U.S. GEOLOGICAL SURVEY

SAUDI ARABIAN PROJECT REPORT 270

RECONNAISSANCE GEOLOGY OF THE AL LITH QUADRANGLE, SHEET 20/40 C, KINGDOM OF SAUDI ARABIA

by

Donald G. Hadley and Robert J. Fleck

U.S. Geological Survey
Jiddah, Saudi Arabia

1979

The work on which this report is based was performed in accordance with a cooperative agreement between the U. S. Geological Survey and the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

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

CONTENTS

Page

ILLUSTRATIONS

TABLES

RECONNAISSANCE GEOLOGY OF THE AL LITH QUADRANGLE, SHEET 20/40 C, KINGDOM OF SAUDI ARABIA

by

Donald G. Hadley and Robert J. Fleck

ABSTRACT

The Al Lith quadrangle (20/40 C) covers an area of approximately 2,897 km^2 along the Red Sea coastal plain between lats 20°00' and 20°30'N. and longs 40°00' and 40°30'E. Approximately the southwestern one-fourth of the quadrangle is covered by water of the Red Sea. Of the land portion, the northern two-thirds is underlain by Precambrian crystalline rocks, and Tertiary sedimentary rocks and mafic dikes. This area has elevations of as much as 620 m and is heavily dissected by wadis that drain toward the Red Sea. The southern one-third of the land area is covered by a variety of Quaternary deposits.

Precambrian layered rocks in the quadrangle include basaltic and andesitic volcanic rocks and interlayered sedimentary rocks belonging to the Baish and Jiddah groups. Tertiary conglomerate of probable Pliocene age constitutes the only other layered sequence in the area.

Precambrian plutonic rocks intruded the layered rocks during three espisodes and range in composition from gabbro and diorite to quartz monzonite and granite. Miocene gabbro dikes were emplaced into the older rocks during extensional tectonics associated with the opening of the Red Sea.

The layered rocks were folded and faulted along northeast- and north-trending axes during the early Precambrian Tihama orogeny, and were possibly deformed during two younger orogenies. The volcanic rocks in the area were regionally metamorphosed to the greenschist facies during one or more of the tectonic and plutonic episodes. In contact with some intrusions, the rocks have been metamorphosed locally to the amphibolite facies.

Three mineralized areas in the quadrangle warranted sampling and study. However, metallic elements at these localities are in concentrations too low to show any economic potential.

INTRODUCTION

The Al Lith quadrangle (20/40 C) covers an area of about 2,897 km^2 along the Saudi Arabian coastal plain between lats 20°00' and 20°30'N. and longs 40°00' and 40°30'E. (fig. 1).

