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GEOLOGY OF THE JABAL ISHMAS QUACRANGLE KINGDOM OF SAUDI ARABIA

by

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With a section on

AEROMAGNETIC STUDIES

by

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GEOLOGY OF THE JABAL ISHMAS QUADRANGLE
KINGDOM OF SAUDI ARABIA

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ABSTRACT

The Jabal Ishmas quadrangle (20/43A) is about 100 km northeast of Qal'at Bishah in the southern part of the Arabian Shield. Most of the terrane in the quadrangle slopes gently westward across broad expanses of pediment, from prominent mountainous north-south ridges in the east to the alluvial and eolian sand-covered plains of Wadi Bishah. Other than the widespread surficial deposits, the quadrangle is underlain by Precambrian metasedimentary, metavolcanic, and intrusive granitic to gabbroic rocks.

Paraschist, paragneiss, and amphibolite of the Hali Group, the oldest rocks of the quadrangle, were derived from pelitic sediments, quartzite, limestone, and mafic to felsic volcanic rocks. The rocks were intensely deformed and regionally metamorphosed to the almandine-amphibolite facies during a long and complex period of Precambrian geological events prior to deposition of the rocks of the Halaban Group. Granodiorite gneiss, the most abundant rock in the quadrangle, is intrusive into and tectonically deformed with the Hali rocks.

Relatively late during Precambrian time sedimentary and volcanic rocks of the Halaban Group were unconformably deposited on the Hali and granodiorite gneiss. The Halaban Group consists of a lower metaclastic unit of conglomerate, graywacke, shale, limestone, and chert, and an upper metavolcanic unit that is predominantly andesitic flow rocks, pyroclastic deposits, tuff, and subordinate basaltic rocks.

The Halaban rocks were moderately to intensely deformed and regionally metamorphosed to the lower greenschist facies during the Hijaz orogeny.

Three major rock types, hornblende quartz diorite, quartz monzonite, and gabbro, are intrusive into the Halaban and older rocks as numerous large and small plutons. Hornblende quartz diorite is the most widespread and oldest and was probably penecontemporaneously intruded during north-south faulting and deformation of the Halaban. Gabbro and quartz monzonite are later and are posttectonic relative to the deformation of the Halaban rocks.

Intensive north-south, left-lateral wrench faulting accompanied deformation of the Halaban rocks and produced the Nabitah fault zone and the Ishmas east and west faults. Sheared serpentine and marble occur along these faults and extensive hydrothermal alteration has produced talc-actinolite schist within the Nabitah fault zone.

The Jabal Ishmas quadrangle may be divided into three structurally dissimilar segments: a) a segment containing a northerly-trending, synformal, down-dropped block of Halaban rocks that are abundantly cut by large north-south shear faults, including the Nabitah fault zone and Ishmas east fault, which commonly contain serpentine and marble; b) schist and gneiss of the Hali Group that is intruded by the granodiorite gneiss and is east of the Nabitah fault zone; c) Hali Group rocks intruded by granodiorite gneiss, and Halaban Group rocks intruded by granodiorite gneiss, and Halaban Group rocks intruded by the younger intrusions west of the Nabitah fault zone.

Several ancient gold mines including the Ishmas Kabir mine and many ancient prospects are on narrow, low-grade gold-quartz veins in the Jabal Ishmas quadrangle. Further exploration of the veins may be warranted.

Magnetic anomalies correlate with mafic and ultramafic rocks along major fault zones, other anomalies correlate with rocks that crop out, and some anomalies probably reflect deep-seated sources.

INTRODUCTION

The Jabal Ishmas quadrangle (20/43A, fig. 1), centered about 110 km northeast of Qal'at Bishah in the southern part of the Arabian Shield, lies between lats 20°30' and 21°N. and longs 43° and 43°30'E. It is named after Jabal Ishmas located near the center of the quadrangle. Alluvial gravel and dune sand cover most of the quadrangle, except for prominent north-south ridges that cross the eastern part of the quadrangle. Other than the widespread surficial deposits, the quadrangle is underlain by Precambrian metasedimentary, metavolcanic, and intrusive rocks.

The quadrangle is included in the 1:500,000-scale geologic map of the southern Najd (Jackson and others, 1963). The Jabal Ishmas quadrangle was mapped in the spring of 1971 as part of a work agreement between the U. S. Geological Survey and the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

SEDIMENTARY, VOLCANIC, AND METAMORPHIC ROCKS

Hali Group

Rocks of the Hali Group are the oldest layered rocks in the Jabal Ishmas quadrangle. They crop out in a wide belt in the eastern part of the quadrangle and underlie three large and several small

