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TO ACCOMPANY MAP GM-27

RECONNAISSANCE GEOLOGY OF THE WADI SALIBAH QUADRANGLE, SHEET 20/40 B, KINGDOM OF SAUDI ARABIA

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CONTENTS

Abstract.— With the exception of some probable Tertiary basalt dikes, all the rock in the Wadi Salibah quadrangle (sheet 20/40 B) are of Precambrian age. The layered supracrustal rocks comprise a sequence of medium- to high-grade metamorphic rocks and the Baish and Jiddah Groups (Schmidt and others, 1973). The medium- to high-grade rocks crop out in the east and south-central parts of the quadrangle and consist of amphibolite, hornblende gneiss, and quartzite to the east; to the west, marble and mica schist predominate. The medium- to high-grade metamorphic rocks may be older than the Baish Group but this is not known with certainty. They probably represent locally metamorphosed portions of the Baish or younger groups (Greenwood and others, 1975). The Baish Group trends northeast across the northwest corner of the quadrangle and consists almost entirely of metabasalt and marble. Between the medium- to high-grade metamorphic rocks to the southeast and the Baish Group to the northwest is a northeast-trending belt of the Jiddah Group, consisting largely of flow and volcaniclastic rocks of intermediate composition; basaltic and sedimentary rocks comprise part of the Jiddah Group but are not abundant. All of the rocks have been highly folded, but the medium- to high-grade rocks in particular have been plastically folded and have undergone repeated metamorphism and intrusion. The Baish and Jiddah Groups have been metamorphosed only to the greenschist facies.

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More than half the area of the quadrangle is underlain by intrusive rocks that range in composition from peridotite to granite, but quartz monzonite is most abundant. With the possible exception of some granite orthogneiss and peridotite that are not in contact with rocks of the Jiddah Group, all the intrusive rocks are of post–Jiddah age. With the exception of the granite orthogneiss and foliated quartz monzonite, the intrusive rocks are only partly gneissic, particularly along their borders, and some are entirely massive, with unsheared contacts. Many of the intrusions are linear and seem to have been intruded along fault zones, some of which have also been active since intrusion.

Two gross structural trends are evident in the quadrangle: to the east, where the medium– to high–grade metamorphic rocks crop out, the regional trend is northerly; to the west, in the area underlain by the Baish and Jiddah Groups, the trend is northeasterly. Folds along both trends may plunge either north or south, but north plunges seem to predominate. The rocks are much sheared and faulted; faults strike in all directions, but most of the larger ones strike northeast, north, or northwest. Lack of strong tectonic deformation in the younger intrusive rocks indicates that the area has been relatively stable since Precambrian time, except for broad epeirogenic movements such as those associated with the Ha'il arch (Greenwood, 1973), other central Arabian structures (Brown, 1972, Powers and others, 1966), and uplift which caused the formation of the Red Sea escarpment.

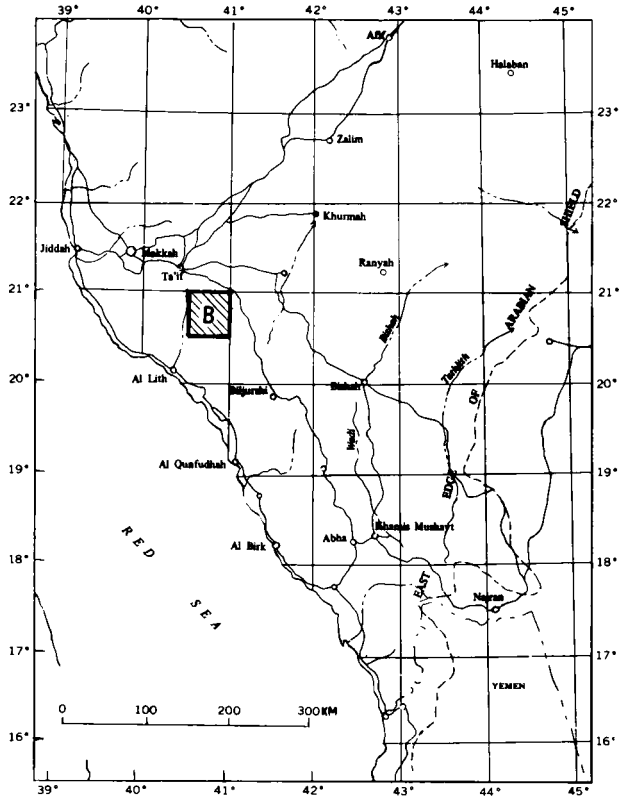

FIGURE 1.—Index map of western Saudi Arabia showing the location of the Wadi Salibah quadrangle (shaded).