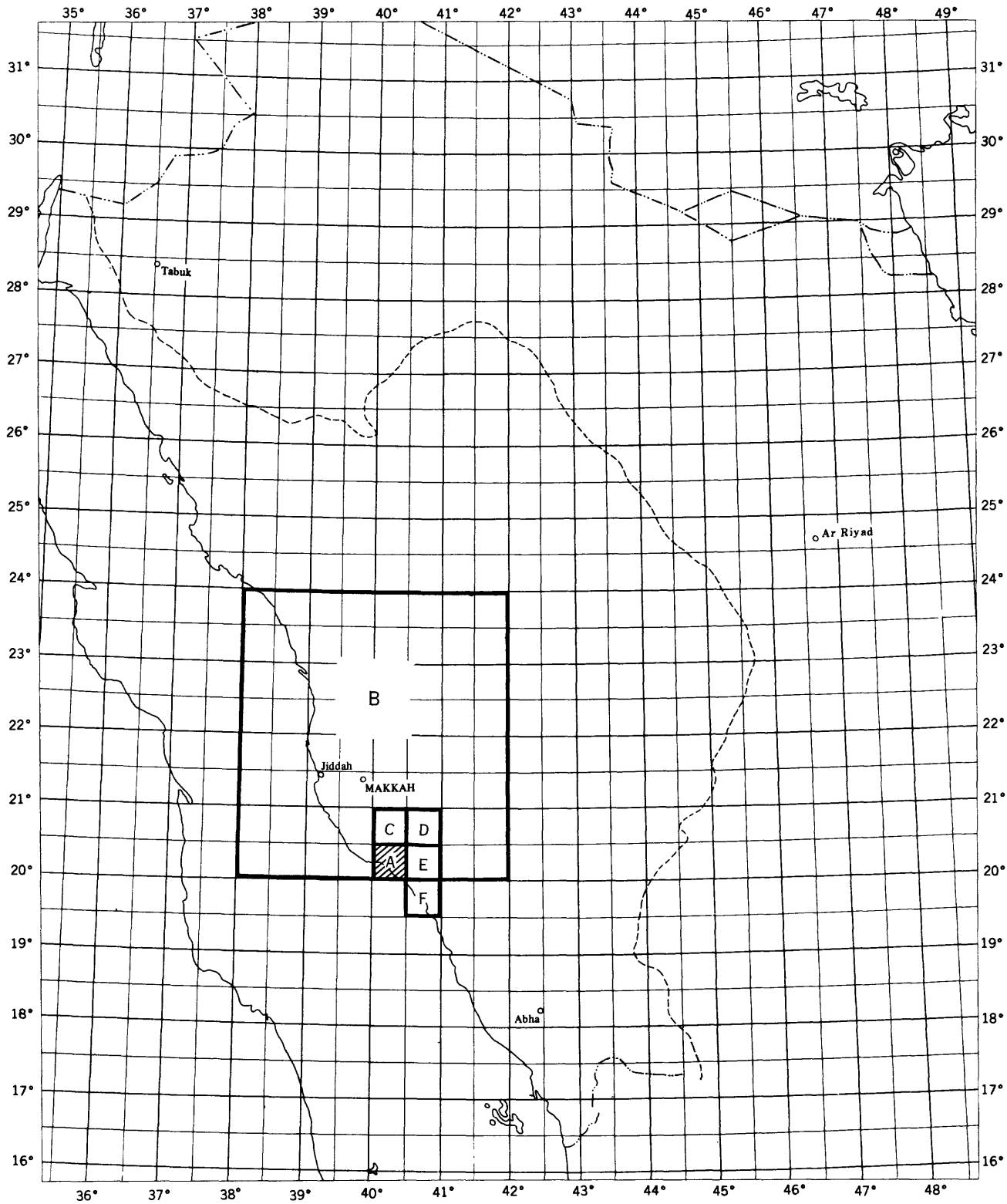

Figure 1.--Index map showing location of the Al Lith quadrangle, A, and adjacent quadrangles cited in this report: B, Southern Hijaz; C, Wadi Sadiyah; D, Wadi Salibah; E, Jabal Afaf; and F, Musaylim.

It is located approximately midway between Jiddah and Al Qunfudhah. The northern half of the area consists of rugged mountainous terrain dissected by several major wadis that flow toward the Red Sea in a southwesterly direction. The southeastern part of the quadrangle is an area of low relief covered by Quaternary deposits of several types, including alluvium, pediment and plain sand, gravel, and silt, and eolian dune fields. Nearly one-fourth of the area in the southwestern part of the quadrangle is covered by water of the Red Sea. Elevations range from sea level to as much as 620 m.

Two communities are found in the quadrangle: Al Lith, a fishing and trading village located on the Red Sea coast, and Ghumayqah, a small trading center located along Wadi al Lith in the east-central part of the area. Both villages are served by the paved road system that extends along the coastal plain from Jiddah to Jizan.

The geology of the quadrangle was first defined by Brown and others (1963) during the course of mapping the Southern Hijaz quadrangle at a scale of 1:500,000 (fig. 1). Subsequently, little geologic work was done in the area until 1972 when the adjacent quadrangle to the north was mapped at a scale of 1:100,000 by Wier and Hadley (1975). Other reports on nearby areas include the geology of the Jabal Afaf (Hadley and Fleck, 1979), Musaylim (Hadley, 1979), and Wadi Salibah (Cater, 1977) quadrangles.

Precambrian layered and intrusive rocks and Tertiary conglomerate and gabbro dikes underlie most of the northern half of the Al Lith quadrangle; unconsolidated Quaternary surficial deposits and coral reefs comprise the main exposures in the southern half of the area. The Precambrian layered rocks consist of volcanic and volcaniclastic rocks of the Baish and Jiddah groups. These are intruded by a wide variety of plutonic rocks that range in composition from gabbro and diorite to granite. Greenschist facies metamorphism characterizes the volcanic rocks and many of the intrusive rocks. Precambrian structural grain trends to the northeast and north and was formed during one or more periods of deformation. Deformation that began during late Miocene time and continued through the Pliocene, tilted the Bathan formation toward the Red Sea escarpment as a result of antithetic faulting.

Fieldwork for this report was done by helicopter during October, 1973. Logistical and personnel support were provided by the Directorate General of Mineral Resources and the U.S. Geological Survey. We specifically wish to thank Ghanim Jeri Alharbi, Yacob Essa Takrony, and Saud Muslih Ashaybani for assistance in the field and office. This work was done under a cooperative agreement between the Ministry of Petroleum and Mineral Resources of the Saudi Arabian Government and the U.S. Geological Survey.

PRECAMBRIAN ROCKS

Precambrian rocks underlie most of the northern half of the quadrangle and consist of two volcanic sequences, the Baish and Jiddah groups, and a wide variety of intrusive rocks including batholithic diorite and quartz diorite that extends into the northern portion of the quadrangle from the Wadi Sadiyah area.

Layered rocks

Baish group

The Baish group consists of volcanic flow rocks of basaltic to rhyolitic composition and associated stratified volcaniclastic rocks. It is divided into three units that are not named or defined as formations in this report. Exposures of the group are found in three belts in the east, central, and western portions of the mapped area, separated by zones of intrusive rock 10-15 km wide. The three units, divided on the basis of gross lithology, comprise 1) basalt, andesite, and subordinate interbedded volcaniclastic rocks, 2) volcaniclastic rocks and subordinate interbedded basalt and andesite, and 3) rhyolite and minor interbedded siliceous pyroclastic rocks.

Basalt, andesite, and subordinate interbedded volcaniclastic rocks.--The lowermost unit of the Baish group crops out in the extreme northeast part of the quadrangle astride Wadi al Lith, is exposed along the east-central edge, and is faulted against the upper rhyolite unit in the northwestern part of the mapped area from Jabal Abu Rawath northward to the edge of the quadrangle boundary. Throughout most of this outcrop area, the unit dips 50°-70° to the west and northwest.

Basalt and andesite are the dominant rock types, interbedded with which are subordinate volcaniclastic or pyroclastic beds of the same lithologic composition. In general, the rocks are strongly sheared and have been metamorphosed to the greenschist facies, but original textures, bedding, and flow features are recognizable at many outcrops.