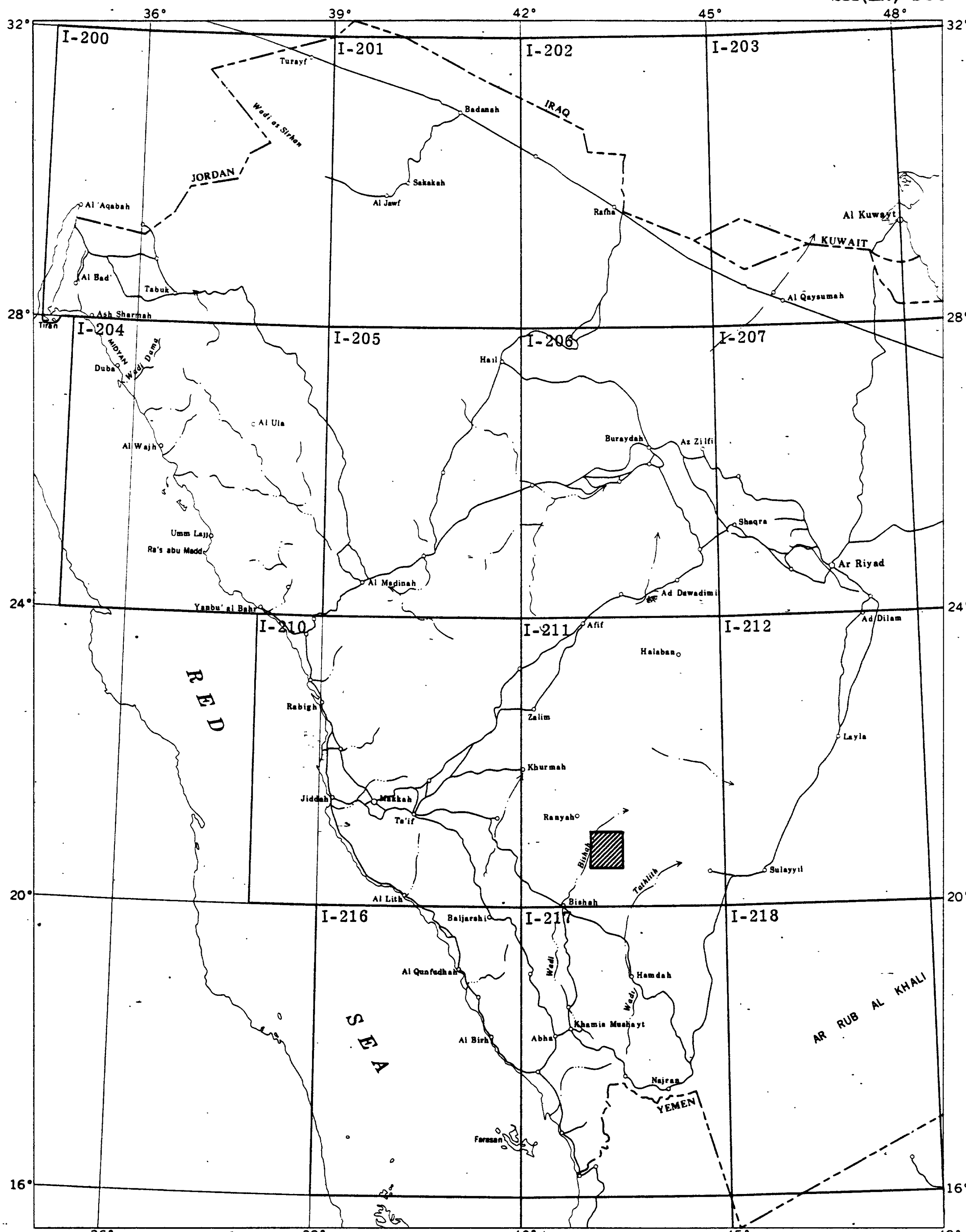

Figure 1.- Index map showing the location of the Jabal Ishmas quadrangle.

areas east of Wadi Bishah in the western part of the quadrangle (plate 1). The name "Hali Group" is that applied by Schmidt and others (1973) to rocks of similar lithology and stratigraphic position in the southwestern Arabian Shield. The Hali Group in the Jabal Ishmas quadrangle consists of light- to medium-colored schist and gneiss derived from pelitic sediments, quartzite, dark impure marble, felsic volcanic rocks, amphibolite, greenstone, and greenschist derived from mafic volcanic and associated clastic rocks.

The schist commonly contains assemblages of sericite-calcite-biotite-quartz, muscovite-microcline-quartz, calcite-oligoclase-hornblende-quartz, and magnetite-biotite-quartz.

Siliceous schist that exhibits relic porphyritic textures and contains mostly quartz, feldspar, sericite, epidote, and biotite probably is derived from acid volcanic rocks. It is fine to medium grained and light tan to dusky brown. Biotite-muscovite-feldspar-quartz paragneiss is derived from quartzofeldspathic sediments. The quartzite commonly contains calcite, feldspar, biotite, and muscovite in addition to quartz. Impure marble contains some quartz, epidote, sericite, and chlorite; locally, it grades into quartzite. The marble is bluish gray to light gray, fine to medium grained, and generally crops out in massive thick beds.

Foliation and compositional layering of the sedimentary rocks trends mostly north and dips steeply east or west. Lineations, which are not common, trend north and plunge gently north or south except near the Nabitah fault zone.

The amphibolitic rocks contain mostly the mineral assemblages epidote-quartz-calcic plagioclase-hornblende, almandine-calcic plagioclase-hornblende, and quartz-clinopyroxene-calcic plagioclase-hornblende. Associated greenstone is composed of quartz, albite, epidote, actinolite and quartz, chlorite, epidote, albite, actinolite. Volcanic textures such as amygdules, phenocrysts, and tuff fragments are preserved in some of the greenstones. Volcanic graywackes and sedimentary structures also are preserved locally in the greenstone. Greenschist consisting of quartz, biotite, calcic plagioclase, and hornblende is derived from clastic rocks of volcanic origin. It is interbedded with the much more abundant dark greenish-gray thick-layered to massive mafic volcanic rocks. Schistosity and compositional layering strike mostly north and dip steeply.

Metamorphism of the mafic rocks is mostly to the low-rank almandine-amphibolite facies, but in a small area in the northeast part of the quadrangle greenschist facies rocks are found. Effects of retrograde metamorphism are not evident in the greenschist-facies rocks and the change in grade of metamorphism of the mafic rocks is believed to be progressive metamorphic zonation.

Halaban Group

The Halaban Group consists of a folded sequence of layered conglomerate graywacke, shale, marble, chert, tuff, and greenstone; the Group is divided into a lower clastic unit and an upper volcanic unit (pl. 1). Halaban rocks of the Jabal Ishmas Quadrangle are similar to and correlate with those in the Jabal Juqjuq area about 50 km northeast. In the eastern part of the quadrangle Halaban rocks crop out in a northerly trending belt about 6 km wide that extends into the adjoining quadrangles to the north and south. The lowest Halaban rocks are exposed in a large antiformal structure near the northeast quarter of the quadrangle. Upper Halaban rocks surround these core rocks and constitute most of the belt to the south. The smaller areas of Halaban rocks west of the belt are tightly to gently folded and represent the lower part of the sequence.

The thickness of the Halaban in the quadrangle is not known because of the complex faulting and folding, but at several places within the belt exposures across steeply dipping strata measure as much as 7 km. The lower Halaban rocks lie unconformably on Hali schist and granodiorite gneiss and are intruded by hornblende quartz diorite, gabbro, and quartz monzonite.

Lower clastic unit

The lower clastic unit of the Halaban consists of abundant graywacke siltstone, shale, tuff, andesitic volcanic flow rocks and marble, as well as subordinate chert, conglomerate, and agglomerate.

The conglomerate near the base of the Halaban contains boulders and cobbles of granitic and volcanic rocks in beds about 2 m thick. The conglomerate section locally is as thick as 20 m. Intraformational agglomerate consists principally of well rounded volcanic pebbles of intermediate composition. The graywacke consists of angular to subrounded clasts of quartz, feldspar, and rock fragments set in a matrix of well recrystallized quartz, feldspar, sericite, chlorite, stilpnomelane, and epidote. Greenish to brownish-gray, fine- to medium-grained graywacke is well bedded with laminae commonly less than 5 cm thick, but with some beds as thick as 40 cm.

Some graded bedding and flute casts are preserved.

Medium- to dark-gray shale grades into siltstone and is interbedded with or grades into graywacke. The shale commonly is massive and has a conchoidal fracture, but where bedded, and laminae beds range from 0.5 mm to 50 cm thick. Generally the shale is recrystallized and consists predominantly of quartz, abundant epidote, feldspar, stilpnomelane, chlorite, and sericite.

Green to grayish- and brownish-green tuff is mostly well bedded with beds 2 to 50 cm thick. Clasts of feldspar and quartz predominate and lithic clasts are sparse. The clasts are set in a recrystallized fine-grained matrix consisting of feldspar, quartz, chlorite, actinolite, epidote, calcite, sericite, and stilpnomelane.

Grayish-green, buff, or gray volcanic flow rocks of intermediate to acid composition are as thick as 1 m. The andesitic rock is massive and commonly porphyritic with phenocrysts of plagioclase, quartz and sparse hornblende set in a fine-grained matrix that is generally altered to tremolite, chlorite, epidote, and sericite.

