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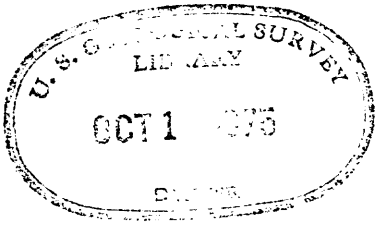

RECONNAISSANCE GEOLOGY OF THE WADI SA'DIYAH QUADRANGLE, SHEET 20/40A KINGDOM OF SAUDI ARABIA

by

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ILLUSTRATIONS

is metasedimentary rocks, plunges south. Quartz monzonite in the crest of an antiform and along the projected trend of the synform implies that the quartz monzonite is syntectonic. Northwest-plunging lineations and the abrupt ending of some lithologic units by what could be structural closure indicate isoclinal folding in the layered rocks. Faults are numerous but most are of small apparent displacement.

Total-intensity aeromagnetic data are available for the map area, and a study of the data does not reveal any magnetic features that conflict with the known geology. None of the magnetic anomalies warrant extensive investigations.

No mineral deposits of economic importance were found. A small ancient gold mine near the southern border is on a quartz vein 5 m thick which is exposed for 50 m at the surface. A sample across a 10 cm width of the vein contained less than 1 ppm gold and silver. Samples from other veins also contained low metal values, and 290 spectrographic analyses of representative rocks did not reveal any significant anomaly patterns.

INTRODUCTION

The Wadi Sa'diyah quadrangle (fig. 1), bounded by lats 20°30' and 21°00'N. and longs 40°00' and 40°30'E., lies about 125 km southeast of Jiddah and comprises slightly more than 2,800 sq km. The terrane is mountainous; local relief is commonly several hundreds of meters and along the Red Sea escarpment in the northeastern part of the quadrangle is as much as 1,200 m. Elevations range from about 150 m near the southwestern corner of the quadrangle to about

