor shale and fine-grained sandstone. Carbonate-rich beds form brown resistant ledges as much as 30 cm thick.

In places the siltstone is strongly cleaved; elsewhere cleavage is less well developed. Most of the Hadiyah formation is weakly calcareous.

Poorly bedded, dark-gray calcareous argillite is interbedded with sandstone and siltstone in places; commonly more resistant to erosion than the well-cleaved shale and siltstone, it forms several strike ridges in the southwestern part of the area.

The sandstone is fine-grained; clasts consist of about 50 percent volcanic lithic fragments, 30 percent angular quartz, and about 20 percent plagioclase, with rare grains of potash feldspar (du Bray, *in press*). Silt, clay, and carbonate matrix make up 20 to 40 percent of the sandstone, which is therefore classified as graywacke.

Layers of marble (recrystallized limestone) (ham) as much as several tens of meters thick are interbedded in the Hadiyah formation. They are present in its lower part along the east side of Jabal Witidah, where the Hadiyah formation is in thrust contact with the Hibshi formation, and are encountered sporadically throughout the extent of the Hadiyah; Jabal Safinah is made up of sheared carbonate rock. For the most part the marble layers are light gray and massive; locally they weather tan and are thin-bedded and dolomitic. Attitudes are generally indeterminate in the gray, massive marble beds, which appear to be tectonically thinned and thickened. Small white calcite veinlets 1-2 cm thick are common. It is believed that the marble was deposited as limestone or dolomitic limestone, unlike the spinel-bearing marble described by du Bray (*in press*), which was derived from carbonatization of serpentinite. Total thickness of the marble nowhere exceeds 500 m, considerably thinner than a correlative(?) marble unit in the Murdama formation in the Jurdhawiyah area (Cole, *in press*).

The marble along Jabal Witidah probably correlates with the Farida formation of the Murdama group in the Nuqrah quadrangle (Delfour, 1977).

A distinctive pillow lava (hap) forms a lens within the Hadiyah formation at Dilay al Raschid near the east boundary of the quadrangle. The lens is about 300 m thick and consists of well-preserved pillows of various shapes as much as 1 m in maximum dimension. The rock is dark gray to greenish gray, and weathers light greenish brown. Squeeze-up forms were observed. Pillow shapes indicate that the section there is upright, not overturned.

In thin-section, the rock is seen to consist of abundant fine-grained, elongate, brown hornblende grains that are strongly aligned by primary flowage, in a very fine grained matrix of albite and chlorite. Sparse phenocrysts as much as 1 cm in diameter consist of remnants of plagioclase that are largely replaced by aggregates of chlorite and calcite. Based on the abundance of primary hornblende, the rock is classified as andesite.

Greenstone, probably metabasalt, crops out in several places in the Hadiyah formation, particularly in the eastern part of the quadrangle. South of Jabal al Muwashsham in the lower part of the Hadiyah formation, black, fine-grained, dense, massive rocks containing tiny sparse plagioclase phenocrysts are interbedded with fine-grained clastic rocks. Similar rocks crop out north of Jabal Sumayrah al Hibeyniyah, where dark massive rocks appear to be altered basalt, and west of Jabal Asha, where fresh, unaltered, fine-grained biotite-bearing amphibolite forms either a sill or lava flows.

Origin and age of the Murdama group.--Rocks of the Murdama group were deposited in an extensive basin or interconnected basins that covered most of the Arabian Shield (Hadley and Schmidt, 1980). There is abundant evidence that the Murdama is closely related to active volcanism in many parts of the Shield. Felsic, intermediate and basic volcanic rocks are commonly interbedded with clastic rocks, which contain abundant volcanic-rock fragments (Greene, 1984).

Recent syntheses of Arabian Shield tectonics suggest that the Murdama group was deposited between converging crustal plates (Greenwood and others, 1980; Hadley and Schmidt, 1980). Magmatic arcs developed during plate convergence and contributed abundant volcanic detritus to the interplate basin; the basin sediments were subsequently folded by continued plate convergence.

The age of the Murdama group has not previously been closely determined. Baubron and others (1976) obtained 7 whole-rock potassium-argon ages ranging from 637 to 533 Ma from rhyolites in the Hibshi formation, of which Delfour (1977) believed the oldest figure to best represent the true age of the rhyolite. Pre-Hibshi quartz diorite from just

west of Jabal al Khidar yielded a U-Pb age of 646± 6 Ma (C. Hedge and J. Cole, written commun., 1983). Similarly, the post-Murdama monzogranite east of Jabal Hibshi at the north edge of the Samirah quadrangle has been dated at 616± 10 Ma (C. Hedge, written commun., 1982). The monzogranite is not the oldest post-Murdama plutonic rock; age determinations of the oldest post-Murdama plutons would fix the minimum age limit even more accurately.

Jibalah group(?)

At Wadi al Jufrah opposite the south end of Jabal al Khidar, rock that strikes parallel to the fault and dip vertically is tentatively assigned to the Jibalah group (jb?). The rock consists of dark-gray pebbly siltstone and sandstone. Principal framework constituents are quartz, feldspar, and lithic fragments. The fragments consist of granule- to pebble-size, angular to subrounded compound quartz grains, metachert, siltstone, calcite-quartz aggregates, which closely resemble quartz veins in the Hadiyah formation, and assorted types of volcanic rocks. The matrix comprises angular, silt-size particles set in fine-grained sericite, chlorite, and quartz, with some calcite. Locally pyrite makes up about 1 to 2 percent of the rock.

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

PRECAMBRIAN INTRUSIVE ROCKS

Pre-Murdama intrusive rocks

All pre-Murdama intrusive rocks lie northwest of the strike ridge of the Hibshi formation that makes up Jabal al Khidar and Jabal al Witidah. These rocks form several plutons that range in composition from quartz diorite to monzogranite. Modal composition of all plutonic rocks, determined by point-counts of stained slabs, is shown in figure 3. Chemical analyses indicate that the rocks are peraluminous, according to the classification of Carmichael and others (1974).