INTRODUCTION

The Wadi Salibah quadrangle (sheet 20/40 B), about 140 km southeast of the city of Jiddah, between lat 20°30′ and 21°00′ N. and long 40°30′ and 41°00′ E., has an area of about 2,840 km^2(fig. 1). It lies astride the Red Sea escarpment, which trends northwesterly across the quadrangle from the southeast corner to the north–central edge. Erosion of the escarpment has produced extremely rugged topography and local relief of more than 1,500 m; the triangular area above the escarpment consists of only low mountains. Elevations range from 220 m near the southwest corner to 2,300 m near the edge of the escarpment. The area above the escarpment is served by roads. The entire area is underlain by Precambrian rocks, except for a thin veneer of alluvium in some wadi bottoms and a few alluviated upland areas that are farmed.

Brown, Jackson, Bogue, and MacLean (1963) mapped the area as part of the 1:500,000–scale map of the Southern Hijaz quadrangle. The present report is based on fieldwork conducted in the spring of 1973 by the U.S. Geological Survey in accordance with its work agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

METAMORPHIC LAYERED ROCKS

MEDIUM– TO HIGH–GRADE METAMORPHIC ROCKS

Medium– to high–grade metamorphic rocks crop out in a number of linear zones in the east of the quadrangle, where they alternate with zones of biotite–quartz monzonite. They also crop out in contact with the younger Jiddah Group in the south-central and central parts of the quadrangle. The rocks consist of amphibolite, hornblende gneiss and schist, mica schist, marble, and quartzite. Hornblendic rocks predominate in the east of the outcrop area; interlayered with these are some impure quartzite and quartz, plagioclase, microcline, and biotite gneiss. The hornblendic rocks appear to be derived from a sequence of mafic volcanic rocks,

but the quartzite is of sedimentary derivation. In the south–central part of the quadrangle, the rocks are predominantly marble; mica schist; and quartz, plagioclase, biotite, and garnet gneiss; here also is at least one layer about 100 m thick of gneiss containing abundant coarse blades of kyanite as much as 3 cm long. The kyanite is randomly oriented in the plane of foliation of micaceous gneiss and constitutes 10–30 percent of the rock. The medium– to high–grade metamorphic rocks contain granoblastic, lepidoblastic, and cataclastic textures, and in this area are derived from a sedimentary, probably a miogeosynclinal, sequence. The rocks are the only medium– to high–grade regionally metamorphosed rocks in the quadrangle, although others, either as inclusions or near contacts of intrusive rocks, have been raised to high metamorphic grades. The medium– to high–grade sequence has undergone extreme deformation and is characterized by highly appressed and complex folds; because of this, the thickness of even the exposed units cannot be deciphered, but the original thickness of the rocks must be measured in thousands of metres.

Neither the nature nor the exact position of the contact between the medium–to high–grade rocks and Jiddah Group in the center of the quadrangle was determined. The sporadic and local occurrence of rocks believed to be of the Jiddah Group enclosed by the medium– to high–grade rocks suggests that the contact is greatly deformed. Delineating the contact is also complicated by the fact that the numerous post–Jiddah intrusions in the area have raised the metamorphic grade of the Jiddah locally to amphibolite grade, approximately equal in metamorphism to the medium– to high–grade metamorphic sequence. For the most part, no original textures or sedimentary features are preserved in the medium– to high–grade rocks which have been retrogressively metamorphosed in many places; conceivably some amygdaloidal metabasalt thought to be of the Jiddah Group may, in fact, belong to the medium– to high–grade metamorphic sequence.

BAISH GROUP

The names "Baish" and "Jiddah" used in this report are believed to correlate with those regional units listed by Schmidt and others (1973) in a synthesis of the stratigraphy of the Precambrian rocks of southern Saudi Arabia.