The flows appear to range from 2 to 10 m in thickness. They are dark to medium green, fine to medium grained, and commonly porphyritic and amygdaloidal. Plagioclase phenocrysts are typically smeared out in the plane of schistosity, but in relatively nonsheared phases they are 0.3-1 cm long, and in some cases glomeroporphyritic texture is preserved. Amygdules are filled by quartz, calcite, epidote, or chlorite.

Volcaniclastic beds are a minor part of the lower unit. They include agglomerate and several types of tuffs, are various shades of green and gray, and are intensely sheared between the

more competent flow rock units. Bedding was rarely observed, but in a few cases beds were noted to be generally 5-10 cm thick. A blotched or mottled appearance is characteristic of the coarser-grained tuffs and resulted from sheared feldspars and lapilli fragments.

Basalt samples collected along Wadi al Faj have been dated by Rb-Sr radiometric techniques, yielding an age of 1165±110 m.y., with a $^{87}Sr/^{86}Sr$ initial ratio of 0.70289± 0.00003 (Fleck and others, *in press*).

Volcaniclastic rocks and subordinate interbedded basalt and andesite.--The middle unit of the Baish group crops out in two northeast-trending fold belts. The smaller of the two extends from Wadi Faj on the eastern edge of the quadrangle southwestward across Wadi al Lith to the edge of the road from Ghumayqah to Jiddah. The largest belt is approximately 8 km wide at its maximum point and is continuously exposed southwestward from Wadi Dhara, in the extreme northeastern part of this quadrangle, to Bir al Abdaliyah.

Compositionally, the rocks differ little from the underlying unit except for the proportion of volcaniclastic rocks, which is substantially greater than in the flow rocks. Agglomerate and lithic, crystal, and ashfall tuffs constitute an estimated 60-70 percent of the unit. The tuff beds are 10-15 cm thick where discernible, are various shades of green and gray, may be traced continuously, in some cases for as much as 20 m, and show a spotted appearance typical of the tuffs in this unit. Internal stratification and other textural features are invariably obliterated due to shearing.

Flow rocks of the unit consist of basalt and andesite. Individual flows are difficult, if not impossible, to recognize when they are stacked one on another. A hint of contacts in some cases is perceptible from amygdule concentration. Flow units are otherwise defined by the interbedded pyroclastic rocks. Due to concentrations of chlorite and epidote, dark green is the dominant color. Amygdules are abundant, are strongly sheared, and are filled by quartz epidote, chlorite, and calcite. Relict plagioclase phenocrysts are common in the andesite flows.

Rhyolite and minor interbedded siliceous pyroclastic rocks.--The uppermost unit of the Baish group consists of rhyolite and minor interbedded rhyolitic pyroclastic rocks. It is found in the extreme northwestern part of the area in a north-trending belt extending from sabkhah deposits along the Red Sea to the northern border of the quadrangle. Structurally, the unit dips about 75° west and is faulted on its eastern side against the lowermost unit of the Baish in the area.

Rhyolite and siliceous tuff are the principal rock types in the unit. The flows are light pinkish gray, very fine grained, contain common to abundant 1-3 mm potassium feldspar phenocrysts, and are strongly sheared in most cases. An accurate average thickness of the flows could not be determined; furthermore, because of their fine-grained character, which is true for the pyroclastic beds as well, flows could be distinguished from tuffs only with difficulty.

The pyroclastic beds are similar to the flows in most respects. Phenocrysts are less abundant, however, and evidence of stratification and bedding is more prevalent. Where undisturbed, beds are uniformly tabular and range from 3 to 10 cm in thickness.

Jiddah group

The Jiddah group crops out in an area just east of the central part of the quadrangle, in a rectangular belt extending from Bir Mutaybah northeastward to the fault that is in Wadi Bathan.

The Jiddah group is composed entirely of andesite flow rocks. Neither thicknesses of flow units nor measurable bedding could be determined in the area and it is assumed that the flows are several tens of meters thick. The rock is dark green and contains abundant saussuritized plagioclase phenocrysts set in a fine- to medium-grained felted intergranular groundmass. Chlorite and epidote, indicative of greenschist facies metamorphism of the group, are abundant. Amygdules are sparse.

Intrusive rocks

The age relationships of the intrusive rocks in the Al Lith quadrangle are discussed in part relative to the Ablah group as pre-Ablah, syn- to post-Ablah, and late Precambrian. This is based on the tentative correlation with intrusive rocks in the Jabal Afaf quadrangle (Hadley and Fleck, 1979) where the Ablah group is exposed.

Pre-Ablah intrusive rocks

Quartz diorite complex.--A complex of mafic to intermediate plutonic rocks crops out across most of the northern part of the quadrangle from fault juxtaposition with the middle unit of the Baish group in the east to Wadi Khadrah in the west. Several rock types are found in the complex, including quartz diorite, diorite, gabbro, tonalite, granodiorite, and quartz-monzodiorite, but these were not mapped as individual intrusive phases because of lack of time. The complex is equivalent to the diorite complex in the Wadi Sadiyah quadrangle (Wier and Hadley, 1975).

The various intrusive phases for the most part merge gradationally one into another; in some cases, however, sharp contacts can be identified. The phases range from fine to coarse grained, are generally medium grained, and range from dark to light gray. Porphyritic texture may be present locally. Hornblende is the chief mafic mineral in the dioritic phases. Biotite predominates in the more potassium feldspar-rich, leucocratic, and tonalitic phases. Mafic xenoliths ranging from 5 cm to several meters in length are common, particularly in the dioritic phases. The rock has a holocrystalline, hypidiomorphic, granular texture, is mostly equigranular, and is non-foliated except near faults.