Gneissic monzogranite

A body of gray, sheared, weakly gneissic, monzogranite (gmg) is poorly exposed just west of the south end of Jabal al Khidar, where it forms a roughly oval pluton that intruded the amphibolite and schist unit and is nonconformably over-

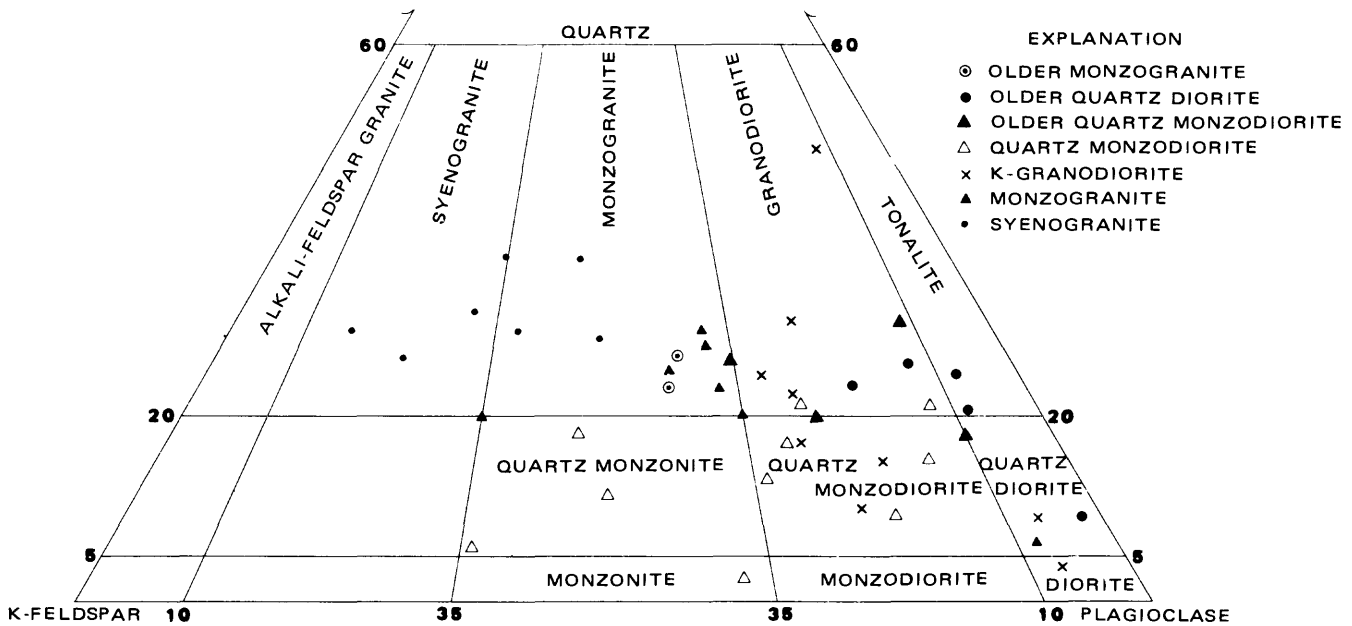


Figure 3.—Quartz-potassium feldspar-plagioclase ternary diagram modified from Streckeisen, 1976, for plutonic rocks in the Samirah quadrangle. Each plotted point represents a modal analysis consisting of 300 to 500 points counted on a stained slab at least 25 cm^2 in area.

lapped by the Hibshi formation. The rock is hypidiomorphic and porphyritic. Quartz (25 percent) and plagioclase (50 percent) are generally rather fine-grained; potassium feldspar phenocrysts (25 percent) are coarse-grained and form a subparallel arrangement suggesting flaser structure. Biotite originally made up about 3 percent of the rock but has been entirely altered to chlorite.

Gneissic quartz monzodiorite

A large pluton of gray gneissic quartz monzodiorite (gqmd) forms a flat, recessive-weathering plain west of Jabal Witidah, extending to and beyond Wadi Samirah. It intruded the metavolcanic rocks of the amphibolite-schist unit and was in turn intruded by the post-(?) Murdama granite of Samirah in the northwestern corner of the quadrangle.

The rock is hypidiomorphic-inequigranular and medium grained. Subhedral, partly sericitized plagioclase is 60 to 70 percent of the rock, anhedral quartz 20 to 30 percent, and interstitial microcline having well-developed grid twinning, 7 to 20 percent. At one locality coarse potassium feldspar phenocrysts were observed. Biotite that is nearly entirely altered to chlorite is about 4 percent of the rock.

The rock is weakly gneissic in most exposures. Fine-grained mafic inclusions commonly make up about 1 percent of the rock.

Quartz diorite

The north end of Jabal al Khidar is the east boundary of a pluton of quartz diorite (qd) that is generally uniform in texture and composition. This pluton intrudes the amphibolite and schist unit (as) and is intruded by the monzogranite (mg) of Wadi Samirah; it is overlain by the Hibshi formation. It is believed to be the youngest pre-Murdama plutonic rock in the area. Its designation as a quartz diorite is somewhat arbitrary because analyses of different samples include tonalite and granodiorite as well as quartz diorite.

Although the quartz diorite is recessive weathering, outcrops are fairly numerous and thus sampling is facilitated. The rock is gray, medium to coarse grained, hypidiomorphic-inequigranular, containing about 70 percent equant euhedral plagioclase, 2 to 15 percent subhedral to anhedral perthitic orthoclase, and 10 to 25 percent quartz. Biotite averages 5 percent, and hornblende and sphene are present in trace amounts. Fine-grained, discoid mafic inclusions to 30 cm in diameter make up 1 to 2 percent of the rock in most places.

Black, hornblende-bearing, nearly aphanitic andesitic or basaltic dikes to 20 m thick trending northwest to west-northwest form conspicuous, low ridges across the outcrop area of this pluton.

As noted above, the age of the quartz diorite is 646± 6 Ma.

Post-Murdama intrusive rocks

Large plutons (10 km^2 or larger) of post-Murdama age may be divided into five types, listed in probable order of decreasing age: (1) quartz monzodiorite forming large plutons in the northeastern part of the quadrangle, (2) granodiorite plutons generally oval in plan, (3) monzogranite, (4) syenogranite, and (5) alkali-feldspar granite forming a pluton circular in plan (youngest). In addition, there are numerous small intrusive plugs of plutonic rock ranging in composition from gabbro to granite. The oldest post-Murdama plutonic rock is probably a metagabbro. Rock types 1-3 and 5 are peraluminous (Carmichael and others, 1974); the syenogranite, type 4, is probably also peraluminous, but chemical data are not presently available.