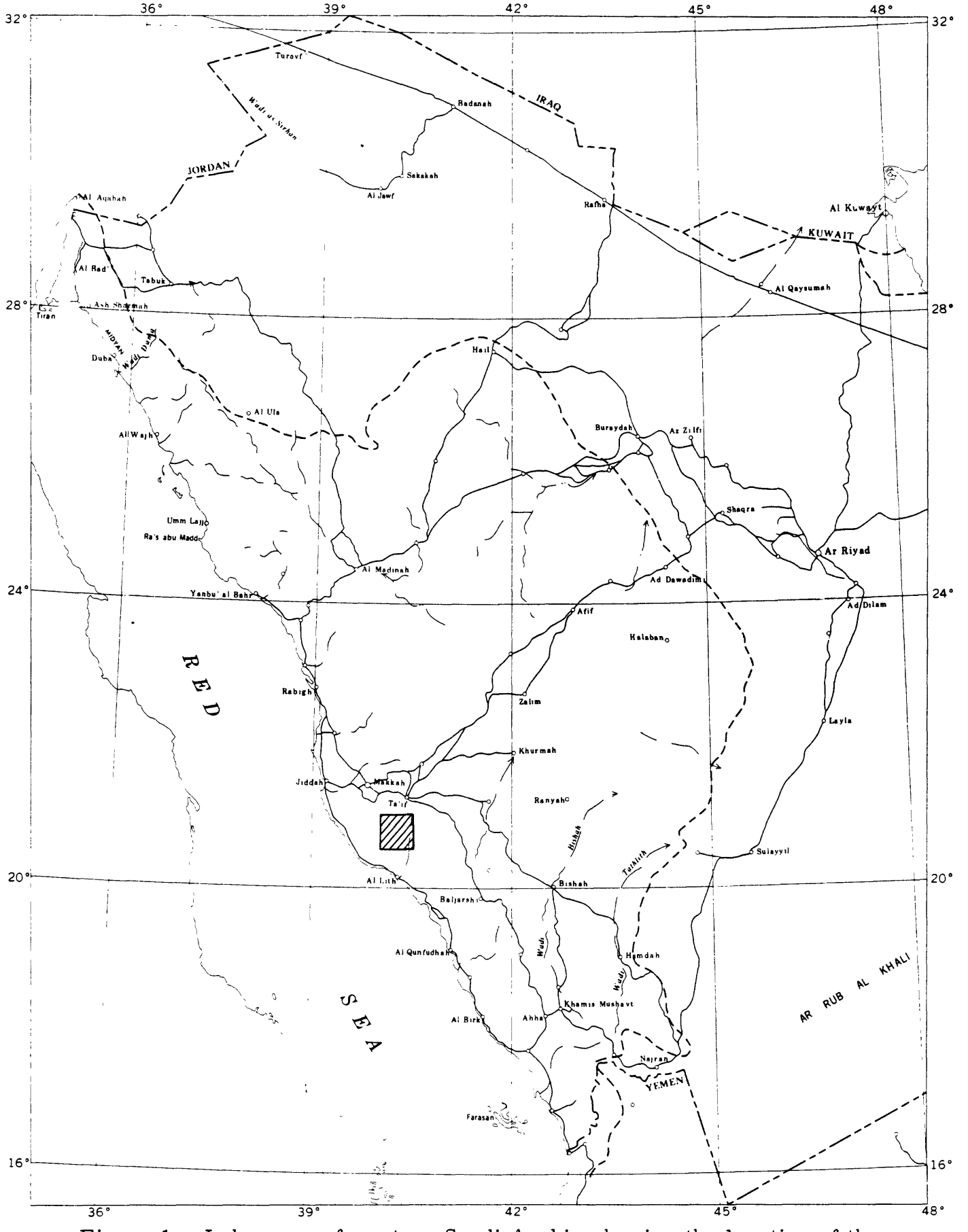

Figure 1. - Index map of western Saudi Arabia showing the location of the Wadi Sa'diyah quadrangle.

2,050 m at the crest of Jabal Jūdah in the northeast part.

The mapped area is part of the headwater region of the erosional escarpment which is related to the arching and tilting of the Arabian Shield and the downwarping of the Red Sea trough. The quadrangle is dissected chiefly by three wadi systems: Wadi Sa'diyah which trends southwest diagonally across the northern part; Wadi al Lith and several of its major tributaries (Wadi Birayn, Wadi Dhara', and Wadi Khasr) in the southeast part; and Wadi Sa'yah and Wadi Khadrah and their tributaries in the southwest part. In most places bedrock is well exposed. Soil cover is thin or absent in the mountainous areas; only locally, where eolian deposits are extensive or where wadi surfaces are covered by alluvium, is bedrock obscured. There are no established roads but vehicles can be driven along the major wadis. Except for dwellings bordering agricultural land on top of the escarpment, no permanent settlements lie within the quadrangle, and virtually the entire population consists of bedouins.

A small warm spring, 'Ayn ad Darakah in Wadi Sa'yah discharges water from a single vent in wadi alluvium at a rate of approximately half a gallon per minute at a temperature of 40°C and a pH of 6-1/2 (White, Donald E., 1970, personal commun.).

Geologic mapping was done from March into May, 1973, mainly with helicopter support, although Land Rovers were used for transportation along some of the large wadis in the southeastern part of the quadrangle. The southern part was mapped in further detail by D. G. Hadley in October 1973. During the spring of 1973, the quadrangle adjacent to the east was mapped by F. W. Cater. These geologic studies are part of a mapping program being conducted by

the U. S. Geological Survey in accordance with a work agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

The various rock units shown on plate 1 were delineated chiefly by observations made on helicopter traverses or by color and textural differences as distinguished on aerial photographs. In places the geology is much generalized and some units outlined in the central part of the quadrangle were not examined on the ground. Classification of intrusive rocks was based mainly on stained feldspar determinations on rock slabs.

The only previously published geologic information of the Wadi Sa'diyah area is the 1:500,000 scale geologic map of the Southern Hijaz quadrangle by Brown and others (1962). They described the rocks within the Wadi Sa'diyah quadrangle, from oldest to youngest, as: (1) the "Wadi Lith series," a complex of metadiorite, metagabbro, and amphibolite, typically retrograded to greenschist metamorphic facies and granitized by gneissic granite; minor slate and quartzite; commonly intruded by granite; (2) "Amphibolite schist", derived largely from volcanic rocks, minor sericite schist, marble, and quartzite; commonly intruded by granite; (3) "Diorite and granodiorite", generally gneissic and contaminated by migmatic xenolithic metamorphic rocks, and (4) "Granite and granite gneiss", largely derived from granitization of schists and volcanic rocks; contains numerous inclusions and xenoliths. Unconformities were noted between the "Wadi Lith series: and the "Amphibolite schist" and below the "Diorite and granodiorite" units.

PRECAMBRIAN ROCKS

Metavolcanic and metasedimentary rocks

Southwest and central parts of quadrangle

Metavolcanic and metasedimentary rocks (pl. 1) extend from the southwestern to the north-central part of the quadrangle. These rocks are not contiguous to rocks of similar composition and probable age elsewhere in the quadrangle. In the central and north-central areas the rocks crop out as several narrow, 1/2 km-wide bands as much as 9 km in length. Near the southwestern edge of the quadrangle the rocks are conspicuously layered and consist mainly of dark-colored metabasalt and chlorite and amphibolite schist of probable volcanic origin interlayered with lesser amounts of light-colored quartz-mica schist and quartzose chlorite-mica schist of probable sedimentary origin. Individual beds range in thickness from a meter or so to several tens of meters, but color or compositional banding within beds may be as narrow as 1 cm. Some beds seem continuous along strike for several kilometers, but others apparently terminate abruptly and may form the ends of tight folds. Strong fold axis lineations plunge at low angles mostly southward, but in a few places northward. Folds in these layered rocks may be more abundant and complex than was revealed by the reconnaissance mapping.