Calcareous metasediments consist of well recrystallized blue-gray marble that is more than 98 percent carbonate and of well recrystallized ferruginous carbonate rock containing impurities of quartz, sericite, actinolite and magnetite.

Brownish-gray to gray massive chert in beds about 5 m thick contains carbonate and clay impurities. The chert is commonly brecciated and recemented.

Upper volcanic unit

The upper volcanic unit of the Halaban consists of predominant andesitic crystal tuff, abundant andesitic flows, and volcanic greenstone, subordinate silicic volcanic rock, and hematitic andesite.

Greenish- to dark-gray, coarse- to fine-grained andesitic crystal tuff consists of phenocrysts of oligoclase-andesine and quartz and lithic fragments in a fine-grained matrix. The plagioclase generally is altered to sericite. The matrix is mostly recrystallized with quartz and feldspar forming an interlocking mosaic texture and with disseminated grains of chlorite, epidote, albite, carbonate, sericite, and biotite or stilpnomelane.

Dark grayish-green, massive, and commonly porphyritic andesite flow rocks are interbedded with the crystal tuff. Phenocrysts of plagioclase are much more abundant in the andesite. A holocrystalline fine-grained matrix is generally partly recrystallized and consists of epidote, actinolite, chlorite, albite, calcite, quartz, biotite or stilpnomelane, and quartz.

Massive, fine-grained, and well recrystallized greenstone is derived from basalt in the lower part of the volcanic unit. Thick layering is characteristic and in many places pillow lava is poorly preserved whereas locally micropillow structure is better preserved. The greenstone consists mostly of actinolite and contains relatively abundant epidote, albite, chlorite, and sparse carbonate and sericite.

Silicic volcanic rock in the upper part of the upper unit has a gray fine-grained, recrystallized matrix with dark parallel aligned streaks suggestive of the compaction structure of an ignimbrite. Quartz is predominant, feldspar abundant, and magnetite common.

Hematitic andesite also in the upper part of the column is probably associated with centers of volcanic eruption. It is brown, massive, and holocrystalline. Fine-grained hematite is disseminated in the matrix and occurs as replacement of oxidized euhedral phenocrysts of pyrite.

INTRUSIVE ROCKS

Granodiorite gneiss

Granodiorite gneiss, the most widely distributed rock in the Jabal Ishmas quadrangle, crops out in an area of 750 sq km. It crops out along the eastern margin of the quadrangle as two elongated bodies in nearly conformable schist and amphibolite, and as large irregularly shaped masses in the central and western parts of the quadrangle.

The gneiss is most commonly a granodiorite, but ranges in composition from quartz monzonite, which is widespread, to quartz diorite, which is not common. It consists principally of quartz, plagioclase, potassic feldspar, and biotite, The plagioclase is oligoclase-andesine (An_{26-36}), generally anhedral with crushed borders, and has some perthitic intergrowth as well as some myrmekitic rims. Albite and pericline twinning is common, and sparse zoning is normal with more calcic cores. The plagioclase is moderately altered to sericite. The potassic feldspar is microcline. It is present as phenoclasts and as small grains in the crushed matrix. The microcline exhibits gridiron twinning and perthitic intergrowths of the flame type. Biotite is reddish brown and is found as frayed plates and clusters of plates. Some of the biotite is altered to chlorite. Quartz is found as phenoclasts and as the most abundant constituent in the crushed matrix. The quartz grains are often rehealed and exhibit an interlocking mosaic texture. The main accessory minerals are sphene, magnetite, and zircon. Epidote and garnet are found in some phases of the gneiss.

The gneiss is homogeneous, medium grained, and has a color index of about 10. Cataclastic textures are typical but granitic fabric is found locally. The cataclastic textures range from a mortar texture, consisting of ovoid shaped fragments of feldspar and quartz set in a fine-grained quartzo-feldspathic matrix, to a well developed flaser texture defined by parallel arrangement of strung-out clusters of biotite. The mortar texture is widespread in the gneiss masses found in the southwest and central part of the quadrangle, the flaser texture is found in the plutons in the southeastern part of the quadrangle, and the granitic texture is found mostly as a porphyritic border facies in the north part of the largest pluton near the eastern edge of the quadrangle.

Banded gneiss, consisting of alternating layers of light-colored minerals and darker, more mafic minerals was found at a single locality in the southwest part of the quadrangle. The layers are from 1 to 15 cm thick and the mafic mineral is biotite oriented parallel to the banding. The light layers are of granodioritic composition and show well developed mortar texture. The banded gneiss has been subjected to plastic deformation and exhibits an incipient migmatitic structure. Widespread banded gneiss probably underlies the extensive pediments covering the southwestern area.

Under the microscope the granodiorite and associated quartz monzonite and quartz diorite gneiss have a granitic texture strongly modified by cataclasis. In general the texture consists of phenoclasts of feldspar and quartz with crushed borders set in a recrystallized quarto-feldspathic matrix. In the porphyritic border facies microcline phenocrysts are found that are as much as 2 cm long and have inclusions of early formed crystals of feldspar and quartz. The matrix of the porphyritic rocks is hypidiomorphic equigranular and is not modified by cataclastic effects.

The gneiss probably represents granodioritic magma that intruded the Hali schist. The gneiss is intruded by the hornblende quartz diorite, gabbro, and quartz monzonite.

Hornblende quartz diorite

Several large plutons of hornblende quartz diorite crop out in the quadrangle, as do many small bodies in and west of the Nabitah fault zone. A large pluton of hornblende quartz diorite of about 120 sq km in the central part of the quadrangle forms Jabal Khattab and underlies the pediment to the west. Another pluton of about 60 sq km forms a wedge-shaped mass in the northcentral part of the quadrangle and composes Jabal Ishmas. Smaller bodies that range in size from 0.5 to 10 sq km crop out mostly in the Nabitah fault zone and are roughly lenticular shape and parallel to the strike of the fault zone.

Hornblende quartz diorite is the predominant rock type in this map unit, but the rocks range in composition from hornblende diorite to granodiorite. The most common variant is hornblende diorite which forms large masses locally within the individual plutons. Granodiorite is sparse and mostly is in narrow zones along intrusive contacts; its higher potassium content maybe due to potassium metasomatism.

Quartz diorite is generally grayish green, granular, and massive in hand specimens. The color is imparted by green mafic minerals set in a greenish-gray groundmass composed mostly of altered feldspar crystals. The color index ranges from 20 to 50, but is generally about 35. The rock is mostly medium grained, but associated small masses of fine-grained rock are common. The fine-grained rock grades locally into microdiorite.