Metagabbro

A narrow ridge of dark green to black, sheared metagabbro (mgb) forms two sharp ridges along the Raha fault zone on the southeastern side of Jabal at Tin. The rock consists of altered plagioclase and dark green chlorite in roughly equal amounts. Texture is cataclastic, in places virtually mylonitic. A small outcrop of similar rock crops out at the east edge of the quadrangle. Like metamorphosed basic plutonic rocks in the Jabal al Silsilah quadrangle (du Bray, in press), which it closely resembles, this rock crops out along a major fault zone, probably the westward continuation of the Raha fault zone of du Bray.

Quartz monzodiorite

An irregularly shaped, probably composite batholith of quartz monzodiorite to quartz monzonite composition (qmd) that lies north and west of Jabal al Musawdayyah and extends southward to the desert flat east of Jabal at Tin intrudes the Qarnayn sandstone and Hadiyah formation. The unit was named the Muwashsham quartz monzodiorite in the Jabal al Silsilah quadrangle (du Bray, in press). This pluton is believed to be composite because there are obvious textural variations and differences in mafic mineral content from place to place, although the ratios of felsic constituents is generally similar throughout. It is fairly recessive weathering, although outcrops are common. The rock contains a few dark-gray mafic inclusions.

The texture of the rock is generally hypidiomorphic inequigranular, and medium to coarse grained. Plagioclase is euhedral and makes up about 50 percent of the rock. Potassium feldspar, 10 to 20 percent, is mostly subhedral to anhedral microcline; interstitial quartz is also 10 to 20 percent of the rock. The mafic mineral content ranges widely, from 6 to 30 percent, and consists of biotite and green hornblende in varying amounts.

North of Jabal al Musawdayyah, the monzodiorite is cut by a swarm of north-northwest-striking mafic dikes, which are andesite, according to du Bray (in prep). Similar trending dikes in the part of the pluton east of Jabal at Tin are of intermediate to silicic composition.

At the northeastern end of Jabal Witidah, a small, poorly exposed, recessive-weathering pluton of quartz monzodiorite is weakly gneissic and contains 8 percent quartz, 15 percent perthitic orthoclase, 50 percent plagioclase, 15 percent biotite, 5 percent green hornblende, and 2 percent augite. This pluton is intruded by small plugs of fresh olivine gabbro.

Granodiorite

Three oval plutons having compositions ranging from granodiorite to diorite (gd),- one near the western edge of the quadrangle southeast of Jabal Witidah, one north of Wadi al Awiin, and one just north of Jabal Khiraysha ad Dieh. The rock weathers very recessively and contains as much as 5 percent dark inclusions. Dikes are sparse.

Compositional and textural differences are as great or greater within a given pluton as between any two of them. The rocks are mostly medium-grained hypidiomorphic-equigranular granodiorite, although fine-grained and slightly porphyritic varieties are in all three plutons. Minerals are euhedral to subhedral zoned sodic plagioclase, subhedral to anhedral perthitic orthoclase, and subhedral to anhedral quartz. Plagioclase is about half of the rock; quartz and orthoclase are subequal in amount in two of the three plutons, except that quartz is more abundant in the granodiorite at Jabal Witidah. Mafic minerals make up from 4 to 12 percent of the rock and are most abundant in the granodiorite at Jabal Khiraysha ad Dieh. The two eastern plutons contain subequal amounts of biotite and hornblende; the pluton at Jabal Witidah contains only biotite.

Monzogranite

Plutons having an average composition of monzogranite (mg) crop out in the northeastern part of the quadrangle, where a septum of the Hibshi formation appears to divide a

single pluton into two bodies, and in the northwest corner of the quadrangle, along Wadi Samirah. The northeastern pluton clearly intruded rocks of the Hibshi formation and the post-Murdama quartz monzodiorite pluton. The pluton of Wadi Samirah clearly intruded the amphibolite-schist unit, the older quartz diorite, and older quartz monzodiorite; it apparently is younger than the rhyolite-quartz latite volcanic unit.

The monzogranite in both areas is generally pink and recessive weathering, although locally it forms knobby inselbergs. The monzogranite at Wadi Samirah is pink, medium-grained, hypidiomorphic-equigranular rock containing 30 percent subhedral to anhedral microcline, 25 percent anhedral quartz, and 40 percent euhedral to subhedral plagioclase. Biotite, slightly chloritized, is 2 to 3 percent of the rock. The monzogranite east of Jabal Hibshi has a dark-colored quartz diorite border phase at the south end. The monzogranite in the large outcrop area to the east is pinkish gray and is coarse to medium grained. The rock is hypidiomorphic-equigranular to slightly porphyritic and contains about 25 to 30 percent quartz, 25 to 30 percent perthitic microcline, and 40 to 50 percent euhedral to subhedral plagioclase. Biotite, 2 to 5 percent, is the principal mafic mineral, although trace amounts of hornblende are present. Sphene and apatite are common accessory minerals. The same pluton has been called the Shuwayman monzogranite by du Bray (in press) in the Jabal al Silsilah quadrangle.

As noted above, a sample of the monzogranite from east of Jabal Hibshi was dated at 616± 10 Ma.

Syenogranite

Near the northwestern corner of the quadrangle, a pink syenogranite (sg) crops out in flat areas interspersed with bold inselbergs. Its contact with the older monzogranite of Wadi Samirah is not exposed in the Samirah quadrangle but is well exposed in the Harrat al Hutaymah quadrangle to the north, where the syenogranite forms a narrow, elongate, north-trending pluton (John Pallister, oral commun., 1983).

The rock is hypidiomorphic-inequigranular and porphyritic. Phenocrysts consist of about 35 percent euhedral perthitic orthoclase as much as 5 mm long, 10 percent euhedral sodic plagioclase as much as 1 cm long, and 25 percent anhedral interstitial partly resorbed quartz. Biotite is about 4 percent of the rock and green hornblende is found in trace amounts. The groundmass, about 20 to 25 percent of the rock, comprises fine-grained intergrowths of about 65 percent potassium feldspar and 35 percent quartz. Radioactivity is significantly higher than in the surrounding monzogranite.

Alkali-feldspar granite

Jabal Qutn at the southern edge of the Samirah quadrangle consists of peraluminous alkali-feldspar granite (ag) forming a circular pluton about 12 km in diameter. The granite is light-orange-gray and forms steep-sided whaleback masses cut by strong west-northwest joints.