Radiometric dating of the complex yields a whole-rock Rb-Sr age of 895±173 m.y. with an initial Sr^{87}/Sr^{86} ratio of .7025±.0003 (Fleck and others, *in press*). Because of the large standard deviation of this date, it should be considered tentative, but it is comparable to ages for other batholiths of similar composition and tectonic setting in the southern part of the Arabian Shield.

Granodiorite.--Granodiorite intrudes the quartz diorite complex in the northwestern part of the quadrangle in an area east of Wadi Khadrah and north of Wadi Basham. It is medium gray, medium grained, equigranular, holocrystalline, and hypidiomorphic in texture, nonfoliated, and contains 25-35 percent quartz, 30-40 percent plagioclase, 10-15 percent potassium feldspar, 4-8 percent hornblende, 2-5 percent biotite, and accessory chlorite, magnetite, epidote, apatite, and sphene.

Quartz diorite and gabbro.--An intrusive body composed of quartz diorite and gabbro crops out in the eastern part of the quadrangle northeast of exposures of the Jiddah group and between Wadi al Lith and the belt of rocks of the lower and middle units of the Baish group; also, in the north-central part of the mapped area from the western edge of rocks of the middle Baish unit, westward on either side of Wadi Lahyayn, to the contact with the granodiorite intrusion. Quartz diorite, gabbro, and minor diorite are the rock types found in the intrusion. They appear to grade from one type into another without any obvious contacts between them. The rock types are dark to medium gray, fine to coarse grained, holocrystalline, and generally massive textured but foliated adjacent to fault zones. Fine-grained mafic xenoliths were observed in many places.

Quartz diorite and diorite.--Quartz diorite and diorite intrude older plutonic units astride the northeastern border of the Al Lith and Jabal Afaf quadrangles. The rock is medium to dark gray, is coarse grained with strong porphyritic texture,

and has abundant moderately to strongly saussuritized plagioclase phenocysts as much as 1.5 cm long. Quartz is moderately to strongly undulose. Mafic and accessory minerals include 15-25 percent hornblende, 2-4 percent biotite, and a few percent epidote, opaque minerals, apatite, and chlorite. The intrusion is eroded to low relief in the Al Lith quadrangle but rises to elevations of 700 m in the Jabal Afaf quadrangle. It is intruded by a close-spaced maze of west-trending Precambrian mafic dikes that are as much as 2 m wide in places.

Syn- to post-Ablah intrusive rocks

Granodiorite.--An elongate body of granodiorite and numerous irregularly shaped satellite masses as much as a kilometer long intrude the quartz diorite complex and the quartz diorite and gabbro in the north-central part of the quadrangle. The elongate portion of the intrusion is moderately sheared. The rock is light pinkish gray, leucocratic, and texturally has 0.5 cm-long plagioclase and potassium feldspar phenocrysts set in a fine- to medium-grained matrix. It contains less than 5 percent ferromagnesian minerals strongly altered to chlorite and 2-5 percent accessory sphene, magnetite, epidote, and apatite.

Tonalite and granodiorite.--Tonalite crops out in a faulted body along the northeast edge of the quadrangle. It forms the southwest extension of a linear intrusion that is exposed mainly in the Jabal Afaf quadrangle. Quartz monzodiorite is a subsidiary phase. The intrusion is light pink, strongly porphyritic, and has microcline phenocrysts up to 3 cm long set in a medium-grained, strongly foliated, and cataclastic groundmass. The groundmass is stippled by 5-8 percent chloritized biotite and includes accessory sphene, magnetite, epidote, and apatite.

Quartz monzonite and granodiorite.--An irregularly shaped body of quartz monzonite and granodiorite is exposed as a large mass surrounded by a plain comprised of medium- to coarse-grained grus in the east-central part of the mapped area in the vicinity of Wadis al Lith and Bathan. The intrusion is medium grained, light pinkish orange, cataclastic, and intensely schistose. Ferromagnesian and accessory minerals include 2-5 percent biotite (moderately altered to chlorite), sphene, apatite, magnetite, and epidote. Cobble-sized mafic inclusions are sparsely distributed throughout the body.

Late Precambrian intrusive rocks

Quartz monzonite.--An intrusion composed chiefly of quartz monzonite, but containing subordinate granite, intrudes rhyolite of the Baish group in the extreme northwest corner of

the quadrangle. Contacts on both the east and west sides are faults. The rock is light gray to pink, fine to medium grained, and contains abundant tabular potassium feldspar grains set in a cataclastic equigranular groundmass. Plagioclase and potassium feldspar are about equally abundant and constitute 40-65 percent of the rock. Quartz that has strongly undulatory extinction makes up 30-50 percent, with 5 percent biotite, 1-2 percent hornblende, and accessory apatite, magnetite, and sphene. Feldspars and mafic minerals are weakly to moderately saussuritized and replaced by chlorite, sericite, and epidote.

Quartz diorite and tonalite.--In Wadi Basham, in the northwest part of the quadrangle, a mafic intrusion is exposed that intrudes the lowermost unit of the Baish group and several different pre-Ablah intrusive units. The intrusion is approximately 5 km long by 2.5 km wide. It is composed of tonalite, quartz diorite, and gabbro. The rock is dark gray, consists of smooth, rounded masses coated with desert varnish, is virtually unweathered, and breaks with sharp edges. It is fine to medium grained, is holocrystalline hypidiomorphic equigranular, and contains abundant unaltered biotite.