The layered strata are parts of a southward plunging synform and an antiform whose axis is near the west side of the quadrangle. The synform is cored by metasedimentary rocks that consist predominately of dark-colored quartzose conglomerate and gray, dense felsic quartzite. The conglomerate contains grayish-white pebble-size

clasts, commonly 2 to 3 cm in diameter, in a dark-gray matrix. In places the clasts are slightly deformed, being either elongated along the lineation direction or flattened parallel to foliation. The conglomeratic character of the rock is obscure on newly fractured surfaces, but is clearly seen on weathered or sand-blasted surfaces. Thin sections reveal a rather homogeneous mosaic of abundant recrystallized quartz and sparse feldspar grains, commonly 0.1 to 0.2 mm in diameter, and accessory mafic minerals.

The quartzite is rather impure and locally resembles graywacke in composition and appearance. It consists chiefly of quartz and feldspar grains, about 0.5 to 1 mm in diameter, scattered in a finer-grained matrix of quartz and feldspar. Mica and pyrite are common accessory minerals and in places the quartzite is heavily pyritiferous. Euhedral quartz and tabular feldspar crystals were seen in some thin sections, suggesting that felsic tuffs may be part of the metasedimentary unit.

Metavolcanic rocks east of the metasedimentary rocks make up the eastern limb of the synform, but they are different than the layered amphibolitic strata of the western limb. They are uniformly light to medium gray, not conspicuously layered, of intermediate rather than basaltic (amphibolitic) composition, and contain only sparsely interbedded sedimentary rocks. Nevertheless, the synformal structure indicates the two bodies of metavolcanic rocks are stratigraphically equivalent.

Southeast part of the quadrangle

In the southeast part of the quadrangle two main areas of metavolcanic rocks are separated by intrusive rocks (pl. 1). The meta-

volcanic rocks consist chiefly of gray and greenish-gray flow rocks, tuff, and agglomerate of intermediate composition. Basalt is present in minor amounts. Flow rocks range from dense and fine grained to porphyritic in which phenocrysts are generally less than several millimeters in diameter. Ellipsoidal structures, usually more or less sheared and vaguely defined, were observed in a few places. Tuffaceous rocks generally are strongly sheared and commonly consist of crystals and fragments of quartz and feldspar that range from less than a millimeter to several millimeters in diameter, scattered in a fine-grained quartz-feldspar matrix. Clasts in the agglomerate consist mainly of nonbasaltic rocks and range from one to several centimeters in size. Except for several minor occurrences of gray quartzite, metasedimentary rocks are not associated with the metavolcanic rocks in the southeastern area.

Most apparent trends and strikes of the metavolcanic rocks are northeasterly; dips are steep, but the beds are tightly folded in a number of places. Locally the intensity of folding is shown by strong fold axis lineations which generally plunge northeastward at low angles. The apparent 10-12 km width of the metavolcanic belt may reflect repetition by isoclinal folding rather than great original thickness of the volcanic strata. The metavolcanic rocks in this part of the quadrangle are uniformly metamorphosed to the greenschist facies.

Northeast part of the quadrangle

Near the northeast corner of the quadrangle the metavolcanic and metasedimentary rocks trend generally northeastward and consist mainly of flow rocks, agglomerate, tuff, and marble. Metavolcanic

rocks include porphyritic and dense fine-grained flow rocks, agglomerate, slaty greenstone, and tuff. Beds range from several meters to several tens of meters thick, but because of probable complex folding the actual thickness of individual layers is difficult to determine. The rocks are chiefly light to dark greenish gray and predominately of intermediate composition.

Dark amygdaloidal basalt of minor occurrence is exposed along the southern part of the area. Clasts in the agglomerate commonly are 1 cm or so in diameter but range in size up to blocks 0.5 m or more. Some of the tuffaceous and slaty rocks are strongly sheared.

Discontinuous linear marble bodies of various sizes, some several tens of meters thick and a kilometer or more long, are scattered throughout the metavolcanic rocks. The marble is grayish white with a faint finely-laminated color banding of different shades of gray interspersed with sparse but conspicuous, irregular, grayish-black layers that range from about a millimeter to several centimeters wide. On weathered surfaces more resistant siliceous seams accentuate apparent bedding; probable algal structures and faintly preserved mud cracks were observed at several places. The marble is dense and fine grained; most crystal grains are about 0.1 to 0.2 mm and only a few are 0.4 mm or more in diameter. In a few places the marble is bordered by finely banded buff to light-gray or dark-gray cherty quartzite, but the quartzite is generally only a meter or two thick and does not persist along strike.

The metavolcanic rocks generally strike parallel to the linear trends of the marble beds, and dip steeply. The distribution of the marble in the metavolcanic rocks suggests complex folding, and, if

the marble represents a single thin stratigraphic unit, the total thickness of these rocks probably is small.

As in the southeast part of the quadrangle, the metavolcanic rocks are regionally metamorphosed to the greenschist facies.