The granite at Jabal Qutn is coarse-grained, hypidiomorphic-granular rock. Potassium feldspar, 35-45 percent of the rock, is perthitic and has both stringer and patch patterns. In the central part of the pluton, potassium feldspar grains are 2 cm long, about twice as large as quartz and plagioclase. In the outer 1 km or so, the rock is equigranular. Thus the pluton is zoned, with a porphyritic core and nonporphyritic outer shell.

Quartz makes up 27-35 percent of the rock and is anhedral; locally it occurs as clusters of grains. Sodic plagioclase (m 8-15), which occurs as euhedral to subhedral phenocrysts that are slightly smaller than potassium feldspar and quartz, composes 20 to 35 percent of the rock. Biotite having pale-yellow to brown pleochroism makes up 1 to 4 percent of the rock. Weakly pleochroic muscovite, occurring with biotite, was observed in several samples.

The highest point on Jabal Qutn, near its western edge (1176 m), is an area of several hectares underlain by dark-red-brown, very fine grained, siliceous felsite that forms a flat-lying caprock about 10 m thick on coarse-grained granite. The rock is porous, containing numerous miarolitic cavities, and has sparse biotite and quartz phenocrysts. In places it forms the matrix of a breccia, the angular clasts of which are granite containing soft altered feldspar and quartz. The felsite is 83 percent SiO_2, 11 percent Al_2O_3, less than 2 percent total iron oxides, 1.5 percent CaO, and less than 0.5 percent total alkalis.

One swarm of thin mafic dikes aggregating 3 m in thickness was observed at the western edge of the pluton. The dikes consist of fine-grained plagioclase and pyroxene. Dikes of aplite and medium-grained leucogranite 1 to 10 cm thick are locally abundant, especially in the peripheral parts of the pluton, where they appear to dip inward toward its center. Dikes intruding the Hadiyah formation country rock are rare.

The granite at Jabal Qutn has a mass radioactivity about two to four times the background for the region, probably because of the large amount of potassium feldspar containing the radioactive isotope K_{40}. No segrations of uranium-bearing minerals were found.

A Rb-Sr age of 579±4 Ma was obtained by C. Hedge (written commun., 1983).

Diorite

Diorite (di) forms several small (<1 km^2) to medium-sized (5 km^2) intrusive bodies within the Samirah quadrangle. In the eastern part of the quadrangle, six small diorite and quartz diorite plugs are arrayed along a northwest trend, the southeasternmost of which is Jabal Asha. The rock is generally dark gray and fine grained, commonly porphyritic, and consists of about 65 percent lath-shaped euhedral sericitized plagioclase, 20 percent brown hornblende, 10 percent chlorite formed by the replacement of biotite, and a few percent of interstitial quartz. The northwesternmost diorite plug is somewhat different. Medium grained, it consists of 60 percent subhedral plagioclase, 5 percent potassium feldspar, 3 percent quartz, 10 percent green hornblende, and 20 percent partly chloritized biotite.

Diorite plugs also crop out within the quartz monzodiorite pluton east of Jabal at Tin and just south of Jabal al Muwashsham, 1-2 km from the eastern edge of the quadrangle.

Three elongate plugs of hornblende diorite intrude monzogranite and older quartz monzodiorite along Wadi Samirah about 10 km southwest of the village of Samirah. The rock is black and weathers to round boulders 30-60 cm in diameter; it is medium-grained, hypidiomorphic-inequigranular rock, consisting of 50 to 60 percent partly sericitized plagioclase, 30 percent hornblende, pleochroic in yellow, brownish-green and green, a few percent interstitial quartz, and accessory sphene.

Gabbro

Small plugs of gabbro (gb), which generally weathers to black boulders, crop out in three places in the Samirah quadrangle. Fourteen km nearly due south of Samirah is a round plug less than 1/2 km in diameter that consists of about 65 percent calcic plagioclase, 25 percent green partly sericitized hornblende, and 5 percent augite.

The poorly exposed quartz monzodiorite body at the northeastern end of Jabal Witidah is host to one or more small, irregular olivine gabbro plugs. One sample of black equigranular hypidiomorphic rock contained about 60 percent calcic plagioclase, 20 percent fresh olivine with abundant very small inclusions of opaque minerals, 15 percent hypersthene, and 5 percent brown, probably uralitic hornblende. Absence of alteration of the mafic minerals suggests that the rock

may be of Cenozoic age and related to Cenozoic volcanic rocks to the north in the Harrat Hutayma quadrangle.

A third gabbro plug near the northeastern corner of the quadrangle is about 2 km long and lies on the contact between the quartz monzodiorite and monzogranite plutons. The black rock consists of 35 percent calcic plagioclase, 30 percent coarse crystals of green hornblende that poikilitically enclose other minerals, 20 percent augite, and 15 percent olivine (?), the original mineral having been largely replaced by antigorite, iron oxides, and secondary tremolite-actinolite.

Dikes

The numerous dikes cutting the plutonic and metasedimentary rocks were not studied in detail. Dikes were classified in the field by general aspect and visible mineralogy into mafic, intermediate, and felsic. A large number of dikes (d) were not visited in the field, were drawn from aerial photographs, and thus were not classified as to type.

A prominent set of north-northwest-trending dark dikes cuts the quartz monzodiorite pluton north of Jabal Muwashsham. In the adjacent Jabal Silsilah quadrangle, du Bray (in press) observed that these dikes, probably andesitic, have a wide range of textures and mineralogy, but generally consist of euhedral calcic plagioclase and hornblende in a commonly felty, trachytic groundmass of plagioclase, actinolite, chlorite, and locally abundant iron oxides. A black, relatively fresh dike 3 m wide in the pre-Hibshi quartz diorite west of Jabal Hibshi consists of sparse plagioclase phenocrysts in a fine-grained groundmass of plagioclase and green pyroxenes, chlorite, and sparse, probably secondary quartz.

Dikes classified as intermediate are generally gray and contain phenocrysts of plagioclase, hornblende, biotite, and less commonly quartz and potassium feldspar.

Felsic (aplitic) dikes are abundant and are pink, red or orange. Phenocrysts are quartz, which is commonly resorbed, potassium feldspar, and biotite, in an allotriomorphic-granular groundmass of quartz and alkali feldspar.