Rocks believed to be of the Baish Group trend northeasterly across the northwest corner of the quadrangle. The Baish is separated from the Jiddah Group by intrusive rocks, and hence contact relations are not known here, but elsewhere the contact is unconformable. Only a small part of the total thickness of the Baish crops out in the quadrangle, but this part is hundreds of metres thick. The group consists almost entirely of metabasalt and white marble in this area. Volcanic features are generally well preserved except where shearing is prevalent. Much of the marble is in large isolated blocks engulfed in diorite and quartz diorite; these marble blocks show minimal contact metamorphic effects. The basaltic rocks are metamorphosed to the greenschist facies.

JIDDAH GROUP

The Jiddah Group occupies a northeast–trending belt of linear masses separated by intrusive rocks that lie between the medium– to high–grade metamorphic rocks to the southeast and the Baish Group in the extreme northwest corner of the quadrangle. The name "Jiddah Group" is used in this report in the sense employed by Greenwood (1975) in the Al 'Aqiq quadrangle. The group consists mostly of volcanic tuff, agglomerate, and flows of intermediate composition, but contains a few conglomerate beds and some basaltic and a few fine–grained, almost cherty, quartzitic layers. Original volcanic textures and sedimentary features are generally well preserved. The thickness of the Jiddah is not known but must be several kilometres. The group has been regionally metamorphosed to the greenschist facies, locally, adjacent to some of the intrusions, metamorphism has reached the amphibolite facies. The rocks are tightly folded and in many places are sheared; in general, deformation is more concentrated in the tuffaceous layers.

INTRUSIVE ROCKS

More than half the Wadi Salibah quadrangle is underlain by intrusive rocks comprising a diversity of plutons that range in composition from peridotite to granite. All the plutons except those of peridotite are younger than the Jiddah Group. No peridotite plutons are in contact with the Jiddah. Although the plutonic rocks were probably intruded during a number of widely separated episodes, as were similar rocks elsewhere in the Arabian Shield, the lack of younger supracrustal rocks or of radiometric dates precludes a precise grouping. The older intrusives, however, tend to be linear and gneissic, or to have gneissic or sheared margins, though

some are massive; the younger intrusives are massive and structureless. Many of the intrusions are notable for vast numbers of inclusions ranging up to blocks a kilometre or more in length. Dikes of various compositions and trends are numerous and widespread, and except for some basalt dikes of probable Tertiary age, these too are Precambrian.

GRANITE ORTHOGNEISS

An irregular mass of fine-grained light-colored granite orthogneiss, believed to be the oldest intrusive rock in the quadrangle, crops out near the center of the quadrangle. The orthogneiss intrudes the gneiss, schist, and marble of the medium- to high-grade metamorphic sequence, but seems to have undergone the same degree of deformation and recrystallization. Foliation in the orthogneiss is conformable to foliation in the enclosing metamorphic rocks, but the orthogneiss cuts across the compositional layering of these rocks.

The granite orthogneiss consists of highly granulated and recrystallized aggregates of potassium feldspar, quartz, oligoclase, biotite, muscovite, and, less commonly, hornblende. The proportions of the constituent minerals vary considerably, but potassium feldspar is generally most abundant and constitutes nearly half of the rock; quartz and oligoclase are about equally abundant, and mafic minerals rarely exceed 5 percent of the rock.

PERIDOTITE

Three sizeable masses and numerous inclusions and larger blocks of peridotite that locally grade into pyroxenite crop out in the southeast of the quadrangle. All are engulfed in quartz monzonite and mafic quartz diorite. The rock is tough, erosion resistant, and forms rough hills that stand above the surrounding terrain. Most is nearly black and coarse grained, but the more highly altered variety is dark green, although the grain remains coarse. Peridotite consists of augite, olivine, and accessory magnetite; the pyroxenite is very largely augite with only accessory olivine. The peridotite has been partially altered to antigorite and magnetite, but locally near contacts with quartz monzonite, it has been converted to a mixture of coarse hornblende and some epidote. In the westernmost of the masses, pyroxenite grades into gabbro that here seems to be a facies of mafic diorite and quartz diorite; near the pyroxenite the gabbro is distinctly layered.