Quartz diorite.--Quartz diorite underlies Jabal Abu Sadi in the northwest quadrant of the mapped area. A grus plain that consists of medium- to coarse-grained fragments derived by mechanical erosion of the intrusion surrounds isolated inselbergs 1-2 km long. Weathering has produced pockets, caves, and a labyrinth of honey-combed surfaces. Chaotic masses of boulders ranging from 1-15 m in size litter the bases of the inselbergs. Rounded to angular masses of mafic country rock are common in most areas of the intrusion. The rock is very coarse grained, light to medium gray, porphyritic, and contains plagioclase phenocrysts 1-2 cm long, and 3-8 percent biotite. Undulose quartz and interstitial orthoclase make up about 25 percent and 3-7 percent of the rock, respectively. Accessory minerals constitute less than 5 percent of the rock and include sphene, zircon, magnetite, epidote, and apatite.

Granite and monzonite.--Granite and monzonite underlie Jabal Basham in the northwest quadrant of the quadrangle. The pluton measures 14 km by 10 km and at its highest point rises to 435 m above sea level. The rock is light pinkish gray and contains sparse orthoclase phenocrysts set in a fine-grained, hypidiomorphic equigranular groundmass. Sparse biotite (2-4 percent) is uniformly distributed throughout the groundmass. Primary minerals include quartz (5-40 percent), orthoclase (20-30 percent), microcline (5-10 percent), and moderately to strongly saussuritized plagioclase (20-30 percent). Apatite, magnetite, epidote, sphene, and zircon compose about 4 percent of the rock.

Granite.--In the extreme northeastern corner of the quadrangle, an irregularly shaped linear body of granite intrudes volcanic rocks of the Baish group, quartz diorite and diorite, and quartz diorite and gabbro. The rock is deeply weathered and as a result is very friable. It is medium grained, light pink to orange, and slightly porphyritic. About 75 percent of the essential minerals is feldspar, of which about two-thirds is kaolinized microcline and the remainder is heavily saussuritized oligoclase. Quartz makes up about 20-25 percent of the rock. Other minerals include 2-7 percent hornblende, about 2 percent biotite, and 1-3 percent magnetite, epidote, sphene, and apatite.

Quartz monzodiorite.--A small pluton of quartz monzodiorite crops out along the east side of Wadi Bathan about 2 km northwest of the quartz monzonite and granodiorite pluton. A small portion of the pluton is exposed along the opposite side of the wadi and the northeast side is faulted against the quartz diorite and gabbro body.

The rock is very light gray and has a strongly bleached character due to deep alteration. The bleached appearance is enhanced by the paucity of mafic minerals. Primary minerals include 10-20 percent undulose quartz, 15-25 percent potassium feldspar, and 55-65 percent plagioclase. The feldspars are strongly altered to kaolin and saussurite. Mafic and accessory minerals are hornblende and muscovite (1-2 percent), and magnetite, sphene, and epidote (less than 2 percent).

Dikes

Four sets of dikes intrude rocks of the quadrangle. Except for the mafic dikes, each set can be traced to its parent pluton. The oldest dikes are composed of granodiorite and are related to the elongate pluton of that composition in the northwest part of the quadrangle. The dikes generally trend north and northwest. They range from about 10 cm to as much as 1 m in width and in most cases can be traced for several hundred meters. They are fine grained, light pinkish gray, and have a positive relief relative to the host rock.

Late Precambrian granitic dikes intrude the granite and monzonite pluton at Jabal Basham and probably are late stage apophyses of that pluton. The dikes trend approximately west, are in places very closely spaced and commonly intersect, and range from about 15 cm to 2 m wide. They are fine grained, pink to orange, and contain less than 1 percent mafic minerals.

Mafic dikes composed of basalt, andesite, and diabase intrude three main rock types: the quartz diorite complex, the quartz diorite and diorite body, and the middle unit of the

Baish group. To a lesser extent, they also intrude the quartz diorite and gabbro. The dikes trend northeast, parallel to the foliation, in the Baish rocks, and primarily north and west in the intrusive bodies. They range in thickness from several centimeters to 2 m, and like some of the older dikes, can be traced for several hundred meters. Dike borders are fine grained and weather in positive relief; central portions are coarser grained and in some cases porphyritic.

Evidence bearing on the age of the mafic dikes is scant. At one locality, a mafic dike intrudes a granitic dike, establishing its younger age. This, together with evidence from mafic dikes elsewhere in the southern part of the Arabian Shield, suggests that dikes of mafic composition are generally late Precambrian. The mafic dikes, however, may be related to Phanerozoic, including Tertiary, volcanic events.

Rhyolitic dikes cross-cut the mafic dikes in the northwestern part of the area and are found only in the rhyolitic unit of the Baish group and in the quartz monzonite pluton that intrudes the Baish. The dikes appear to be genetically related to the quartz monzonite intrusion.

They are light orange and contain quartz and potassium feldspar phenocrysts 1-3 cm across, set in a fine-grained groundmass.

TERTIARY ROCKS

Bathan formation

The Bathan formation crops out adjacent to the confluence of Wadi Bathan and Wadi al Lith. The main body of outcrop strikes northwest and is 7 km long by 3 km wide. A smaller portion of outcrop, located 2 km southeast of the main area, is surrounded by flood-plain silt deposits of Wadi al Lith. The Bathan formation is named herein after Wadi Bathan. The exposures here were first described by Brown and others (1963). They concluded that the sequence was "dissected and not obviously related to present drainage" and that the formation may be much older than the Quaternary age that they assigned to it. The Bathan is herein assigned to the Pliocene for the following reasons: it bears no relationship to the Holocene drainage system; it is strongly indurated; it is moderately tilted; and it dips toward the Red Sea escarpment.