Quartz

White milky quartz (q) crops out in two small pods in the upper Murdama group in the southeastern part of the Samirah quadrangle. In the northernmost of these, the quartz is in two sets of vertical veins as much as 1 m in diameter; one set trends north to N. 15° E. and the other set, N. 65° E. In the southernmost, a quartz pod 30 m long and 6 m wide

trends N. 60° E. Locally, the quartz contains small, irregular iron oxide masses; otherwise there is no visible mineralization.

A small east-trending set of white, gray, and purplish quartz veins about 30 m wide crops out just south of Jabal Witadah. The country rock is not exposed but is probably granodiorite.

Small, irregular quartz veins, in places stained by iron oxide and containing variable amounts of calcite, are common in the Hadiyah formation. East of Jabal Witidah and to a lesser extent elsewhere, these weather out of the Hadiyah to form a white lag deposit of quartz chips that commonly masks the nonresistant parent bedrock. Ancient mine workings are associated with some of these quartz vein systems, and free gold was apparently obtained; there is also copper, lead, and zinc mineralization.

QUATERNARY DEPOSITS

Large areas in the Samirah quadrangle are mantled with alluvial deposits of Quaternary age that commonly conceal geologic relations between bedrock units. On the geologic map, Quaternary units are divided into lag, fan gravel, sabkha, and sand and silt units, but no attempt was made to determine relative age of the different sediment types.

Quartz lag deposits

In places, particularly along Wadi al Mahalani, the Hadiyah formation is eroded to a flat plain mantled with white chips of vein quartz mapped as quartz lag deposits (Ql). This mantle is 0.5 to 1 m thick and formed as a residium from quartz veinlets (0.5 to 5 cm thick) that are abundant in the Hadiyah formation, particularly in the area of the quartz lag deposits. In places poor outcrops of cleaved fine-grained sandstone, siltstone, and shale are exposed where the quartz lag mantle has been partly removed by erosion.

Alluvial fan gravels

Mountain areas formed from resistant rocks are flanked by alluvial surfaces sloping gently downward toward major wadis. These slopes are underlain by alluvail fan gravels (Qg) of cobble to pebble size, most of which is subangular to subrounded and mixed with small amounts of coarse sand. The base of the gravel is rarely exposed; trenching of the fans by erosion has exposed as much as 15 m of gravel, and it is likely that the gravels are considerably thicker. Probably the gravels were deposited during floods that result from

infrequent but torrential rains in desert regions; the fans are continually regraded, trenched, and reworked by subsequent floods.

Sabkha deposits

Small playa lakes in the Samirah quadrangle are floored by sabkha deposits (Qsb) composed of light-brown silt, clay, and sand that is commonly saline. In places, the upper layer is white, consisting of salts formed from evaporation of water that accumulates from sporadic rainfall.

Wadi Deposits

Drainage in the Samirah quadrangle, as in the northern Arabian Shield as a whole, consists of a branching network of generally shallow intermittent stream channels. The channels are filled with wadi deposits (Qs), a light-brown mixture of sand, silt, clay, and, in larger wadis, fine gravel, that is generally no thicker than 1 to 2 m. In places the channels are scoured down to bedrock.

This map unit includes areas of eolian sand and silt, particularly in the plain surrounding Jabal Qutn. Small areas of eolian sand dunes in the mountains are not mapped.

STRUCTURE

Figure 4 is a simplified structure map of the Samirah quadrangle, with the alluvium stripped off. In the following discussion of structure, the map is useful because structural units can be seen unbroken by alluvial contacts.

There are two major types of structural units in the Samirah quadrangle: large plutons of quartz diorite to syenogranite composition and layered metasedimentary rocks, mainly clastic rocks of the Murdama group. Each of these two rock types occupies about half of the quadrangle, excluding surficial deposits. Because the plutons are relatively rigid bodies that resist tectonic stresses, the structural history of the area is better recorded in the metasedimentary rocks and associated volcanics.

The unconformity at the west side of the Hibshi formation monoclinal strike ridge marks a structural boundary, as well as marking the approximate depositional margin of the Murdama basin. The area to the northwest is underlain by amphibolite and schist intruded by pre-Hibshi plutons of intermediate composition and by post-Hibshi granites. The area to the southeast is underlain by a thick clastic section that is moderately deformed and intruded by numerous large granodiorite to granite plutons.