FOLIATED QUARTZ MONZONITE

The north end of a highly foliated mass of quartz monzonite extends into the southwest corner of the Wadi Salibah quadrangle. The pluton intrudes metavolcanic rocks of the Jiddah Group and in turn is intruded by a considerably deformed biotite-quartz monzonite. These relations, plus the fact that it is one of the most highly deformed intrusive masses in the quadrangle, strongly suggest that it is also one of the oldest intrusions.

The quartz monzonite is conspicuously foliated as a result of intense shearing; foliation planes are either flat or dip moderately east or west. The rock is nearly white or light gray, and mostly fine grained because of milling, but the least sheared rocks are medium grained. Potassium feldspar and oligoclase in roughly equal proportions make up 60–70 percent of the rock. Biotite, largely altered to chlorite, rarely exceeds 5 percent. Oligoclase is moderately saussuritized. Textures range from hypidiomorphic-cataclastic to mylonitic.

GABBRO

Several gabbroic masses crop out in the quadrangle, particularly in the northwest. The gabbro masses comprise two varieties: a highly mafic black, porphyritic type, and a medium-grained, gray, feldspar-rich type. The two varieties were not seen in contact and their interrelations are not known, but, locally, some rocks were seen to be more or less intermediate in composition. The black porphyritic variety is more abundant; it consists of about 50 percent augite, 30 percent labradorite (An_{65}), and 20 percent olivine. Most striking are the megacrysts of augite as much as 10 cm across that poikilitically enclose corroded grains of other augite, labradorite, and olivine. The felsic variety consists of about equal proportions of augite and labradorite (An_{58}) and about 10 percent olivine. The texture is coarsely ophitic. Olivine alters to antigorite and magnetite; augite to hornblende, mica, and chlorite; and labradorite to saussurite. Both varieties of gabbro range from unaltered and undeformed to highly altered and sheared.

The gabbro intrudes the Jiddah and Baish Groups, but is cut by nondeformed or slightly deformed diorite and by more alkalic and silicic intrusions. The age of the gabbro relative to the more deformed and older intrusions is not known.

DIORITE AND QUARTZ DIORITE

Diorite and quartz diorite crop out in numerous masses throughout the quadrangle, and in the west, where intricately mixed with gneiss, schist, marble, and various intrusive rocks, they form a large complex that is separately delineated on plate 1 and separately described. The rocks are younger than the gabbro but older than the biotite-quartz monzonite. In places they are gneissic; elsewhere, massive.

Most diorite and quartz diorite weather to dark reddish gray, but fresh surfaces are dark to medium gray. The large mass in the southeast of the quadrangle, however, is very dark and locally grades into gabbro. The bulk of the rock is medium grained but locally may be coarse grained. The composition varies considerably; the diorite consists of andesine (An_{35} – An_{47}), hornblende, and biotite, and, locally, some augite as essential minerals. In addition to these minerals, the quartz diorite also contains as much as 15 percent quartz and, locally, 1–2 percent potassium feldspar. Magnetite, titanite, and apatite are accessory; saussurite, chlorite, and epidote are alteration products. Generally, hornblende is the predominant mafic mineral, but, locally, biotite is much more abundant. Mafic minerals constitute from 25 to 35 percent of the rock. The massive varieties have hypidiomorphic textures, but in the gneissic varieties the textures are cataclastic and crystalloblastic.

COMPLEX OF DIORITE, QUARTZ DIORITE, GRANODIORITE, GABBRO, AND METAMORPHIC ROCKS

The extreme northwest of the quadrangle is underlain by a complex that consists mostly of diorite and quartz diorite but contains lesser amounts of granodiorite, gabbro, and metamorphic rocks. The metamorphic rocks belong mainly to the Baish and Jiddah Groups. The various rock types in the complex are intricately and intimately mixed within the diorite and quartz diorite matrix. The complex formed as a result of assimilation and stoping of volcanic (Baish and Jiddah Groups) and gabbroic rocks by intrusion of the intermediate plutonic rocks and later by smaller amounts of granodiorite. Inclusions of metamorphic rock range from those that are not noticeably affected by intrusion of diorite and quartz diorite to those that are almost indistinguishable from the intrusive rocks. Marble of the Baish Group is the most resistant to alteration, and forms a number of sharply bordered inclusions showing little or no contact effects.