The Bathan is a terrigenous clastic sequence that consists of boulder conglomerate, pebble conglomerate, and sparse beds of coarse-grained sandstone. Detrital fragments consist of a wide variety of Precambrian rock types including most plutonic, metavolcanic, and metasedimentary rocks exposed in the area.

The formation contains beds that are commonly poorly sorted, graded bedding is common, plutonic clasts are rounded but those of other rock types are angular, plutonic clasts are as much as 1 m in diameter, and the formation is strongly indurated.

Deposition of the Bathan and its structural development are interpreted to be related to the Pliocene tectonics of Red Sea basin evolution, and simultaneous Pliocene uplift and faulting of the escarpment and development of the Red Sea axial trough.

Miocene gabbro

Miocene gabbro dikes extend across the quadrangle in a northwest direction from Wadi al Lith to the northern border and to the northwest corner of the area. The dikes are generally parallel, but commonly bifurcate and intersect one another. They range from 75 to 500 m wide, are medium to dark gray, and are fine to very coarse grained. Borders of the dikes are fine grained, and are more resistant to weathering than the coarse-grained centers that weather to U-shaped troughs.

Textures range from diabasic to gabbroic and ophitic. Poikilitic augite crystals, as long as 2 cm, make up 40-60 percent of the rock, followed in decreasing order by saussuritized labradorite (30-40 percent), olivine altered to serpentine (4-8 percent), magnetite (5-8 percent), chlorite (2-4 percent), and a little sphene.

The gabbro dikes are part of the dike swarm that parallels the Red Sea from the Yemen border to the Gulf of Aqaba (Brown, 1972; Coleman, 1974). Based on potassium-argon methods, the dikes range in age from 19 to 27 m.y. and average 22 m.y. (Brown, 1972). Several papers contain more detailed discussions of the geologic relations of the dikes; the reader is referred especially to papers by Blank (1978), Brown (1972), and Coleman and others (1979).

QUATERNARY DEPOSITS

Quaternary deposits include carbonate island sand, pediment and plain sand, gravel, and silt, alluvial sand and gravel, wadi flood-plain silt, sabkhah deposits, shallow bank and coral reef, and eolian dune sand. Age relations of the older and younger deposits seem fairly clear, but the age relations of the fluvial and pediment deposits are not well know. A systematic study of the sedimentology and chronology should be done and is justified on the basis of their importance to both water resources and agriculture.

Shallow bank and coral reef

The shallow bank and coral reef deposits are found along the coastal margins and surrounding islands. They are located in water depths ranging from about 0.5 m to 5 m and are as long as 1.75 km. The bank deposits are a mixture of calcareous and terrigenous muds. Grain size is medium and smaller.

Carbonate island sand deposits

Numerous small islands are found within 1-3 km of the main shoreline and range from 300 m to 1.75 km in length. They consist of fine- to coarse-grained calcareous sand composed of broken shell and coral fragments. Some are dotted with grasses of various kinds and larger woody shrubs, and are generally fringed by the Holocene reef.

Pediment and plains deposits

Extensive areas along the coastal plain are covered by pediment and plain deposits. These areas slope away from the main Precambrian outcrops, toward the Red Sea, range in elevation from near 100 m to 2 m above sea level, and are broken by exposures of Precambrian rock and by large areas of eolian sands. They are mostly flat, are hummocky in places because of sand mounded around desert shrubs, are dotted by sparse acacia trees, and are composed of poorly sorted, fine- to coarse-grained sand and gravel. Near outcrops, detritus is as coarse as boulder size.

Alluvial sand and gravel

Quaternary sand and gravel occupies all the major wadis such as Wadis al Lith, al Faj, Basham-Lahyayn, and Iyar, and their tributaries. The sediment consists of well-stratified, poorly sorted, unconsolidated sand, gravel, and cobble-sized detritus commonly showing well-developed graded bedding. The material is generally tan to brown but the color varies somewhat depending on the color of outcrops adjacent to headwater areas. In places, the alluvium is as much as 5 m thick, but the average thickness is less than 2 m.

Wadi flood-plain silt deposits

Within and marginal to the major wadis, there are extensive flood-plain deposits composed principally of silt, but which include some fine-grained sand and clay. The deposits are tan and commonly, though not always, well stratified. They average

about 1 m in thickness. The silt is over-bank material deposited in a low-energy regime adjacent to wadi banks and on high ground within wadis during stages of intermittent flooding.

Sabkhah deposits

Sabkhah deposits extend unbroken along the entire coastal length of the quadrangle. The deposits extend inland from the coastline as far as 6 km and consist of brown-to-white, flat-lying, salt-impregnated, crusty silt. A 1-3 cm crust characterizes the surface of the sabkhah in most places, beneath which the material is spongy and in places impossible to traverse. Total depth of the sediment is unknown but it has a minimum thickness of 20 cm. The mineralogy and chemical composition of the salt being precipitated was not determined.