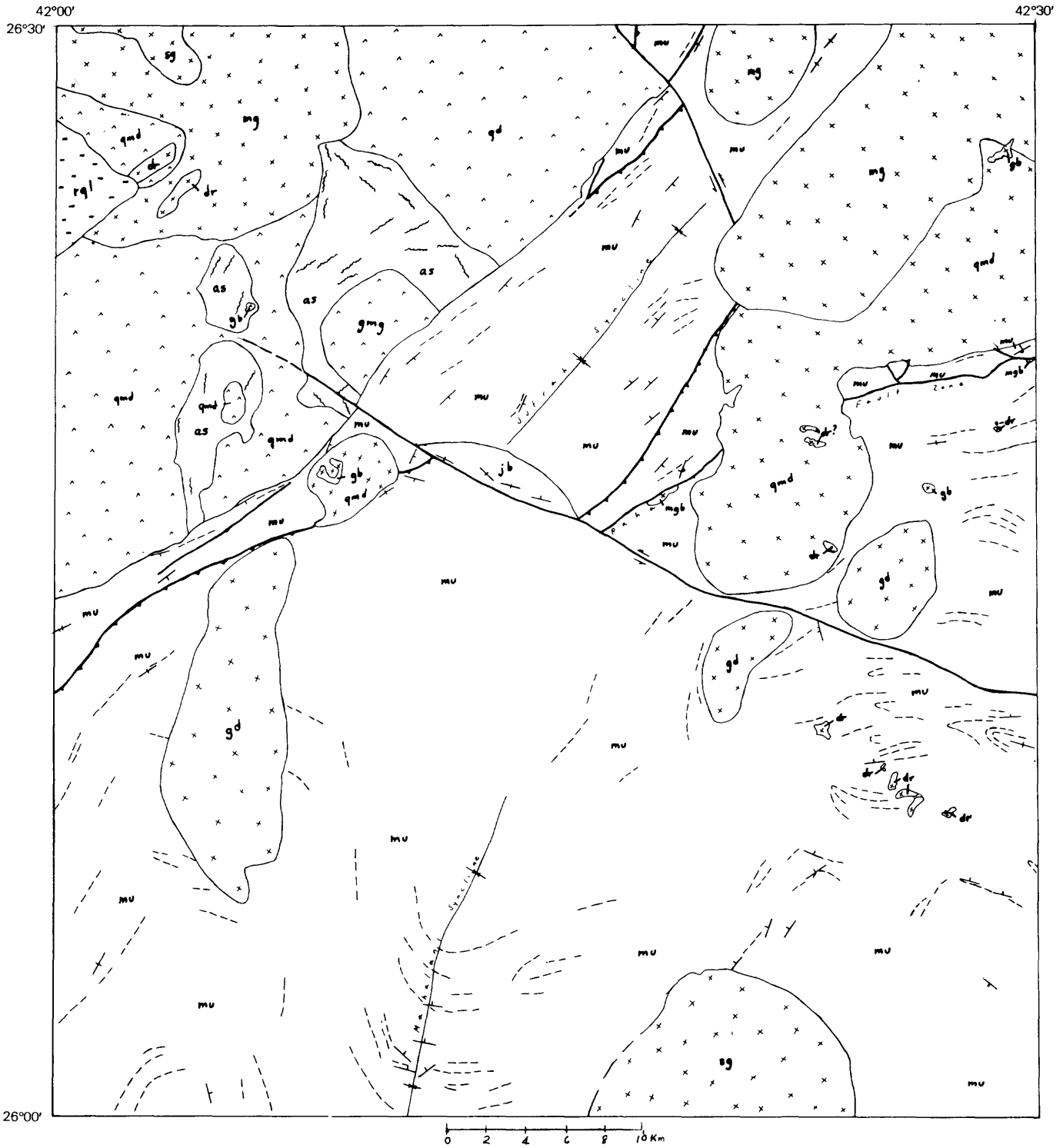


Figure 4.--Generalized structure map of the Samirah quadrangle.

Folds

The Murdama group rocks are deformed by major northeast- to north-northeast-trending folds, the most obvious of which are the Jufrah and Mahalani synclines (fig. 4). A third large fold, an anticline, may exist near the granodiorite body southeast of Jabal Witidah, as suggested by a few strike ridges of resistant beds.

Minor folds are mappable in the Hadiyah formation along the eastern margin of the quadrangle, about 20 km from the southeastern corner. Those are mostly east-trending, and have wave-lengths of 1-2 km. The folds are generally symmetrical and have dips of 60-80° on both limbs. Probably the Hadiyah is similarly folded elsewhere, but folds are not mappable due to poor exposure. Certainly the existence of such folds precludes the possibility of determining thickness of the Hadiyah by measuring width of outcrop.

Rock cleavage

Fracturing of rocks on outcrop scale is largely related to lithology. Widely spaced, rather irregular fracture cleavage with fractures 10 to 20 cm apart are present in the coarse conglomerates of the Hibshi formation. Sandstones of the Hibshi possess a steeply dipping, generally irregular fracture cleavage with planes spaced 1 to 5 cm apart. Well-developed slaty cleavage is common in the siltstone and shale of the Hadiyah formation; spacing is a few millimeters or less and contributes to the poor resistance to erosion of the Hadiyah. Plutonic rocks appear to be essentially undeformed, although dikes are offset along faults and the older monzogranite extensively fractured.

Faults

Raha fault zone

South of Jabal al Muwashsham, at the eastern boundary of the quadrangle, an east-trending fault zone forms a major structural discontinuity separating the Quarnayn sandstone from the Hadiyah formation but dividing into two or more strands westward, all of which terminate against the younger pluton. West of the pluton, what is apparently the same fault passes along the southeastern side of Jabal at Tin, where it separates the limestone-pebble conglomerate from sheared metagabbro.

The fault passes eastward into the Jabal Silsilah quadrangle, where it was mapped by du Bray and named the Raha fault zone. Du Bray noted the presence along the fault zone of mafic and ultramafic rocks, some of them similar to the metagabbro at Jabal at Tin and at the eastern edge of the

Samirah quadrangle. Listwanite, or carbonate rock derived from serpentinization of peridotite, was also noted along the fault zone. Presence of these rocks suggests that the fault zone penetrates the crust to a considerable depth. The sense of movement on the fault is unknown. In the Samirah quadrangle it appears to be a steep normal fault, with the south side down. Du Bray (in press) suggests that it is a relatively low-angle thrust fault dipping north, with the north side thrust over the south. A third and intriguing possibility is that the fault is an overthrust dipping steeply to the south subparallel to bedding, with the Hadiyah formation on the south side thrust over the Qarnayn sandstone on the north. This model implies a genetic relationship to the thrust fault along Jabal Witidah and perhaps right-lateral offset on the transcurrent fault between the two thrust faults.

Thrust fault along Jabal Witidah

The boundary between the Hibshi and Hadiyah formations along the southeastern flank of Jabal Witidah is interpreted to be a steeply dipping thrust fault subparallel to bedding. Evidence supporting this interpretation is cross-cutting of bedding in the Hibshi formation, with abrupt thinning of the Hibshi south of Wadi Safaq, and intermittent absence of the marble unit of the Hadiyah formation along the trace of the fault. The fault terminates at its northeastern end at a west-northwest-striking transcurrent fault. Thrusting is believed to have occurred during the same compressive episode that folded the Hadiyah along northeast- to east-trending axes.

Transcurrent faults

A major west-northwest-trending transcurrent fault crosses the quadrangle just north of its center, passing between Jabals al Khidar and Witidah. The fault trace coincides with a strong magnetic lineament and is flanked on the northeast side along the valley of Wadi Jufrah by the Jibalah(?) formation. Apparently it is a tear fault, separating folded and thrusted Hadiyah formation on the south from folded Hibshi on the north. The small lateral offset of the pre-Hibshi unconformity suggests that most of the fault movement consisted of differential movement within the Murdama on opposite sides of the fault.

A second transcurrent fault trends northwest through the gap between Jabals Hibshi and al Khidar and terminates on the southeast against the monzogranite pluton. The Hibshi formation is offset about 3 km in a left-lateral sense. Left-lateral offset is actual, not apparent; vertical dikes in quartz diorite in the Harrat al Hutaymah quadrangle to the north are also offset in a left-lateral sense (J. S. Pallister, oral commun., 1983).