The essential minerals of the granitic-textured rock are plagioclase, hornblende, and quartz. The plagioclase is oligoclase-andesine in euhedral to subhedral crystals, and commonly is extensively altered by saussuritization and sericitization. Alteration masks twinning, but emphasizes zoning in that the more calcic zones and cores are more altered. In quartz-rich quartz diorite, the plagioclase crystals are rimmed by myrmekite in a few places. Hornblende, as ragged edged plates, is generally altered to uralite and chlorite. Quartz is interstitial and does not show undulatory extinction. Pyroxene is uncommon and is enclosed by hornblende. The potassium feldspar is microcline. The accessory minerals are sphene, apatite, and magnetite. Secondary minerals are common and are predominant in the more altered rocks. The alteration products are uralite, sericite, epidote, fine-grained opaque saussurite, chlorite, calcite, and quartz.

Hornblende quartz diorite intrudes the granodiorite gneiss and the Hali schist, but these relations are obscured by the widespread surficial deposits. Hornblende quartz diorite also clearly intrudes the lower Halaban clastic unit and the lower part of the Halaban volcanic unit, but contact relations with the uppermost Halaban rocks are obscure. The small elongated bodies of hornblende quartz diorite intrusive into the Nabitah fault zone suggest intrusion during or after fault movement. At several localities the hornblende quartz diorite is clearly intruded by the quartz monzonite.

Gabbro

Gabbro grading to diabase is widespread in the quadrangle. Jabal Adhant, near the southwestern corner of the quadrangle consists of a gabbro stock of about 25 sq km of surface extent that intrudes granodiorite gneiss. In the west-central part of the quadrangle about 10 sq km of gabbro is exposed surrounded by extensive sand and gravel deposits. West of Jabal Ishmas a gabbro pluton of aobut 8 sq km has produced an aureole of hornfels in the intruded Halaban clastic rocks. A stock about 4 sq km surface extent, 10 km west-southwest of Jabal Ishmas, intrudes granodiorite gneiss and the Hali schist. In the central part of the quadrangle a stock of about 5 sq km, partly hidden by gravel deposits, a large segment of a ring dike about 6 km long by as much as 100 m wide, and several small plugs intrude the hornblende quartz diorite and lower Halaban clastic unit. A gabbro stock of about 8 sq km and two small plugs intrude the Hali schist of the Nabitah fault zone near the southeast corner of the quadrangle.

The gabbro generally is medium grained, massive, and brownish gray with a color index ranging from 40to 60. Locally the texture of the gabbro grades to diabasic, but its composition is generally uniformly gabbroic. The gabbro consists of predominant calcic plagioclase, abundant clinopyroxene - commonly with narrow reaction rims and patches of brown hornblende, - sparse dark opaque minerals, and sparse orthopyroxene. Olivine gabbro is a rare variant type. In thin sections, the gabbro has a diabasic texture consisting of laths of plagioclase with interstitial pyroxene crystals. An exception is at Jabal Adhant where the gabbro has a fine layered texture due to subparallel orientation of strung-out clusters of pyroxene crystals. The plagioclase is labradorite (An_{50-60}) as well twinned subhedral to anhedral crystals. The clinopyroxene in places has a schiller texture and is found as stubby anhedral crystals. Orthopyroxene is anhedral. The hornblende is anhedral and of deuteric origin. Olivine is sparse. Opaque minerals consist mostly of ilmenite and magnetite. Alteration of the gabbro is widespread and generally the plagioclase is partly replaced by saussurite and sericite, and hornblende and pyroxene by uralite and chlorite.

The relative order of intrusion of the different gabbro bodies is not known, but most appear to be of equivalent age. The gabbro is closely associated with the hornblende quartz diorite and possibly is a late magmatic phase of it.

Quartz monzonite

Quartz monzonite crops out in the western and southcentral parts of the quadrangle. Several masses of quartz monzonite along the western boundary, on both sides of Wadi Bishah, total about 60 sq km in outcrop extent. These masses are, apparently, parts of a single underlying batholith that is intrusive into granodiorite gneiss and Hali schist. The other large area of quartz monzonite, in the south-central part of the quadrangle, is 5 to 8 km wide and extends 20 km north from the south boundary. This pluton has intruded granodiorite gneiss, hornblende quartz diorite, and the Halaban clastic unit. Small plugs of quartz monzonite cut the Halaban clastic and volcanic units in this locality, and a small mass of quartz monzonite has intruded a large north-trending fault south of Jabal Ishmas.

Larger bodies of quartz monzonite are mostly medium to coarse grained, massive, and light gray to pink and have a color index generally under 10. In thin sections the texture is granitic with faintly developed mortar texture. The rock is composed of potassium feldspar and plagioclase in ratios that range from 2.5:1 to 1:1 and quartz, biotite, and/or hornblende. The potassium feldspar is anhedral microcline with gridiron texture and commonly with flame type perthitic intergrowth. Plagioclase is generally subhedral oligoclase-andesine (An_{30-34}), and partly altered to sericite; some grains show normal zoning. The quartz is interstitial and has undulatory extinction. Biotite is in laths and plates. The most common accessory minerals are sphene and magnetite. Secondary minerals are fine-grained opaque clay, sericite, epidote, and chlorite. Quartz monzonite near the borders of larger masses and from narrow bodies that have been intruded along faults generally exhibit a primary cataclastic texture consisting of subparallel oriented ovoid shaped grains of feldspar wrapped by wisps of mafic minerals. These rocks also show extensive development of myrmekite. A locally important dark border variant found in the southcentral area of quartz monzonite is a gray fine-grained granitic rock with a color index of about 20. The dark minerals in this rock are mostly hornblende, magnetite, and some biotite.

Quartz monzonite intrudes all major units in the quadrangle and is the youngest plutonic rock.

Dikes

Diabasic to rhyolitic dikes are abundant in the Jabal Ishmas quadrangle and have intruded rocks of all the major units except the quartz monzonite. The dikes generally seem relatable to plutonic rocks of similar composition but actual age is difficult to establish.

Dikes of andesite and dacite are most widespread and seem relatable to the hornblende quartz diorite. They occur mostly west of the Nabitah fault zone where they are numerous in the granodiorite gneiss and less abundant in the Hali schist, the Halaban rocks, and the hornblende quartz diorite. The dikes commonly fill northwest-trending fractures and generally are about 1 m wide by a few tens of meters to 10 km long. East of the Nabitah fault zone andesite and dacite dikes are sparse but a few cut the granodiorite gneiss and Hali schist.

Diabasic dikes (not shown on pl. 1) are abundant in the central part of the quadrangle where they may be associated with the gabbroic plutons. They intrude the hornblende quartz diorite and the Halaban clastic unit. Diabase dikes associated with the gabbroic pluton in the southeast corner are intrusive into the Hali schist (pl. 1). The rock of these dikes has a diabasic to gabbroic texture.

Rhyolitic to quartz latitic dikes seem relatable to the quartz monzonite unit or perhaps a younger granite plutonic phase not exposed in the Ishmas quadrangle. The dikes cut the granodiorite gneiss, the Hali schist, and the hornblende quartz diorite. The dikes are generally irregular in shape and range from a few centimeters to more than 10 m wide by as much as 10 km long. Most dikes strike north-westerly but some trend east-west or north-south and others form ring dikes. Some of the dikes in the granodiorite gneiss were emplaced along fracture planes containing earlier andesite or dacite dikes and both the older dike rock as well as the host wall rock are hydrothermally altered.