LEUCOCRATIC QUARTZ DIORITE AND GRANODIORITE

Two masses of leucocratic quartz diorite and granodiorite crop out in the quadrangle. The larger one, in the extreme southwest corner of the quadrangle, extends to the south, and the other is an oval mass in the north–central part of the quadrangle. The larger mass intrudes the contact between the Jiddah Group and foliated quartz monzonite and granite; the smaller one intrudes the Jiddah and is cut off by quatrz monzonite and granite. The rock is fine to medium grained, massive, and white to light gray on fresh surfaces, but weathers red. It superficially resembles the younger granophyric quartz monzonite in outcrop, but, unlike the quartz monzonite, only the relatively scarce granodiorite contains appreciable potassium feldspar . The sparse biotite has largely altered to chlorite; the texture is mostly aplitic. The constituent minerals are andesine (An_{33}), quartz, rare potassium feldspar, and biotite. Most of the rock is considerably altered.

BIOTITE–QUARTZ MONZONITE

Biotite–quartz monzonite underlies much of the east half of the quadrangle, where it forms elongate, north–trending masses intruded largely into the medium– to high–grade metamorphic sequence. It extends northeastward into the Jabal 'In quadrangle, where Gonzalez (1973) called it "granite gneiss." Although most of the rock is quartz monzonite, local facies are granite or granodiorite. Much of the rock has a strong foliation that generally dips either vertically or steeply eastward; some of the rock is massive, and nearly structureless. The rock is red, pink, or gray, medium to coarse grained, and either equigranular or slightly porphyritic.

The rock consists of 40-60 percent oligoclase (An_{10}–An_{28}), 15–45 percent potassium feldspar (mostly perthitic microcline), and quartz in amounts ranging from 10 to 30 percent. Biotite and scattered grains of hornblende rarely constitute more than 10 percent of the rock. Titanite, opaque minerals, apatite, and zircon are accessory. Oligoclase, particularly in the more calcic cores, is slightly saussuritized in places, and mafic minerals are partly replaced by chlorite and epidote.

Although the quartz monzonite is closely similar in composition throughout the quadrangle, intrusion probably spanned a considerable period of time, for the rock forms a number of plutons, some of which clearly intrude others that are sheared and more highly deformed. Generally, the younger plutons are more massive, and contain numerous inclusions and stoped blocks hundreds of metres across, mostly of hornblendic rocks which are described separately below. Also present are gneissic quartz monzonite, gabbro, and peridotite from older intrusions. It was not practicable to outline these separate plutons on plate 1, but some of the larger stoped masses are delineated.

HORNBLENDE, AMPHIBOLITE, AND HORNBLENDE GNEISS

Hornblendite, amphibolite, and hornblende gneiss occur as inclusions and blocks, some of them as large as 2 km^2 in outcrop area, in the biotite–quartz monzonite in the south–central and southeast parts of the Wadi Salibah quadrangle. The rocks are dark; the hornblendite is nearly black and contrasts strongly with the enclosing biotite-quartz monzonite. Hornblendite is rather coarse grained with hornblende blades as much as 2 cm long forming a felted mass of crystals that may or may not exhibit preferred orientation. The hornblendite consists very largely of hornblende and contains only accessory plagioclase. Amphibolite and hornblende gneiss are medium grained and are compositionally similar, both containing hornblende and medium to calcic plagioclase in different proportions. Hornblende gneiss differs from amphibolite significantly only in the segregation of minerals as light and dark folia. Contacts of the inclusions with biotite–quartz monzonite are mostly sharp, but locally the contacts are gradational through a distance of a metre or two.

The origin of these rocks is not known with certainty, but they are probably derived from stoped masses of suitable composition from the medium– to high-grade rocks and Jiddah Group that have been modified by immersion in the biotite-quartz monzonite.

BIOTITE GRANODIORITE

Scattered through the quadrangle are numerous small irregular masses of biotite granodiorite, but the largest and most numerous of these are in the northwest. The rock is cut by the late quartz monzonite and granite and by dikes of granophyric granite and quartz monzonite but otherwise shows little effects of deformation and is unrecrystallized. For these reasons, the biotite granodiorite is thought to be one of the younger intrusive rocks.