Correlation

The metavolcanic rocks in the quadrangle include flow rocks, tuff, and agglomerate and are predominantly of intermediate composition. Marble is interbedded with metavolcanic rocks in the northeast and north-central parts of the map area. Small remnants of marble also are present in mixed rocks of a diorite complex in the east central part, but is absent in the metavolcanic rocks in the southeast part of the quadrangle. Metasedimentary rocks, other than marble, are associated with metavolcanic rocks abundantly only in the southwest and central area. The three general areas of metavolcanic and metasedimentary rocks are separated by intrusive rocks or the mixed complex of metavolcanic, metasedimentary, and intrusive rocks so that contact or stratigraphic relationships are uncertain. Considering the intricate distribution of the marble beds and local isoclinal folding of some metavolcanic strata, the layered rocks may be so deformed and folded that their aggregate thickness in the quadrangle may be less than 10,000 m.

The metavolcanic and metasedimentary rocks cannot be assigned with any great assurance to specific stratigraphic units recognized by Schmidt and others (1973) for Precambrian rocks in the southern part of the Arabian Shield. Lithologically, the layered metavolcanic and metasedimentary strata in the quadrangle resemble the Baish and Jiddah Groups as those units are described by Schmidt and others (1973, pages 6-7), but the results of the mapping do not justify definite correlations.

Intrusive rocks

Biotite-hornblende gneiss

Two bodies of biotite-hornblende gneiss are exposed along the north edge of the quadrangle. Most of the gneiss ranges from granodiorite to quartz monzonite in composition, commonly consists of as much as 30 percent dark mafic minerals, and is only slightly gneissic. It contains tabular feldspars as long as 2 cm locally, but the typical texture is medium grained, slightly cataclastic, and hypidiomorphic-granular. Mineral constituents vary commonly in the range of 10-15 percent quartz; 30-40 percent plagioclase; 15-25 percent potassium feldspar; 10-20 percent biotite; 5-15 percent hornblende; and accessory apatite, zircon, and iron oxides. The gneiss contains irregular patches and zones of less mafic material, and discontinuous stringers that commonly are less than 10 cm thick and oriented parallel to foliation of granitic pegmatite. Amphibolite inclusions of probable volcanic deviation are scattered in the gneiss, which indicates it is younger than the metavolcanic rocks. It is older than surrounding quartz monzonite that intrudes it, but the age of the gneiss relative to other intrusive rocks is not known.

Diorite complex

A complex unit of diorite in which are abundant remnants of metavolcanic rocks underlies most of the southeast part of the quadrangle. Other intrusive rocks of the unit include gabbro, granodiorite, quartz diorite, diorite, quartz monzonite, granite and aplite. The various rocks commonly are intermixed with other metavolcanic and intrusive rocks and crop out as small bodies too small to be

classified and shown on plate 1. The older metavolcanic and metasedimentary rocks were intruded by younger rocks of the diorite complex. Large metavolcanic remnants measured in tens or hundreds of meters to small fragments only a few centimeters in diameter are common in the intrusive rocks. Many of the small inclusions have been almost completely assimilated and are now only vaguely defined mafic concentrations that grade into the normal composition of the various intrusive rocks. Remnants of the metavolcanic rocks are regionally metamorphosed to the greenschist facies but show little or no contact effects from the intrusives. Remnants and inclusions of metasedimentary rocks are scarce and, except for diopside observed along the border of a small lens of marble next to intrusive diorite, contact metamorphic effects also seem slight.

In the northern part of the quadrangle the contact between the diorite complex and the mixed unit of quartz monzonite, metavolcanic, and metasedimentary rocks is largely arbitrary. Both geologic units contain remnants and inclusions of metavolcanic rocks and biotite-hornblende gneiss, and the two are separated mainly on the distinction of whether rocks intrusive into them are predominately dioritic or monzonitic.

Diorite and quartz diorite

Diorite and quartz diorite are the most common types of intrusive rock in the southeast half of the quadrangle and occur both as discrete and arbitrary bodies. The separate bodies delineated on the map are predominantly diorite or quartz diorite which is more or less mixed with other intrusive rocks and metavolcanic rocks so that contacts are somewhat arbitrary. Mafic inclusions are common in the dioritic

intrusions and range from small areas of amphibolite to large blocks of recognizable volcanic rocks. In the southeastern part of the quadrangle, where large masses of metavolcanics and diorite-quartz diorite are in contact, the stoping effect of the intrusive has formed a "breccia" zone of metavolcanic fragments along the contact.

The dioritic rocks are gray to dark gray, range from medium fine to coarse grained, and commonly are massive and nonfoliated although in places they are slightly gneissic or foliated. Mineral composition varies greatly but commonly ranges from 40 to 65 percent plagioclase, as much as 10 percent potassium feldspar, 5 to 30 percent quartz, and 5 to 30 percent mafic minerals of which either biotite or hornblende may predominate. Accessory and alteration minerals include iron oxides, apatite, zircon, sphene, epidote, chlorite, sericite, and muscovite. Textures are mostly hypidiomorphic-granular to crystalloblastic, and in sheared and gneissic rocks are strongly cataclastic.