Some of the dike rock is a microquartz monzonite that grades along strike into rhyolite. Quartz veins most commonly small in size are abundant in the quadrangle. A few large dike-like masses of quartz are conspicuous as white ridges and are either about the same age or younger than the rhyolite dikes.

ROCKS ASSOCIATED WITH NORTH-SOUTH FAULTS

Serpentine, marble, and talc-actinolite schist are associated with large north-south faults: the Nabitah fault-zone, the Ishmas east fault, and the Ishmas west fault. The serpentinite and the marble are in discrete bodies along the faults, and the talc-actinolite schist is a metamorphosed fault-zone rock derived from pre-existing country rock. The Nabitah fault zone is of Precambrian age and the talc-actinolite schist is probably also of Precambrian age, but the age relationship between the serpentinite and marble and between them and the other Precambrian rock units in the quadrangle is unknown.

Serpentinite

Masses of serpentinite of lenticular and tabular shape, ranging in size from less than 100 sq m to about 20 sq km, are found along the Nabitah fault zone and the Ishmas faults. The largest masses are along the east side of the Nabitah fault zone and generally intrude and are concordant with the Hali schist. Smaller masses of serpentinite are along the center and west edge of the Nabitah fault-zone and along the Ishmas faults, but owing to the small scale of the map many of the small serpentinite masses are not shown on plate 1.

The large serpentinite bodies consist generally of a central core of massive serpentinite that is progressively more sheared toward its contacts. At the edge of the bodies the serpentinite is intensely sheared and the shear planes are concordant with the schistosity of the country rock. The masses of serpentinite are crisscrossed by carbonate-quartz veinlets that range from 0.5 cm to 30 cm in width and locally form a honeycomb boxwork in weathered serpentinite. The large serpentinite masses contain randomly oriented wallrock inclusions mostly several meters long by about 2 m wide. The contact zones of the serpentinite locally grade abruptly into a massive light brownish-red talc-carbonate rock that forms irregular shaped masses as much as several square meters in area.

In hand specimens the serpentinite is generally dark greenish gray and dark bluish green to green and rarely brown. The rock commonly has a characteristic soapy feel and lustrous surface but some is dull with earthy appearance. Under the microscope it is a fine grained, well recrystallized rock consisting mostly of antigorite and some ferroan carbonate, magnetite, and chromite. Talc is sparse and crysotile is rare. The antigorite generally forms fine-grained fibro-lamellar aggregates. The associated talc-carbonate rock is dominantly talc in platy to fibrous clusters, abundant carbonate in clusters of crystals or as disseminated grains, sparse chromite and magnetite disseminated throughout the rock, and locally abundant to sparse actinolite, quartz, and chlorite.

Marble

Marble underlies several conspicuous ridges of the Nabitah fault zone and the Ishmas faults. The steep-sided low ridges are generally several hundred meters long. Because of the scale of the map only the largest ridges along the Ishmas west fault and the westernmost Nabitah fault are shown on plate 1.

The marble ranges from relatively pure blue-gray marble to yellowish-brown dolomite that grades into calc-silicate rock. The blue-gray marble is commonly fine to medium grained and siliceous. The dolomite is even more siliceous and apparently has been greatly metasomatized and hydrothermally altered. It contains abundant fragments and nodules of jasper, opaque oxides, and some disseminated chlorite and epidote.

Talc-actinolite schist

Talc-actinolite schist underlies about 25 sq km in the Nabitah fault zone in the northeastern part of the quadrangle. The unit is found only within the fault zone. It is intruded by bodies of hornblende quartz diorite and encloses serpentinite masses, quartz veins, and marble masses. It is cut by numerous parallel north-trending faults. The talc-actinolite schist grades into the greenstone of the Halaban volcanic unit to the west. The rock has been dynamothermally metamorphosed to the middle greenschist facies and metasomatized by solutions which probably were derived from serpentinization. It exhibits compositional banding which is tightly folded about axes that dip steeply to the north and south.

Under the microscope the rock shows a well developed schistose texture and is mostly a calcite-albite-epidote-actinolite schist; variant types are calcite-quartz-epidote schist, sericite-biotite-epidote quartzite, and calcite-quartz-sericite-chlorite-epidote greenstone.

QUATERNARY DEPOSITS

Surficial deposits of terrace silt and gravel, pediment gravel, wadi channel alluvium, and eolian sand mantle nearly 50 percent of the quadrangle. A dune complex covers about 350 sq km in the northwest part and about 50 sq km, Nafud al Mistajid, near the southeast corner. These dune complexes consist of compound barchan dunes that are alined and partially reworked into east-northeast trending longitudinal dunes as much as 10 km long by several tens of meters high. The primary source wind for the sand is from the north-northwest. A secondary seasonal wind from the west southwest reworks the sand into the longitudinal dunes.

Low terrace deposits of silt, sand, and gravel of Wadi Bishah probably underlie the broad plain east of Wadi Bishah. These deposits are seen in vertical sections as much as 3 m high only where the modern channel of Wadi Bishah has recently cut laterally into them. Beds of well sorted sand and rounded gravel are a few centimeters to 2 m thick. Scattered well-rounded pebbles and cobbles of Wadi Bishah gravel are found at the surface as far east as the Ishmas Kabir mine but the actual mapping of the extent of the Wadi Bishah gravel is difficult without a topographic base map and because of the eolian surface cover.

The modern channel deposits of Wadi Bishah consist of well sorted, subrounded gravel and sand and flood-plain silt that is washed for a few days during the spring of each year. The channel deposits of secondary and smaller wadis consist of angular, poorly sorted debris mixed with abundant eolian sand. Water flows in these small wadis a few hours a year or only a few hours every several years.

Pediments cover large areas of the Jabal Ishmas quadrangle. They consist of gentle to moderately steep slopes covered with a veneer of poorly sorted, angular cobbles and pebbles in a mixed matrix of eolian sand and silt.

STRUCTURE

Structural segments

Three dissimilar structural segments are found in the Jabal Ishmas quadrangle; an eastern segment east of the Nabitah fault zone, a central segment bound on the east by the Nabitah fault zone and on the west by the Ishmas east fault, and a western segment west of the Ishmas east fault.

The eastern structural segment consists entirely of the Hali schist intruded by the oblong-shaped bodies of granodiorite gneiss. Gross structures in the gneiss and schist are mostly conformable and suggest syntectonic intrusion of the granodioritic rock. Only locally does the granodiorite gneiss cross the schistosity of the Hali schist. The granodiorite gneiss has a well developed north-northwest striking, steeply dipping foliation and similar trending mineral lineations that plunge gently north in the northern part of the segment and gently south in the south. The Hali rocks are tightly isoclinally folded about north-northeasterly trending axes that plunge gently north or south. Schistosity and compositional banding strike about parallel to the minor fold axes and dip steeply from 90° to 70° to the east or west.