The rock is remarkably uniform in appearance wherever it crops out. It is massive, medium grained, and gray. The composition, however, is rather variable; although most of the rock is granodiorite, locally it grades into quartz monzonite or to quartz diorite. Constituent minerals are andesine (mostly An_{35}), quartz, and potassium feldspar (mostly orthoclase), biotite, and, in places, hornblende; titanite, opaque minerals, apatite, and zircon are accessory. Most of the rock is fresh, but some replacement by epidote and chlorite can be seen in thin section. Andesine commonly shows many oscillatory zones, and textures are typically hypidiomorphic.

BIOTITE GRANODIORITE AND QUARTZ MONZONITE

An irregular northeast–trending pluton and two smaller masses of biotite granodiorite and quartz monzonite crop out in the west-central part of the quadrangle. They intrude rocks of the Jiddah Group; the larger pluton is cut off at its northeast end by quartz monzonite and granite. The rock is gray, medium grained, and massive except near its contacts, where it is foliated. The rock is composed of oligoclase or sodic andesine (An_{25}–An_{32}), quartz, microperthitic potassium feldspar, and biotite. Scattered hornblende crystals are visible in some of the rock, and titanite, magnetite, and apatite are accessory. Potassium feldspar is fresh, but the plagioclase is extensively saussuritized. Biotite forms clots of variously oriented crystals which seem to be pseudomorphous after earlier mafic minerals; some of the biotite has been altered to chlorite. The texture is hypidiomorphic, but mortar textures are also pervasive; and the smaller masses and the borders of the pluton are sheared.

The biotite granodiorite and quartz monzonite are older than the quartz monzonite and granite pluton, but their age relative to the other intrusive rocks is not known, inasmuch as they are not in contact. The relatively undeformed nature of the rock suggests that it is one of the younger plutons.

QUARTZ MONZONITE AND GRANITE

Quartz monzonite and granite form a number of roughly oval plutons that intrude the biotite–quartz monzonite. The rock, in general, rather closely resem-

bles the more massive parts of the biotite–quartz monzonite, but tends to be somewhat more porphyritic, lighter in color, and gray rather than pink or red. In the south of the quadrangle, the rock forms huge, smoothly rounded domes that tower over the surrounding country; elsewhere it forms rough, uneven surfaces.

The rock consists predominantly of perthitic potassium feldspar, which in the granites is at least twice as abundant as oligoclase; oligoclase (An_{15} – An_{25}) and quartz make up most of the remainder. Biotite and sparse hornblende rarely exceed 7 percent of the rock. Accessory minerals are magnetite, titanite, zircon, and apatite. Minor amounts of epidote, chlorite, and sericite partly replace the minor constituents. Textures are characteristically hypidiomorphic, variously modified by cataclasis. Much of the rock contains innumerable inclusions, ranging in size from those only a few centimetres across to huge stoped blocks hundreds of metres across. Most of the inclusions are hornblendic, but some of the larger ones consist of blocks of older biotite–quartz monzonite and metavolcanic rock.

COMPLEX OF GRANITE, QUARTZ MONZONITE, GRANODIORITE, GABBRO, AND AMPHIBOLITE

In the northwest of the quadrangle are a number of irregular masses consisting of intricate mixtures of all the rock types that occur in the general area. The masses are similar to the complexes formed mainly from diorite and quartz diorite, but contain many more rock types and are dominated by biotite granodiorite, quartz monzonite, and granite rather than diorite and quartz diorite. The source of the abundant amphibolite in these masses is not known, but these highly hornblendic rocks may be highly altered volcanic rocks of the Jiddah Group or hornblende gneisses derived from the medium– to high–grade metamorphic sequence.

GRANOPHYRIC GRANITE AND QUARTZ MONZONITE

One large and numerous small satellitic bodies of granophyric granite and quartz monzonite crop out in the northwest of the quadrangle; the large pluton is a linear northeast–trending mass about 20 km long, and the smaller intrusions are mostly dikes and irregular masses. The rock is hard and resistant to erosion, and the larger mass forms an extremely rugged and precipitous ridge. The rock is red to greenish gray, massive, fine grained, and has a granophyric texture. Quartz is the most abundant mineral, and much of it forms micrographic intergrowths with potassium feldspar. Oligoclase is commonly less abundant than the potassium feldspar, and biotite makes up less than 5 percent. The rock is variably altered, and in places biotite has been completely replaced by magnetite and muscovite.