The transcurrent faults apparently belong to the late Precambrian northwest trending Najd system. Movement on the faults probably occurred in several episodes, including pre-Jabaylah movement, as discussed by Delfour (1977).

Other faults

A steep fault trends north-northwest between Jabals Musawdayyah and At Tin, separating the upthrown Qarnayn sandstone on the east from the downthrown Hibshi formation on the west. Considerable shearing has produced a strong vertical foliation in the Hibshi conglomerate along this fault.

Steep strike faults occur in places along the Hibshi formation strike ridge. On the west side of Jabal Hibshi, the plane of a reverse fault dips 72° east, and green coarse-grained sandstone is thrust over older conglomerate.

METAMORPHISM

The amphibolite and schist northwest of Jabal al Khidar is the oldest rock unit in the Samirah quadrangle and has the highest metamorphic grade. The mineral assemblage hornblende-oligoclase-epidote-quartz and the well-developed schistose and gneissic foliation in most of the rocks indicate synkinematic regional metamorphism of amphibolite grade.

Metamorphic grade of the Qarnayn sandstone and rocks of the Murdama group is lower greenschist facies, indicated by a matrix mineral assemblage of fine-grained sericite, chlorite, epidote, and quartz. Greenstone interlayered with clastic rocks in the Hadiyah formation contain mafic minerals replaced by calcite, epidote, and tremolite-actinolite; a matrix of epidote and calcite encloses relict plagioclase crystals that are albitized in some places but that remain calcic in others. Sedimentary textures and structures are well preserved in the rocks; the principal kinematic effect of the low-grade metamorphism is development of fracture cleavage in sandstone and slaty cleavage in siltstone and shale.

A contact-metamorphic aureole as much as 1 km wide surrounds plutons that intruded the Murdama group. The rock commonly is of a darker shade than similar rocks outside the aureole, and slightly more indurated. Sedimentary textures are partly preserved, but in siltstone and shale randomly-oriented red-brown biotite, muscovite, and tremolite-actinolite are present. In one sample of shale taken 50 cm from the granite-Hadiyah contact at Jabal Qutn, the rock is entirely recrystallized to fine-grained quartz, muscovite, biotite, and cordierite.

SUMMARY OF GEOLOGIC HISTORY

The major events in the geologic history of the Samirah quadrangle are summarized below. Several radiometric ages are cited; additional ages, particularly those of all the major plutons, would more accurately establish the chronology of events and perhaps lead to revision of their relative order, as outlined below.

(1) Deposition of basalt and interbedded sediments.

(2) Regional synkinematic metamorphism of basalt and sediments to amphibolite grade.

(3) Successive intrusion of the metamorphic terrain by monzogranite, quartz monzodiorite, and quartz diorite plutons. The quartz diorite has a U-Pb zircon age of 646±4 Ma (C. Hedge and J. Cole, personal commun., 1982).

(4) Deposition of Qarnayn sandstone and limestone pebble conglomerate.

(5) Deposition of the Murdama group. The Hibshi formation includes a basin-margin, coarse-grained clastic facies that interfingered with the deep-basin fine-grained clastic rocks of the Hadiyah formation to the east. A Rb-Sr age on felsic volcanic rocks in the Hibshi is 637 Ma (Delfour, 1977).

(6) Northwestward-directed compression, folding and thrusting the Murdama group; transcurrent faulting. Deformation probably began early in the depositional history of the Murdama, resulting in coarse clastic wedges derived from erosion of the uplifted Hadiyah formation interbedded with the Hibshi.

(7) Emplacement of rhyolite and quartz latite flows and hypabyssal(?) rocks in the western part of the area.

(8) Successive intrusion of large plutons of quartz monzodiorite, granodiorite, and monzogranite; the last-named was dated at 616± 10 Ma (C. Hedge, written commun., 1982).

(9) Intrusion of syenogranite and alkali-feldspar granite plutons. The Jabal Qutn granite is dated by Rb-Sr method at 579±4 Ma (C. Hedge, written commun., 1982).

(10) Renewed movement of southern transcurrent fault.

(11) Deposition of Jibalah(?) formation.

(12) Renewed movement on southern transcurrent fault.

ECONOMIC GEOLOGY

Metallic minerals

Minerals of potential economic value occur in several localities in the Samirah quadrangle. Most of these are in quartz veins in the Hadiyah formation and were mined in ancient times for their content of native gold; several such deposits are described by Mytton (1970). The following descriptions are based largely on studies recently made by C. W. Smith (written and oral commun., 1982-3) who discovered additional mineral localities, and who has extensively sampled most localities for assay.

An Najadi (MODS 01277)

The northern end of an area of very extensive workings extends into the southern margin of the Samirah quadrangle. North-trending dacitic(?) dikes are in close proximity to a complex network of quartz veins in silty limestone of the Hadiyah formation. The veins were worked principally for gold, although small amounts of galena, sphalerite and chalcopyrite also occur, together with pyrite.

Agob (MODS 01271)

Extensive ancient workings striking north explored Hadiyah formation rocks for about 600 m. Gold is present but amounts are not known.

Ar Rahail (MODS 03272)

Ancient workings in Hadiyah formation clastic rocks follow an aplite dike that is poorly exposed at the surface. The rock contains small amounts of gold, according to C. W. Smith.

Wudayy (MODS 03273)

Quartz veins in Hadiyah formation clastic rocks at the southern end of a granodiorite pluton contain gold, as much as 18 grams per ton, according to C. W. Smith. There are no ancient mine workings in the vicinity.

Khidar (MODS 03270)

Ancient workings in carbonate beds of the Hadiyah formation are associated with slag piles indicating smelting operations. Copper-stained gossans were noted by C. W. Smith, and traces of gold and silver were reported by Mytton (1970).

Jufrah (MODS 03271)

Near Wadi Jufrah, a line of boulders of heavy, brownish-black ironstone trend N. 60° W. several hundred meters parallel to a major fault and to the strike of vertical beds of the enclosing Jibalah(?) formation. The rock has a calcareous matrix and is probably a replacement vein. One sample was analyzed and contains about 50 weight percent Fe_2O_3, probably limonite that may have formed by alteration of magnetite. The strong magnetic lineation parallels the vein and the fault, but no ironstone was found elsewhere along it.

An Nimriyah South (MODS 03274)

Small outcrops of calc-silicate skarn occur in a large quartz monzodiorite pluton; possibly the skarn is from a stoped block of Murdama group rocks. The rock is sparsely mineralized with copper oxide, pyrite, and galena, according to C. W. Smith.