The central segment is a down-faulted block that progressively narrows in width from more than 8 km in the north to about 6 km in the south. The east boundary of this block is the easternmost Nabitah fault and the west boundaryof the Ishmas east fault. Halaban rocks of this down-faulted block are part of a moderately south plunging anticline. The clastic and volcanic rocks dip moderately to steeply east or west and generally strike north.

The western segment underlies about 60 percent of the quadrangle and much of its surface is covered by alluvial and eolian deposits. It represents an uplifted tectonic block which exposes much granodiorite gneiss and some Hali schist and Halaban rocks. Large volumes of hornblende quartz diorite, gabbro, and quartz monzonite have intruded this segment. The Hali rocks are tightly folded about north-trending axes and the Halaban rocks are mostly openly folded except in areas near major faults where beds dip steeply and parallel fault planes.

Faults

The Nabitah fault zone is complex and is necessarily simplified on the plate 1. It is named the Nabitah fault zone after Jabal Nabitah in the northeastern part of the quadrangle. The fault zone is about 3 km wide in the northern half of the quadrangle, it widens to about 5 km north of the Nafud al Mistajid and narrows to about 1.5 km farther south. The fault zone is marked by numerous parallel and vertical fault planes with accompanying quartz veins and widespread hydrothermal alteration. Discrete lenticular bodies of serpentinite hornblende quartz diorite, and marble have been emplaced in and along the fault planes. The intensely deformed and metamorphosed rocks of the fault zone have a steep plunging lineation. The fault is left lateral but the amount of horizontal displacement is unknown.

The Ishmas east and Ishmas west faults are parallel faults striking north-northwest. They are so named because they are respectively east and west of Jabal Ishmas. These faults are marked on the surface by discrete, tectonically emplaced bodies of serpentinite and marble, and by locally widespread hydrothermal alteration and quartz veins. Some quartz veins are mineralized with sparse pyrite, copper sulfide, and sphalerite in the northern part of the quadrangle.

A major fault trends approximately N.55°W. in the southwestern corner of the quadrangle. The fault is not well defined because it is partly covered by surficial deposits.

Faulting in the Nabitah fault zone and on the Ishmas east and west faults was part of the Hijaz orogeny (Schmidt and others, 1973) and was in part synchronous with the deformation of the Halaban and the intrusion of the hornblende quartz diorite. The northwest faulting is probably later and may in part correspond to the time of intrusion of the quartz monzonite.

REGIONAL METAMORPHISM

Hali Group

The layered rocks of the Hali Group have been regionally metamorphosed to the almandine-amphibolite facies, except in an area of greenschist facies metamorphism east of Jabal Nabitah. The Hali rocks are thoroughly recrystallized and generally are medium grained. Almandine-amphibolite facies is indicated in rocks of basic composition by the widespread presence of plagioclase ranging in An content from 15 to 30 percent, almandine garnet, and the absence of chlorite.

Rocks of greenschist facies were found in an area of only several sq km just east of Jabal Nabitah. The mineral assemblage in the facies is chlorite, quartz, albite, actinolite, and hornblende.

Nabitah fault zone

Carbonate-actinolite schist in the Nabitah fault zone has been metamorphosed to the middle-rank greenschist facies, as indicated by the widespread presence of actinolite together with chlorite and quartz.

Halaban Group

Rocks of the Halaban Group have undergone regional metamorphism ranging from low- to middle-rank greenschist facies. Middle grade greenstone, derived from basalt and intermediate volcanic rocks is found in the northern part of the quadrangle. Middle-rank greenschist facies is indicated in these basic rocks by the presence of much actinolite, some chlorite in contact with quartz, and the absence of hornblende. Biotite is present in pelitic rocks. The rocks are recrystallized and are medium to fine grained. Low-rank greenschist facies metamorphism is widespread in rocks that are moderately recrystallized and generally fine grained. In aluminous rocks the rank of metamorphism is indicated by widespread stilpnomelane and absence of biotite.

CONTACT METAMORPHISM

Contact metamorphism has developed strong hornfels texture in lower Halaban rocks that crop out in an aureole several hundred meters wide around the gabbro stock west of Jabal Ishmas. In calcareous rocks, the contact metamorphic mineral assemblage is diopside, garnet, epidote, plagioclase, hornblende, and calcite.

ECONOMIC GEOLOGY

Seven ancient gold mines and numerous associated prospects are in the quadrangle (pl. 1). The mines are described in table 1.

The Ishmas Kabir mine, in the north-central part of the quadrangle (pl. 1) is the most extensively worked deposit in the area. The mine workings are marked by ancient dumps that rise 3 or 4 m above the surrounding plain. The dumps are in an area 450 m long. Three trenches were bulldozed across the dumps to facilitate sampling and to expose workings buried by dump debris and sand. Data on findings are given in table 1.

Two induced polarization profiles were run parallel to the strike of the Ishmas Kabir vein to determine whether concentrations of metal might occur in the vein zone (V. J. Flanigan, written communication, 1969). Anomalous polarization values were recorded at the northeast end of the ancient dumps, in a locality where low resistivity values were obtained. The cause of the induced polarization anomaly is not known. It may represent an increase in metallic concentration of either disseminated or massive sulfides in the vein zone. On the other hand, the anomaly may reflect fracturing in the rock. Clay minerals in fractures would give contrasting values to the enclosing rock.

The Shark Umm Shāt and the Gharb Umm Shāt mines are northeast of the Ishmas Kabir mine (pl. 1) and both have been worked extensively. A single induced polarization profile was run across the dump area at the Shark Umm Shāt mine in 1969 (V. J. Flanigan, written communication). An induced polarization anomaly was detected at the southwest end of the old workings, which may reflect a fault or may be

Table 1.- Ancient gold mines in the Jabal Ishmas quadrangle.