DIKES

Many dikes of basalt, diabase, aplite, pegmatite, andesite, rhyolite, and granitoid rocks crop out in the quadrangle. Most of the mapped dikes (pl. 1) are basaltic and are believed to be of Tertiary age because they are unaltered and in places show columnar jointing normal to the attitudes of the dikes. Most of these strike northeastward, but some strike northwestward. Most other dikes, both mafic and felsic, follow similar trends or parallel the prevailing local structural trends. A few pods of quartz–potassium feldspar pegmatite cut biotite–quartz monzonite and granite in the northeast of the quadrangle.

STRUCTURE

The quadrangle lies astride two distinct structural units: (1) to the east, a unit of north–trending rocks more or less coextensive with the medium– to high–grade metamorphic rocks and the intrusive masses that cut them, and (2) to the west, a unit of northeast–trending rocks coextensive with the Baish and Jiddah Groups and accompanying intrusive rocks. Probably the layered rocks in both units have been repeatedly deformed, but evidence is distinguishable and incontrovertible for only two periods: a possible pre–Baish episode during which the medium– to high–grade metamorphic rocks were intensely deformed and metamorphosed to amphibolite grade, and a post–Jiddah episode during which the Baish and Jiddah rocks were highly folded and metamorphosed to the greenschist facies. Obviously, this latter event also involved the medium– to high–grade metamorphic rocks which may or may not be older than the Baish Group. Since the intrusion of the younger Precambrian igneous rocks the region has undergone no regional deformation other than epeirogenic disturbances that had little or no visible effect on the younger intrusive rocks—in other words, the region has been relatively stable during Phanerozoic time.

Although all the layered rocks are tightly folded, particularly striking are the spectacular and intricate

large- and small-scale folds so excellently displayed in the marble, schist, and gneiss in the south-central part of the quadrangle. Here the medium- to high-grade rocks describe a great northward-plunging antiform cored by somewhat foliated biotite-quartz monzonite. Both flanks of the antiform are marked by numerous closely appressed folds, along the axial planes of which huge masses of rock have been squeezed and sheared out. In all probability, the flanking rocks are similarly folded elsewhere, but the nature of the rocks is such that the folds are not so readily visible. Rocks of the Jiddah Group are also isoclinally folded and intricately crumpled, but deformation does not seem to have attained the extreme proportions so evident in the medium- to high-grade metamorphic rocks. The differing structural trends of the medium- to high-grade sequence and the Baish and Jiddah Groups may possibly represent a plate of the younger groups thrust over the more highly metamorphosed rocks, but, if so, the thrust plane is folded, and the rocks adjacent to the plane are annealed and recrystallized.

The rocks are extensively cut by numerous faults of small displacement and fewer faults of large displacement. Most of these may be grouped into three systems of northeasterly, northerly, and northwesterly trend. These systems have been repeatedly active, so that individual faults of any of the principal trends can cut faults of the other trends. Many of the older linear intrusions appear to have been injected along old zones of shearing, and in some of these zones shearing has continued after the intrusive rocks were emplaced. Most of the faults dip steeply.

METAMORPHISM

All the rocks except the youngest plutons have been regionally and, in places, contact metamorphosed. Rocks of the medium- to high-grade metamorphic sequence have all been raised to the amphibolite grade of metamorphism, producing hornblende, biotite, garnet, and kyanite gneiss and schist. Retrogressive metamorphism of the greenschist facies is noticeable locally. The Baish and Jiddah have been regionally metamorphosed to the greenschist facies, but locally rock of both groups have been contact metamorphosed to a higher grade. Metamorphism of the intrusive rocks is evident in recrystallization of the older intrusions and destruction of typical igneous features such as oscillatory and patchy zoning of plagioclase.

ECONOMIC GEOLOGY

Other than some quarrying of quartz monzonite and granite at the edge of the Red Sea escarpment in the north-central part of the quadrangle, no evidence of any mining activity was seen. Locally, small amounts of copper carbonate staining are visible in basaltic rocks of the Jiddah Group, but the staining is not extensive enough to warrant exploration. The thick layer of coarse-grained kyanite rock just east of the biotite-quartz monzonite core of the antiform in the medium- to high-grade sequence in the south-central part of the quadrangle, may have some potential value when the area becomes more accessible.

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