Granodiorite

Several widely separated bodies of granodiorite occur in the southeast ~~half~~ quarter of the quadrangle. Although predominately granodiorite most of the bodies are mixed with and locally grade into other types of intrusive rocks, especially diorite, quartz diorite, or quartz monzonite. In the vicinity of lat. 20°39'N. and long. 40°26'E., a small body of granodiorite intrudes metavolcanic rocks, but the other bodies lie within the diorite complex and the age of the granodiorite relative to the other intrusive rocks is not known. The granodiorite is generally lighter gray than the dioritic rocks, and ranges from medium fine to coarse grained and from nonfoliated

to gneissic. Mineral composition varies greatly but generally is on the order of 50-70 percent feldspar, 20-40 percent quartz, and 5-10 percent mafic minerals. Biotite is the most common mafic mineral, although hornblende locally may be more abundant. Hypidiomorphic textures are typical, and in places the granodiorite is granulated and intensely sheared.

Mixed quartz monzonite, granite, and metavolcanic and metasedimentary rocks

An irregular contact zone, as much as several kilometers wide, of quartz monzonite and granite mixed with metavolcanic and metasedimentary rocks, borders the quartz monzonite and granite batholith locally and is between it and the diorite complex. The zone extends from the southwest and west-central part of the quadrangle to the north-central border. The zone of mixed rocks was formed by stoping, contact metamorphism, and the incomplete assimilation of the layered metavolcanic-metasedimentary rocks by the intrusive quartz monzonite and the diorite complex. The mixed rocks are delineated as a map unit chiefly because of the presence of mafic inclusions and on the basis of their color contrast with adjacent and enclosing rocks. In many places the contacts are indefinite and, as shown, are quite arbitrary. The contact between the mixed zone and the diorite complex is especially arbitrary and was decided on the relative abundance of dioritic rocks versus the various lithologies of the mixed zone.

Mafic inclusions, chiefly amphibolite, within the mixed zone commonly decrease in size and number away from the bodies of metavolcanic-metasedimentary rocks. The inclusions range greatly in size

from small lenses a few meters in length to large masses measured in hundreds of meters. Many are linear, apparently because of the layered character of their parent source and the "lit-par-lit" injection of the intrusives. Individual inclusions range from distinct mafic bodies with cores of recognizable original material to vaguely defined aggregates of hornblende or biotite that grade into the enclosing intrusive rocks. Foliation and schistosity in the mixed zone are generally parallel or subparallel to bedding trends in the nearby metavolcanic and metasedimentary rocks.

In the northern part of the quadrangle the mafic inclusions may have been derived chiefly from biotite-hornblende gneiss which is exposed in two areas near the edge of the quadrangle. Locally, inclusions similar in appearance and composition to the gneiss form a "mega-breccia" in the mixed zone where blocks up to several hundred meters in diameter are engulfed in a quartz monzonite matrix. Between and south of the two exposures of gneiss, a number of large dark-colored areas within the quartz monzonite contain abundant schistose biotite-hornblende concentrations and are noticeably more mafic than the surrounding intrusive rocks. These dark areas probably represent inclusions or remnants of the biotite-hornblende gneiss that have been injected by and partially to almost completely incorporated into the intrusive quartz monzonite.

Quartz monzonite and granite

Most of the northwest part of the quadrangle is underlain by quartz monzonite and granite, the southern part of a batholith. The granite, of minor occurrence within the main body of quartz monzonite, was not mapped separately as the two are not easily distinguished in

the field. The two types of rock probably are different phases of the same intrusive pluton. Pre-intrusive rocks probably were mostly layered metavolcanic and metasedimentary strata, were displaced, engulfed, and partially assimilated, by the intrusive body so that the contact with the pre-intrusive rock is extremely irregular and complex. Several satellitic intrusive masses lie along the edges of the main intrusion, and separate bodies of quartz monzonite and granite occur in the eastern part of the quadrangle. The separate intrusive bodies are generally in sharp contact with adjacent rocks, but the main part of the batholith is bordered by a zone of mixed-layered rocks and intrusive rocks that in places is several kilometers thick. Mafic inclusions, probably derived mainly from metavolcanic rocks, are scattered throughout the batholith and are increasingly numerous toward the edges. The inclusions range in size from huge blocks hundreds of meters in diameter to pieces as small as several centimeters. They range from conspicuous lenses oriented parallel to contacts or foliation and clearly defined irregular shaped blocks to "ghost-like" aggregates of biotite and/or hornblende which have been partially absorbed into the intrusive rock.