Map no.	Name and location of mine	Type of deposit	Description of workings	Geologic description of deposit	Sample data
1	Ishmas Kabir 20°51.6'N. 43°13.4'E.	Quartz vein	Trenches and open cuts in a belt 450 m long and 30 m wide. Workings are on a low ridge that rises 5 to 7 m above the plain. Dumps from mine workings estimated to contain 120,000 tons material	Trenches excavated on quartz vein or veins that are about 1 m wide, strike N. 40-50°E., and dip 70°NW. Veins cut dark schist of the Hali Group and intrusive quartz diorite. Veins are massive milky quartz and carbonate (ankerite). Vein quartz brecciated and cemented by younger quartz. Limonite and malachite seen at outcrop; sparse pyrite and chalcoprite	Dump material averages 3 g Au per ton
2	Gharb Umm Shat 20°57.8'N 43°18'E.	Quartz vein	Pits, trenches, and inclined shaft along narrow mineralized zone more than 1 km long. Dumps from workings contain 20,000 tons or more excavated material	Vein strikes N. 30-35°W., dips 70°SW, consists of parallel quartz veinlets in zone 1 m wide with 1 or 2 m of altered rock on each side. Vein in metamorphosed siltstone, sandstone, and conglomerate of lower Halaban which are cut by narrow felsite dikes. Hematite, limonite, and sparse malachite along vein outcrop; sulfides are pyrite, chalcopyrite, sphalerite, and a black glossy mineral that may be chalcocite. Vein is brecciated, has extensive strike length, but is poorly exposed	Two channel samples across 1 m of vein contain about 3 g Au per ton. Dump material averages 2.64 g Au per ton. Oxidized wall rock contains 1.4 ppm Ag and 1000 ppm Ba, but no detected Au
3	Shark Umm Shat 20°57.9'N. 43°20.3'E.	Quartz vein	Pits, trenches, and vertical shaft 1 m in diameter in an area 200 m long and 20 to 30 m wide. Largest workings is a small stope near the shaft. Mined width of trenches about 1 m; dumps along trenches	Shear zone strikes N. 50°E., dips 35°SE, contains quartz stringers 2 to 5 cm wide, giving a mineralized zone of about 15 cm total width. Five to eight cm of tan, sheared gouge on footwall of zone. Country rock is biotite-rich quartz monzonite, which is altered and contains pyrite-chlorite-calcite for about 10 m on each side of shear zone. Sparse iron oxides and malachite at outcrop; no sulfides seen	Twenty channel samples taken across vein, only one of which contained Au (6.8 g Au per ton). Dump samples averaged 2.6 g Au per ton
4	Ishmas 20°52.7'N. 43°16.6'E.	Quartz vein	Open cut 150 m long, 2 m wide, shallow, partly filled with sand. Working is on crest of ridge	Podiform quartz vein 150 m long and as much as 5 m wide, strikes N. 15-20°W, dips 60°SW. Vein in Halaban schist parallel to schistosity near quartz diorite contact. Slickensides on vein wall plunge down dip of vein. Quartz is milky color, vuggy, stained by hematite; sparse malachite; some pyrite seen, no other sulfides	Dump material estimated to average about 1.3 g Au per ton
5	Abu Tal	Quartz vein	Open cuts and pits in area several hundred meters long. Dumps around pits estimated to contain 20,000 tons material	Milky quartz vein in Halaban schist near gabbro contact. No sulfides seen	Gold recovered in panned concentrates, but no sample assayed
6	Najeeb 20°34.5'N. 43°29.1'E.	Quartz vein	A circular pit 8 m in diameter and 1 m deep and two nearby smaller pits are principal workings. Many smaller pits in small quartz veins scattered in area extending about 2 km west	Massive quartz veins in quartz diorite, the tectonic foliation of which strikes N. 15-20°W. Sheared boudins of amphibolite are in the quartz diorite parallel to foliation. Country rock is altered to a calcite-chlorite-pyrite assemblage near small quartz veins in the quartz diorite and in schist to the west	One grab sample assayed 3.5 g Au per ton. Dump material estimated to average about 1.9 g Au per ton
7	Khatteb 20°40.6'N. 43°14.8'E.	Quartz vein	Several pits	Quartz veins in quartz diorite. Vein strikes NE, is iron stained, but no sulfide minerals seen	Grab sample from dump assayed 19.2 g Au per ton

related to the subsurface contact of the quartz monzonite with nearby schist. Two trenches were cut across dumps of the Shark Umm Shāt mine and some ancient excavations were reopened to sample the mineralized areas.

Two trenches, 1 km apart, also were cut across dumps of the Gharb Umm Shāt mine and several ancient open cuts were uncovered. Samples from the vein (table 1) were not encouraging.

That the ancient miners mined, hand cobbed, crushed, and ground vein quartz containing free gold, is indicated by stone hammers, stone anvils, and fragments of grindstones found in abundance at the ancient mine sites and by the absence of slag. The veins in the ancient gold mines are narrow and prcbably low in grade, as indicated by the gold assays (table 1). Though not especially encouraging, some further exploration may be warranted to determine gold values and distribution at depth.

AEROMAGNETIC STUDIES

by

Vincent J. Flanigan

Introduction

The total intensity aeromagnetic data shown on plate 1 were recorded during a 1966-67 magnetic survey of the Precambrian shield of Saudi Arabia. The survey was flown and compiled by a consortium which included Aero Service Corp., Hunting Geology and Geophysics Ltd., Lockwood Survey Corp. Ltd., and Arabian Geophysical and Surveying Co., under the supervision of the Bureau de Recherches Géologiques et Minières. The aeromagnetic data were obtained along northeast-southwest flight lines spaced at 800 m apart at a flight elevation of 300 m above the terrain.

The contours are at 20 gamma intervals and represent the residual total magnetic intensity relative to an arbitrary datum. A linear gradient which included corrections for diurnal variations and instrument drift was removed from the basic data prior to compilation and contouring.

The qualitative interpretative approach used in this section has not taken into account the role of remanent magnetization inasmuch as no laboratory measurements on rock magnetic properties were made.

Aeromagnetic anomalies

Several distinct patterns and/or lineations can be distinguished from the magnetic data shown on plate 1. Perhaps the most striking of these is a zone of anomalies along the eastern edge of the quadrangle marked A_1 on figure 2. This zone is characterized by high