Eolian sand dune fields

Eolian sand dune fields are extensive in the coastal plain area of the quadrangle. They constitute the youngest Quaternary material in the area, and are generally highly irregular in shape, but some have a linear form, which for the largest field (near Bir al Asaliyah) measures 2.5 by 10.5 km. The fields consist of tan, fine- to medium-grained sand in continuous sand hills that merge one into another to form areas covered by closely associated but isolated lunate dunes separated by flat, wind-deflated, barren ground. The dunes and hills are 2-5 m in height.

STRUCTURE

The Al Lith quadrangle forms part of the southern Arabian Shield structural block, a region characterized by tightly compressed upright isoclinal folding, greenschist- to amphibolite-grade metamorphism, and steeply dipping wrench faults of regional extent. In the Precambrian rocks of the Al Lith area, the two major structural trends are northerly and northeasterly. The most prominent of these is the northeasterly-trending block of Baish volcanic rocks extending from the northeast corner of the mapped area to the central part. Less prominent, because it is not as continuously exposed and because it is much intruded by the quartz monzonite and granodiorite, is the northeast-trending belt of Baish rocks in the east-central part of the quadrangle. Within these two belts, the Baish is monoclinally folded for the most part, has dips ranging from 55° NW. to vertical, and is offset by several steep northeast- and northwest-trending wrench faults. Volcanic rocks of the Jiddah group crop out between the two belts of Baish rocks and extend from Bir Mutaybah to Wadi Bathan. Because the Jiddah is younger than the Baish, it is most likely overturned where

it is in contact with the Baish near Wadi al Faj. The structural habit of the Jiddah could not be determined, however, as the andesite flows are massive and bedding plane contacts or other features that would indicate the attitude of the volcanic rocks were not observed.

In the northwest area, on either side of Wadi Khadrah, the Baish trends north, dips 55° W. to vertical, is intensely sheared, and is displaced by three north-trending wrench faults.

The Baish and Jiddah groups are the oldest rocks in the area. They were probably folded during the several periods of deformation that characterize the tectonics of the southern part of the Arabian Shield (Schmidt and others, 1973; Greenwood and others, 1976). Evidence for multiple folding is somewhat obscure in the quadrangle, but is suggested by small-scale folded schistosity and by variably oriented linear elements.

Precambrian layered rocks in the quadrangle appear to have been intruded during three periods by pre-Phanerozoic plutonic rocks and in some areas, such as Jabal Basham and in the vicinity of Wadi Ghalah, the layered rocks have been either totally engulfed by the intrusions or removed by erosion or both. The intrusive series believed to be the oldest because of its general composition and radiometric age (1165 ± 110 m.y.; Fleck and others, 1979) is the quartz diorite complex. It comprises part of four intrusive units probably intruded synchronously with the earliest period of deformation. All intrusions of this period are mafic to intermediate in composition.

The last two periods of intrusive activity include plutonic rocks of intermediate to granitic composition that were probably emplaced during late Precambrian syn- to post-Ablah orogenic or post-orogenic cycles. There are no radiometric data available for these intrusive rocks nor for layered sequences younger than the Jiddah group that could be used to determine more clearly the age relationships of the intrusions. The only significant evidence bearing on the age relations of these rocks is the sequence of intrusion, by which relative ages are established. Thus, the relative ages of most of the plutonic rocks are very tentative.

Tertiary plutonic and tectonic events in the quadrangle are recorded by the Miocene gabbro dikes. The dikes are about 22 m.y. old (Brown, 1972; Coleman and others, 1977) and were emplaced during extension and tectonic events associated with initial opening of the Red Sea (Coleman, 1974; Coleman and others, 1979). The Bathan formation defines a final phase of deformation that probably occurred during the Pliocene. The Bathan conglomerate is monoclinally tilted 15 degrees toward the northeast and strikes parallel to the Red Sea. This suggests that it has been folded in response to antithetic

faulting associated with the late Miocene and Pliocene uplift of the Red Sea escarpment (Hadley and others, unpublished data; Ross and Schlee, 1973). The main antithetic fault probably lies in the wadi on the northeast side of the Bathan outcrop and may be the fault that extends northwest from this wadi across the Miocene gabbro dike, the Jiddah group, and Wadi al Faj. There are probably several such faults in the area, but there is no way of knowing in the absence of more extensive exposures of the Bathan formation.

METAMORPHISM

Rocks in the Al Lith quadrangle have been metamorphosed to the greenschist and amphibolite facies. The Baish and Jiddah groups are regionally metamorphosed to the greenschist facies and contain the corresponding mineral assemblages (chlorite, epidote, sphene, actinolite, albite, and calcite). Locally, they are metamorphosed to the amphibolite hornfels facies in aureoles surrounding some of the plutons. Amphibolite in the aureoles is thoroughly recrystallized to granoblastic, lepidoblastic, and poikiloblastic textures immediately adjacent to the contacts and has hornfels textures 0.5 km or more away from the contacts. Mineral assemblages developed in the amphibolite-grade rocks include hornblende, biotite, andesine, garnet, sphene, epidote, apatite, and quartz.

ECONOMIC GEOLOGY

Three areas that show mineralization were identified in the quadrangle. All are located in metavolcanic rocks of the Baish and Jiddah groups. Samples collected from these areas were analyzed by semi-quantitative spectrographic and atomic absorption methods in the Directorate General of Mineral Resources laboratory in Jiddah. Only the ranges of the atomic absorption analyses for the elements shown are presented here (table 1) because the mineralized areas are small and the results are very low. The complete data are stored in RASS and can be readily retrieved.