The quartz monzonite and granite commonly forms smoothly rounded topographic surfaces and underlies most of the high mountainous areas. Quartz monzonite makes up about 90 percent of the main intrusion and most of the separate bodies elsewhere. The rocks are foliated or gneissic locally and commonly are strongly sheared and granulated. They are light gray, except where mafic contamination by numerous inclusions gives the rock an overall darker color. Locally, the feldspars are faintly salmon colored and the rock is grayish pink.

Much of the quartz monzonite is medium to coarse grained, massively porphyritic, and contains tabular feldspars as much as 2 cm long. Some of the finer-grained rocks have an average grain size of about 2 mm and are equigranular. Most feldspar crystals and quartz aggregates and grains are rounded.

Mineralogically, the quartz monzonite is highly variable; oligoclase generally is equal to or greater than potassium feldspar both of which account for 40-70 percent of the rock. Other minerals include 30-60 percent quartz, and mafic minerals, chiefly biotite or rarely hornblende, generally less than 5 but as much as 20 percent. Common accessory minerals include apatite, magnetite, leucoxene, sphene, and zircon. In places the rocks are slightly saussuritized or sericitized, and common replacement minerals are chlorite, sericite, biotite, and epidote.

Texture of the rock is chiefly hypidiomorphic-granular, modified locally by strong cataclasis and shearing.

Granite

Massive, medium- to coarse-grained granite intrudes the metavolcanic rocks near the southeast corner of the quadrangle and is exposed in several sill or dike-like bodies in the east-central part of the quadrangle. Mafic inclusions are common. These isolated outcrops may be related to the quartz monzonite intrusions, and in places the granite is foliated and graulated. The primary minerals are 30-40 percent undulose quartz, 45-55 percent perthtite, and 20-30 percent oligoclase (An_{15-20}). Accessory minerals include 3-8 percent biotite and hornblende, and minor amounts of magnetite, sphene, zircon, and apatite. The primary and secondary minerals are moderately

replaced by sericite, chlorite, and epidote. Texture of the rock is uniformly hypidiomorphic, except near fault zones where it is cataclastic.

Gabbro

Irregular bodies of gabbro intrude the diorite complex in the southeast part of quadrangle and quartz monzonite in the northwestern part of the quadrangle. Two varieties of gabbro were seen: dark-gray-black, coarse-grained, porphyritic gabbro with poikilitic pyroxene crystals up to 10 cm in diameter, and light gray, medium-grained equigranular gabbro that is megascopically indistinguishable from some of the diorite. Both varieties are largely altered to metagabbro and are strongly sheared locally. The least altered poikilitic gabbro consists of about 40-50 percent pyroxene (augite?), 30-40 percent calcic plagioclase (labradorite?), and as much as 20 percent olivine. The light-gray non-porphyritic gabbro is more felsic and generally consists of as much as 60 percent plagioclase, less than 50 percent pyroxene, minor olivine, and accessory quartz. Saussuritization of plagioclase, partial replacement of pyroxene by hornblende and micas, and serpentinization of olivine is widespread.

Gabbro occurs in several ways; some grades into or is in fault or shear with adjacent rocks so that age relationships are not clear. Fine-grained, chilled-textured gabbro next to diorite indicate a younger age, as does the outcrop pattern in the diorite complex. Intrusions of gabbro in quartz monzonite suggest the gabbro may be the youngest of the main intrusive rocks.

Mafic dikes and sills

Dikes of various compositions crop out throughout the quadrangle. In the southern part metabasaltic and metadiabasic dikes are numerous,

both as single dikes and swarms of dikes in the metavolcanic rocks, diorite and quartz diorite, and in the diorite complex. The dikes range from about 1 to 10 m thick, and, in the swarms, are irregularly spaced at intervals as close as several meters but usually from 10 to 50 m. Most of these dikes dip steeply and strike northeasterly parallel to the regional structural trend. Those in the metavolcanic rocks cannot always be distinguished from mafic flow rocks or possible sills. Most, if not all, are of Precambrian age, and some seem to be folded with the metavolcanic rocks, which, if so, are predeformation in age.

Leucocratic dikes and pegmatite

Leucocratic dikes composed chiefly of aplite, granite, granodiorite, and quartz monzonite dikes are sparsely scattered throughout much of the southern part of the quadrangle. The dikes are generally fine grained, less than a meter thick, continuous for not more than a few hundred meters, and variable in strike and dip. In several places medium-grained aplite dikes, up to 5 m thick, intrude dark mafic rocks irregularly at low angles so that surface expressions are conspicuous, and the dikes appear on aerial photos and from a distance as much larger than they actually are. Sill-like granitic bodies up to 50 m thick and hundreds of meters long are locally interlayered with the metavolcanic rocks, especially in the diorite complex. Many of these intrusive rocks are strongly sheared and may have been emplaced along zones of recurring fault movement.