Hebairiah (MODS 01265)

Small workings are found along a northeast-trending quartz-sulfide vein just south of a small diorite plug (Mytton, 1970). Host rock is carbonate-rich Hadiyah formation. Mine dumps are quartz gossan stained by copper oxides. One assay of dump material reported moderate gold values, about 5 grams per ton.

Meshaheed (MODS 01266)

Ancient workings consisting of pits and trenches are scattered over an arcuate area about 5 km long in which sandstone, siltstone, and greenstone of the Hadiyah formation are hydrothermally altered. Alteration is particularly intense adjacent to a small diorite plug. Quartz veins 50 cm or so thick contain small concentrations of pyrite, stibnite, and gold.

Asha North (MODS 03275)

Small ancient workings were opened along a N. 55° W.-trending pod of white quartz adjacent to a thin altered porphyry sill. East-trending calcareous shale and siltstone of the Hadiyah formation are cut by small north-trending faults. Some quartz samples were found by C. W. Smith to contain about one gram per ton of gold.

In summary, the mineral deposits of potential economic value in the rocks of the Hadiyah formation have several features in common. Ore mineral concentrations tend to occur

where numerous small quartz veins or pods cut carbonate-rich rocks. Deposits also tend to occur near small to large dioritic, quartz dioritic, and granodioritic intrusive igneous bodies. This relationship was previously noted by Kleinkopf and Cole (1983) in the Al Jurdhawiyah area and by du Bray (in press). Generally, there appears to be no obvious association between major faults and most mineral deposits.

Nonmetallic minerals

Mafic dike rock is being mined in the eastern part of the quadrangle for road metal in the construction of the paved highway between An Nimriyah and Al Fawarrah. Alluvial fan gravels, and, to some extent wadi sand and silt, are used for road fill along the same highway.

DATA STORAGE

Mineral localities described in this report are entered into the Mineral Occurrence Documentation System (MODS) data bank and are identified by a unique 5-digit number. Inquiries regarding this data bank may be made through the Office of the Tehnical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah.

Field and laboratory data used in this report are filed as USGS-DF-03-13.

REFERENCES CITED

Baubron, J. C., Delfour, J., and Vialette, Y., 1976, Geochronological measurements (Rb/Sr; K/Ar) on rocks of the Arabian Shield, Kingdom of Saudi Arabia: Bureau de Recherches Geologiques et Minieres (Saudi Arabian Mission) Technical Record 76 JED 22, 152 p.

Bramkamp, R. A., Ramirez, L. F., Brown, G. F., and Pocock, A. E., 1963, Geologic map of the Wadi ar Rimah quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Miscellaneous Geologic Investigations map I-206A, scale 1:500,000.

Brown, G. F., Layne, N., Goudarzi, G. H., and MacLean, W. H., 1963, Geologic map of the northeastern Hijaz quadrangle, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-205A, scale 1:500,000.

Brown, G. F., and Jackson, R. O., 1960, The Arabian Shield: International Geological Congress, 21st, Copenhagen 1960, Proceedings, Sec. 9, p. 69-77.

Bureau de Recherche Geologiques et Minieres, 1966, Airborne magnetometer - scintillation counter survey, Sheet 67.

Carmichael, I. S. E., Turner, F. J., and Verhoogen, J., 1974, Igneous petrology: New York, McGraw-Hill, 739 p.

Cole, J. C., in press, Reconnaissance geology of the Al Jurdhawiyah quadrangle, sheet 25/42 D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources map series. scale 1:100,000.

Delfour, J., 1970, The J'balah group, a new unit of the Arabian Shield: Bureau de Recherches Geologiques et Minieres (Saudi Arabian Mission) Report 70-JED-4, 31 p.

Delfour, J., 1976, Geology of the Nuqrah quadrangle (25E), Kingdom of Saudi Arabia: Bureau de Recherches Geologiques et Minieres (Saudi Arabian Mission) Report 76-JED-3, 167 p.

Delfour, J., 1977, Geology of the Nuqrah quadrangle, sheet 25E, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-28, 32 p., scale 1:250,000.

du Bray, E. A., in press, Reconnaissance geology of the Jabal al Silsilah quadrangle, sheet 26/42 D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral

Resources map series, scale 1:100,000.

Greene, R. C., 1984, Stratigraphy of the Murdama formation between Afif, Halaban, and As Sawadah, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 84-327, (IR)SA-622.

Greenwood, W. R., 1973, The Ha'il arch--a key to the Arabian Shield during evolution of the Red Sea rift: Saudi Arabian Directorate General of Mineral Resources Bulletin 7, 5 p.

Greenwood, W. R., Anderson, R. E., Fleck, R. J., and Roberts, R. J., 1980, Precambrian geologic history and plate tectonic evolution of the Arabian Shield: Saudi Arabian Directorate General of Mineral Resources Bulletin No. 24, 35 p.

Hadley, D. H., and Schmidt, D. L., 1980, Sedimentary rocks and basins of the Arabian Shield and their evolution, in Evolution and mineralization of the Arabian-Nubian Shield: King Abdulaziz University, Faculty of Earth Science, I.A.G. Bulletin No. 3, is. 4, p. 25-50; published by Pergemon Press, New York.

Kleinkopf, M. D., and Cole, J. C., 1983, Geologic interpretation of geophysical data for the Wadi al Jarir and Al Jurdhawiyah quadrangles, 25/42 C and D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-03-01, 29 p.; also, 1983, U.S. Geological Survey Open-File Report 83-371.

Letalenet, J., 1974, Geology and mineral exploration of the Jabal al Murdama quadrangle, 23/43 A: Bureau de Recherches Geologiques et Minieres (Saudi Arabian Mission) Report 74-JED-10, 35 p.

Mytton, J. W., 1970, Reconnaissance for mineral deposits in the Precambrian rocks of the Wadi ar Rimah quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Saudi Arabian Project Report 121, 75 p.; also U.S. Geological Survey Open-File Report (IR) SA-121.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, no. 1, p. 1-33.

U.S. Geological Survey and Arabian American Oil Company (Aramco), 1963, Geologic map of the Arabian Peninsula: U.S. Geological Survey Miscellaneous Geological Investigations Map I-270 A, scale 1:2,000,000.