The first area is located near a shear zone in Baish rhyolite approximately 3 km north-northeast of the main mass of Jabal Abu Sadi. It consists of a north-trending zone in strongly sheared rhyolite and is mineralized over a width of about 20 m and a length of 100 m. Mineralization consists of sparse to locally abundant 1-3 mm pyrite cubes and small disseminated masses of chalcopyrite set in the rhyolite groundmass, with minor malachite coating shear surfaces.

The ranges of 7 samples collected across the strike of the zone (table 1) show no important concentration of metals.

Table 1.--*Atomic absorption analytical ranges for samples collected from three mineralized areas in the Al Lith quadrangle*

[Data in ppm except Fe, in percent]

Mineralized Rocks	Au	Ag	Cu	Pb	Zn	Mn	Fe
Baish rhyolite	.04 - .05	.2 - .5	5 - 43	10 - 12	10 - 90	25 - 430	1.5 - 2.5
Baish basalt and tuff	.04 - .23	.9 - 5.6	90 - 760	75 - 290	90 - 140	10 - 130	1.6 - 3.6
Jiddah tuff	.04	.7 - 1.6	5 - 8	10 - 85	10 - 190	45 - 130	5.1 - 36.0

The second area, located 3.5 km northwest of the village of Ghumayqah, is in schistose metabasalt and interbedded siliceous tuff of the Baish that dips 45° NW. The mineralized zone is 3-5 m wide and 50 m long. Ore minerals present include malachite and minor pyrite, chalcopyrite, and hematite. Copper is the most important metal in this zone, and samples contain as much as 760 ppm, but none of the metals are sufficiently concentrated to justify further exploration.

The third area is mainly an iron prospect. It is found in tuffaceous rocks of the Jiddah group, less than 0.25 km from the northwest end of the outcrop of Bathan formation. The mineralized beds dip 15° SW., are 2-3 m thick, and are exposed for a strike distance of 150 m. Hematite, the only detected ore mineral, is uniformly distributed--though not at the same concentration--throughout the ore zone, and the iron concentration ranges from 5.1 to 36.0 percent (table 1). In spite of the relatively high iron content of the beds, additional exploration is not recommended because the tonnage of ore available appears to be very small.

REFERENCES CITED

Blank, H. R., Jr., 1978, Aeromagnetic and geologic study of Tertiary dikes and related structures on the Arabian margin of the Red Sea *in* Red Sea research 1970-1975: Saudi Arabian Directorate General of Mineral Resources Bulletin 22, p. G 1-18.

Brown, G. F., 1972, Tectonic map of the Arabian Peninsula: Saudi Arabian Directorate General of Mineral Resources Arabian Peninsula Map AP-2, scale 1:4,000,000.

Brown, G. F., Jackson, R. O., Bogue, R. G., and Maclean, W. H., 1963, Geologic map of the Southern Hijaz quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-210 A, scale 1:500,000.

Cater, F. W., 1977, Reconnaissance geology of the Wadi Salibah quadrangle, sheet 20/40 B, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-27, scale 1:100,000, 8 p.

Coleman, R. G., 1974, Geologic background of the Red Sea, *in* Burk, C. A., and Drake, C. L., eds., The geology of continental margins: New York, Springer-Verlag Inc., p. 743-751.

Coleman, R. G., Fleck, R. J., Hedge, C. E., and Ghent, E. D., 1977, The volcanic rocks of southwest Saudi Arabia and the opening of the Red Sea: Saudi Arabian Directorate General of Mineral Resources Bull, 22, p. D1-D30.

Coleman, R. G., Hadley, D. G., Fleck, R. J., Hedge, C. E., and Donato, M. M., 1979, The Miocene Tihama Asir ophiolite and its bearing on the Red Sea opening: Geologic Conference on Arabian-Nubian Shield, Jiddah, Feb., 1978. ... -- p.

Fleck, R. J., Greenwood, W. R., Hadley, D. G., Anderson, R. E., and Schmidt, D. L., in press, Rubidium-strontium geochronology and plate tectonic evolution of the southern part of the Arabian Shield: U. S. Geological Survey Professional Paper.

Greenwood, W. R., Hadley, D. G., Anderson, R. E., Fleck, R. J., and Schmidt, D. L., 1976, Late Proterozoic cratonization in southwestern Saudi Arabia: Royal Society of London Philosophical Transactions, v. A280, p. 517-527.

Hadley, D. G., 1979, Reconnaissance geology of the Musaylim quadrangle, sheet 19/40 B, Kingdom of Saudi Arabia: U.S. Geological Survey open-file rept. _____, (IR)SA-272, 11 p.

Hadley, D. G., and Fleck, R. J., 1979, Reconnaissance geology of the Al lith quadrangle, sheet 20/40 C, Kingdom of Saudi Arabia: U.S. Geological Survey open-file rept. _____, (IR)SA-270, 19 p.

Ross, D. A., and Schlee, J., 1973, Shallow structure and geologic development of the southern Red Sea: Geological Society of America Bulletin, v. 84, p. 3827-3848.

Schmidt, D. L., Hadley, D. G., Greenwood, W. R., Gonzalez, Louis, Coleman, R. G., and Brown, G. F., 1973, Stratigraphy and tectonism of the southern part of the Precambrian shield of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Bulletin 8, 13 p.

Wier, K. L., and Hadley, D. G., 1975, Reconnaissance geology of the Wadi Sa'diyah quadrangle, (sheet 20/40A), Kingdom of Saudi Arabia: U. S. Geological Survey open-file rept. 75-493, ((IR)SA-193), 27 p., 1 pl., 1 fig.