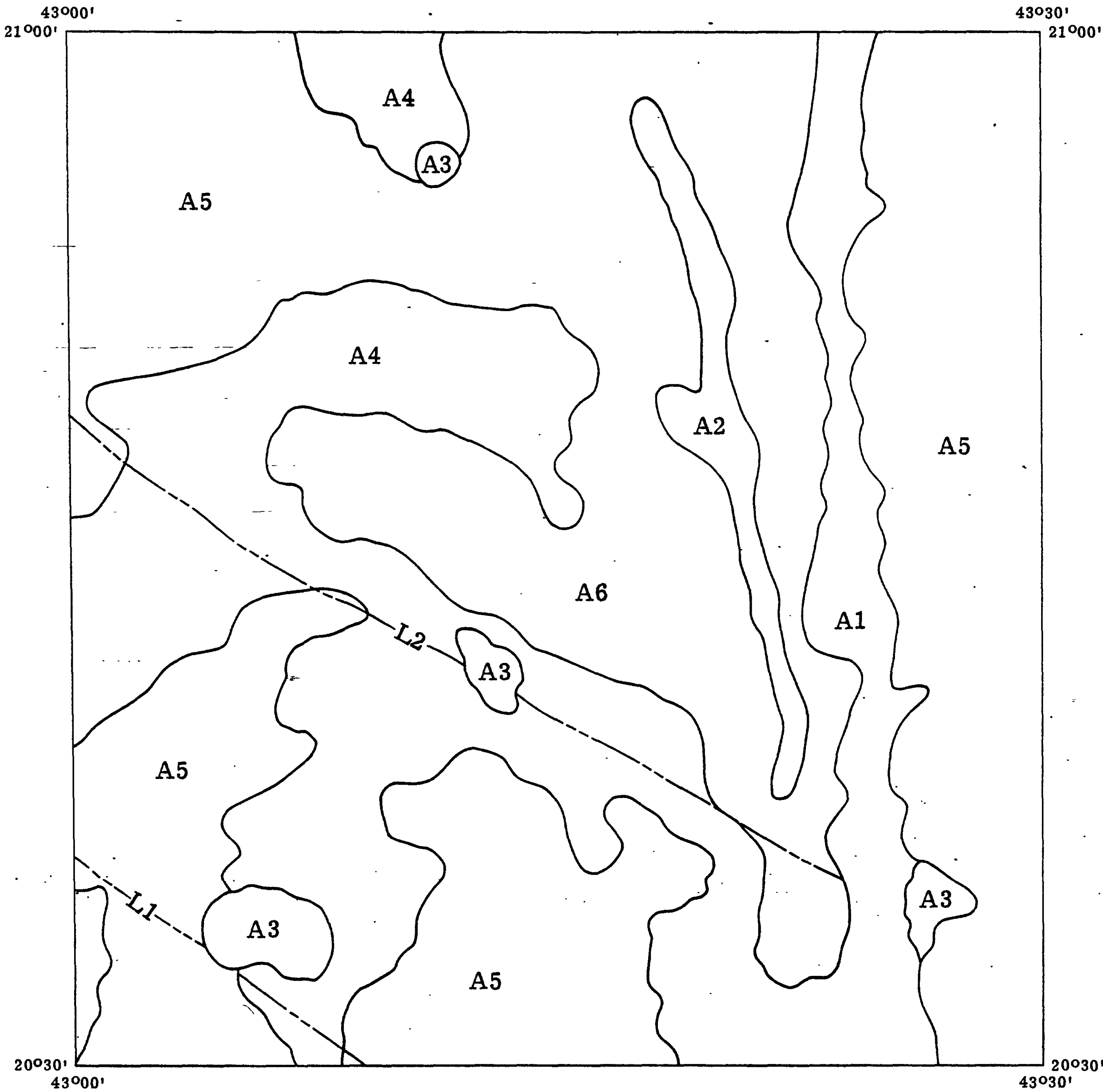

Figure 2. - Map of the Jabal Ishmas quadrangle showing magnetic features discussed in the text.

frequency interwoven anomalies of 500-600 gamma intensity. They form a north-south zone 2-4 km wide crossing the entire quadrangle. The extension of this zone can be seen in the quadrangle to the north; it also crosses the adjoining Jabal al Qarah quadrangle on the south (Flanigan, 1973). The individual anomalies for the most part seem to be normally polarized, that is, with a magnetic high south of the corresponding magnetic low. The magnetic expression of the rocks reflects induction from the earth's present magnetic field. The magnetic pattern of zone A_1 is attributed to serpentine or other basic rocks injected in or developed along the Nabitah fault zone.

About 10 km west of the A_1 zone is another northerly zone of anomalies marked A_2 (fig. 2). Normally polarized anomalies of 100-200 gammas form a lineation which, in the northern third of the zone, coincides with the Ishmas east fault contact between quartz diorite and greenschist. The magnetic anomaly probably represents realignment of the ferromagnetic minerals in the fault zone, or mafic rocks intruded into weaker zones of the fault. The north-trending Ishmas west fault, 3-4 km further west has no unique magnetic lineation associated with it. The reason for this is not known.

Other northwest-trending magnetic lineations in the Jabal Ishmas quadrangle may reflect regional structures associated with Najd faulting. One crosses the southwest corner of the quadrangle and is marked L_1 on figure 2. The lineation is not as readily apparent in the Ishmas quadrangle as it is in the adjoining Jabal al Qarah quadrangle to the south, where it is a striking northwest-trending magnetic feature. In that quadrangle, the magnetic lineation is related to a recognized fault, which is part of the regional structural pattern. Another northwest-trending lineation comprising elongated anomalies of 100-200 gammas, crosses the lower half of the quadrangle, and is marked L_2 on figure 2. The regional extent of the lineation is more clearly seen in GM-13, a colored 500,000 scale magnetic map (Andreasen and Petty, 1973). Over most of its length, the fault either is covered by pediment alluvial deposits or follows a major wadi. In the south center of the map, the lineation crosses exposed rocks mapped as diorite and gabbro. The magnetic pattern in the vicinity of the gabbro body (A_3, fig. 2) suggests that the gabbro was intruded after fault movement but the age relationship to the diorite is not known. The magnetic data suggest that the diorite may be older; however, no evidence of faulting was mapped in the field which would confirm this interpretation. The southeastern end of the magnetic lineation (L_2) appears to cross the north-south magnetic anomaly zone A_1, but there is no apparent displacement in the older north-south structure. This is true also in the Jabal al Qarah quadrangle to the south where the continuation of the magnetic lineation L_1 intersects the north-south fault zone. Schmidt (personal commun., 1974) suggests that regional structural patterns that represent zones of weakness, perhaps intruded by deep seated ultrabasic rocks, were developed parallel to the Najd fault system. In many such cases, there is little or no evidence in rocks at the surface of relative movement or of the source of the magnetic lineations.

Three distinct magnetic anomalies marked A_3 on figure 2, coincide with gabbro bodies (pl. 1). The magnetic anomalies are about 800 gamma intensity, normally polarized and are subcircular, roughly approximating the size of the mapped exposure. One exposure of gabbro mapped in the west-central part of the quadrangle (pl. 1) has no such correlative magnetic expression; the reason for this is not known but the lack of magnetic expression over this body suggests that the content of ferromagnetic mineral in this body is not appreciably higher than the surrounding country rocks.

Other zones of higher magnetic character are marked A_4 (fig. 2). These areas are largely covered by pediment alluvium and eolian sand. The zone on the northern edge of the quadrangle consists of interwoven elongated anomalies of 300-400 gamma intensity and clearly indicates the existence of mafic rocks underlying the alluvium and eolian sand. The other zone marked as A_4 is not as sharply defined inasmuch as the northwest-trending lineation crossing this area complicates the magnetic pattern. The boundary lines shown on figure 2 indicate only that within area A_4 there possibly are rocks of more mafic character.

Contrasting to the areas of higher magnetic character are zones of lower magnetic intensity marked A_5 and A_6 (fig. 2). These areas are characterized by a broad, open magnetic pattern consisting of low amplitude anomalies of a few tens of gammas. This type of aeromagnetic pattern is typical to that elsewhere on the shield over more silicic igneous rocks such as granodiorite, quartz monzonite and granite (Hase, 1970). Along the eastern edge of the quadrangle a quartz diorite mapped gives the expected magnetic pattern, and correlates reasonably well in areal extent. Quartz monzonite and granitic rocks account for the open magnetic patterns in the western half of the Ishmas quadrangle. Through the central part of the quadrangle (A_6, fig. 2), rock mapped as predominantly marbles and tuffs shows a magnetic pattern similar to the more silicic rocks.

In summary, the most striking magnetic zones correlate with mafic and ultramafic rocks along major fault zones and zones of weakness that were developed during major tectonic movement on the shield. Some of the magnetic features can be associated with rocks mapped at the surface, but some may reflect deep-seated sources.

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