Stringers, pods, and patches of coarse-grained granitic pegmatite are widely distributed through the main body of quartz monzonite in the northwestern part of the quadrangle. They vary

in size but generally are less than a meter thick, and are irregular, discontinuous, and both truncate and lie parallel to regional and local foliation of the intruded rocks. The pegmatite consists almost entirely of quartz and feldspar; locally, it contains minor amounts of mica. Some of the pegmatite patches gradually blend into and seem to have been derived from the immediately surrounding quartz monzonite.

TERTIARY ROCKS

Gabbroic dikes

Several Tertiary dikes of gabbroic composition trend northwest across the southern part of the quadrangle. The largest is 150-200 m thick. Because of resistant chilled borders and a coarse-grained easily eroded interior, the dike is marked by a large, trough like, linear depression. The dikes are of probable Miocene age as they are reversely magnetized and otherwise similar to gabbroic rocks in southwestern Saudi Arabia for which Brown (1972) reported an average K-Ar age of about 22 m.y. Other northwesterly trending gabbroic dikes that are not as continuous nor as thick, and shorter ones that trend in other directions, may also be of Miocene age, but some are not noticeably magnetized and seem more altered and may be Precambrian. In the north-central part of the quadrangle a northwesterly trending gabbroic dike 15 m thick is cut by a northeasterly trending meta-diabase dike that is 3 m thick.

QUATERNARY SURFICIAL MATERIAL

Alluvium and wadi terrace deposits

Alluvial deposits cover wadi surfaces and consist mostly of sand and gravel in the lower and wider reaches and coarse gravel and boulders in the upper reaches, where gradients are steeper. The

deposits are unconsolidated except along Wadi Dhara' in the southeastern part of the quadrangle where the alluvium is cemented by calcium carbonate for a distance of several hundred meters downstream from where the wadi cuts through metagabbro. The gabbro is the apparent source of the carbonate cement, and the hardened, cemented alluvium probably is still accreting. The present stream has cut into the cemented alluvium to a depth of 2 to 3 m.

Along Wadi al Lith, near the southeastern edge of the quadrangle, remnants of an older terrace deposit are preserved where they were protected from erosion in such places as the lee of rock outcrops, the inside curves of the stream bed, and along tributaries. The terrace material is a sandy silt of distinctive brown coloration and stands 2 or 3 m above the present wadi surface. The deposit probably resulted from a sudden influx of fine debris that choked the wadi and temporarily dammed the stream. The terrace deposits are a distinctive feature elsewhere in southwest Saudi Arabia but in the map area they have been eroded from other drainages except Wadi al Lith.

Eolian sand

Along the western part of the quadrangle wind-blown sand partially covers many of the low outcrops and is drifted along the bottom of some of the larger wadis. The sand is tan and fine grained. It forms complex dune fields; the individual dunes being lunate-semilunate and as much as 5 m high.

METAMORPHISM

All the volcanic rocks have been regionally metamorphosed to the greenschist facies, and the volcanic and sedimentary rocks within and adjacent to the main quartz monzonite intrusion have been raised

locally to amphibolite grade by contact metamorphism. Remnants and inclusions of mafic volcanic rocks have been altered to amphibolite and amphibole schists, and in sediments of appropriate composition mica, garnet, or staurolite crystals have formed. Most of the intrusive rocks also are metamorphosed and now are largely metagranodiorite, metadiorite, metagabbro, metadiabase, and metabasalt. The time of regional metamorphism is not known, but the metamorphism is probably related to one or more thermal events that predate the main quartz monzonite intrusion.

STRUCTURE

Gross geologic and structural trends in the quadrangle are northerly and northeasterly. In the western part strong fold axis lineations plunge predominately southward at low angles, and near the southwest corner a synform of metavolcanic rocks is cored with metasedimentary rocks and plunges south. A complimentary antiform is adjacent to the west. A few north-plunging lineations and abrupt ending of some lithologic units by what could be structural closures indicate subsidiary isoclinal folding in the metavolcanic and metasedimentary rocks. Elsewhere, the erratic distribution of marble in the metavolcanic rocks in the northeast part of the quadrangle and the scattered isoclinal folds observed in the metavolcanic rocks in the southeast part suggests that deformation may be more intense, complex, and widespread than is apparent from the map patterns.

Emplacement of quartz monzonite in the crest area of the antiform and as separate bodies along the projected trend of the synform axis implies that the quartz monzonite is syntectonic. The similar southward plunging lineations in both the quartz monzonite and layered

rocks, apparently related to the major structures, show that intrusion of quartz monzonite occurred early in the deformational history. Many of the intrusive bodies, and especially those in the diorite complex, are elongated northeast-southwest, which is also a common direction of shearing; the emplacement of intrusive rocks may have been controlled in part by persistent zones of structural weakness along which movement repeatedly occurred.

Faults are numerous, and most are of small apparent displacement. They strike in various directions but northeasterly and northwesterly trends are most common and all seem to dip steeply; no low angle reverse or thrust faults were recognized. In the east-central part of the quadrangle a long northwest-trending fault offsets geologic units and two northeast-trending cross faults with a left-lateral horizontal movement of slightly less than a kilometer. Many of the dikes were probably injected into fault or shear zones and now also mark faults. The large northwesterly trending gabbroic dike in the southwest part of the quadrangle, and probably some of the other similarly oriented gabbroic dikes, probably are localized in a flexure zone related to downwarping of the Red Sea trough and the uplift of the adjacent escarpment (Coleman and Brown, 1971).

Straight drainages, or straight segments of drainages, also probably mark faults; but because of no apparent displacement, they are not shown as faults on the map.

AEROMAGNETIC DATA

Total-intensity aeromagnetic data as unpublished contour maps, parts of a general 1966-67 aeromagnetic survey of the Precambrian Shield of Saudi Arabia, were available for inspection. Flight

traverses, at a mean flight-line spacing of 300 m and mean terrane clearance of 300 m, cover the quadrangle.

The large area of quartz monzonite in the northwest quadrant of the map produces a relatively flat, expressionless magnetic pattern that is typical of this type of rock. The pattern consists of low amplitude, medium to long wave-length anomalies of less than 100 gammas, some of which may be wholly or in part altitude induced, or they may reflect the mafic character of the metavolcanic rocks into which the quartz monzonite has intruded.

Rocks of the high ferro-magnetic character in the southeast half of the map reflect a more intense magnetic pattern. These areas of greater magnetic expression are characterized by positive-negative anomaly pairs, which, where normally polarized, are positive in the south and negative in the north. The individual anomaly pairs are interwoven into a complex pattern which makes it difficult to relate specific anomalies to specific rock exposures where mafic rocks lie next to or intrude rocks of low magnetic character such as the sharply anomalous and reversely magnetized gabbroic dike that trends northwestward in the southwestern part of the quadrangle. The larger exposures of gabbro can generally be distinguished as areas of more intense magnetic character. Anomalies related to these outcrops suggest that the intrusive gabbro bodies may be more extensive at depth than at the surface.

In general, the magnetic data grossly differentiate between the silicic and mafic rocks, but the complex geology in the areas of higher magnetic expression cannot be separated on the basis of the magnetic patterns. Overall, the aeromagnetic data does not conflict

with the known geology and none of the anomalies appear to warrant extensive investigation.

ECONOMIC GEOLOGY

No mineral deposits of economic importance were found nor are any likely to be located by further investigations. The only known evidence of mining activity is a small ancient gold mine in the vicinity of lat. 20°31'N. and long. 40°12'E. The mine working is about 15 m long, 5 m deep, slightly more than 1 m wide, and has been excavated along a mineralized quartz vein. The vein averages about 0.5 m thick and is exposed for 50 m on the surface, but does not seem to extend beyond the immediate vicinity. The mine workings are partly caved, but the lack of a mine dump indicates there was virtually no production. A sample taken across a 10 cm width of the most mineralized part of the vein analysed less than 1 ppm gold and silver.

During part of the time the geologic mapping was being done, Ghanim Jeri Alharbi, a mineral prospector for the U. S. Geological Survey Saudi Arabian project, searched accessible wadis by four-wheel-drive vehicle. He traced mineralized quartz float to gold bearing quartz veins at two different localities in the central part of the quadrangle. At one of these localities, in the vicinity of lat. 20°38'N. and long. 40°19'E., a discontinuous quartz vein, averaging about 0.5 m thick, strikes northeast and dips 10°- 20°SE. The vein is only partly mineralized and contains chiefly megascopic iron oxides, chalcopyrite, galena and sparse flakes of native gold. In one place the vein contains massive barite and calcium carbonate.

A sample from the richest part of a mineralized zone of the vein analysed 0.5 ppm gold, 75 ppm silver and 700 ppm copper. The other locality is near lat. 20°45'N., long. 40°19'E. where another partly mineralized quartz vein averages about 1 m thick, trends northeasterly, and dips 10°- 20°SE. A sample taken across a width of several centimeters, from a strongly mineralized part of the vein, analysed about 2 ppm each for gold and silver and 1.5 percent copper. Neither vein was traced out on the ground, but as observed from helicopter both were discontinuous and extended for only a few hundred meters along trend.

Much of the quartzite in the metasedimentary rocks in the southwestern part of the quadrangle contains disseminated pyrite, but of several samples of the rock only one showed slightly anomalous gold and silver values.

Spectrographic analyses were made of approximately 290 representative samples of the various rock types, which included: 35 metavolcanic rocks; 25 metasedimentary rocks; 80 gabbros and diorites; 130 granodiorites, quartz monzonites, and granites; and 15 dike rocks. Analyses conformed to those expected for the various lithologies and revealed no significant anomaly patterns. Metal values vary widely and maximum amounts, mainly from the mafic rocks, are: 100 ppm cobalt; 2,000 ppm chromium; 500 ppm nickel; and 1,000 ppm vanadium. Several of the rock types contain 50 ppm each of copper and lead. Tin was detected in only one sample, and that was 100 ppm from an aplite dike.

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