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Reconnaissance geology of the Ha'il Quadrangle, sheet 27/41B, Kingdom of Saudi Arabia

by

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ABSTRACT

The Ha'il quadrangle is located on the northeastern margin of the Arabian Shield. The northern three quarters of the quadrangle are underlain by the Cambrian-Ordovician Saq Sandstone and the Ordovician-Devonian Tabuk Formation. The southern quarter is underlain by intrusive rocks of the Late Proterozoic Arabian Shield. The intrusive rocks are divided into an older orogenic assemblage and a younger postorogenic assemblage. The older orogenic plutonic rocks (greater than 620 Ma), metagabbro, quartz diorite gneiss, and foliated granodiorite and monzogranite, were probably formed in an island-arc environment. The younger postorogenic intrusive rocks (590-565 Ma), syenogranite, alkali-feldspar granite, alkali granite, granitic granophyre, and rhyolite porphyry, occur mainly in the Akash granite pluton and the Jabal Aja intrusive complex, and may have formed during a regional episode of continental collision.

No ancient mines are known in the quadrangle, nor were any base- or precious-metal mineral occurrences located. A tin greisen was discovered along the western margin of the Akash granite, and niobium and rare-earth minerals are associated with the Nisiyah alkali apogranite stock on the flank of the Jabal Aja intrusive complex.

INTRODUCTION

Geographic setting

The Ha'il quadrangle occupies a 2,740 km^2 area bounded by lat 27°30' N. and 28°00' N., and long 41°30' E. and 42°00' E., and straddles the contact between rocks of the northeastern part of the Precambrian shield and the overlying lower Paleozoic sedimentary sequence. The most striking geographic feature of the quadrangle is the rugged granitic massif of Jabal Aja, which extends into the quadrangles to the west and southwest. The altitude of the highest peaks in Jabal Aja are almost 1500 m above sea level (a.s.l.) and the eastern mountain front of Jabal Aja rises about 500 m very steeply from a nearly flat pediment surface which defines most of the quadrangle area.

The city of Ha'il, a rapidly expanding administrative center for the region, lies at the foot of the Jabal Aja mountain front in the southern part of the quadrangle, at an altitude of about 980 m (a.s.l.). Wadi Dayra is the major drainage in the southern part of the quadrangle, and flows northeastward from the city of Ha'il.

The southern margin of the Great Nafud, a sea of stabilized seif dunes (Whitney and others, 1983) that extends for over 200 km to the northwest, occupies the northwestern part of the quadrangle. Isolated peaks composed of sandstone of the Tabuk Formation occur along the southern edge of the Great Nafud.

Numerous villages are scattered throughout the Ha'il quadrangle, and large areas are under cultivation. Alfalfa and wheat are the primary crops of the region, and are irrigated from wells that are tapping a rapidly lowering water table (Ha'il Regional Planning office, oral commun.).

Five major highways radiate from the city of Ha'il. Numerous graded roads and desert tracks exist, and, except for the higher regions of Jabal Aja, access to most areas by ground vehicle is excellent.

Previous investigations

The first geological investigations in the area were reported by Brown and Jackson (1960), and several years later Brown and others (1963) produced a reconnaissance geological map at a scale of 1:500,000 of the northeastern Hijaz region. Delfour (1981) has presented a broad picture of the Precambrian evolution of the northern part of the Shield, although most of his interpretations are based on observations made at least 150 km south of the Ha'il quadrangle.

Greenwood (1972) has pointed out that the area around Ha'il occupies the axis of a broad north-plunging arch (the "Ha'il arch") that initially developed in pre-Permian time.

Several topical studies have been undertaken in the Ha'il quadrangle, all concerned with the granitic rocks of Jabal Aja. An aerial scintillation-counter survey of the Arabian Shield revealed a number of radiometric anomalies within the Jabal Aja complex. The anomalies were re-assessed by J.L.Irvine (Irvine and bin Abri, written commun., 1976). Ground assessment (Meissner and Petty, written commun., 1970; du Bray and Stoeser, 1984; Stoeser and Elliott, (1985, unpub. data) failed to detect any mineralization associated with the anomalies. Matzko and Naqvi (1978) investigated dikes along the eastern side of Jabal Aja which contain appreciable amounts of niobium, thorium, and rare-earth elements. Stuckless and others (1982a,b) have reported on the geochemistry and uranium favorability of rocks from Jabal Aja, and include several whole rock chemical analyses of granitic rocks from Jabal Aja, within the Ha'il quadrangle.

The quadrangles to the south and west of the Ha'il quadrangle have either been mapped or are currently being compiled (fig. 1). These include the Al Hufayr quadrangle to the west (27/41 A; du Bray and Stoeser, 1984) the Al Qasr quadrangle (27/41 C; Stoeser and Elliott, 1975 unpub. data), the Qufar quadrangle (27/41 D; Kellogg, 1983), and the Rák quadrangle (27/42 C, Kellogg, 1984).

Present investigations

Field work for this report was completed in two stages. Stoeser mapped the rocks of the Jabal Aja intrusive complex in the 27/41 one-degree sheet during 5 days in December, 1978, 10 days during March, 1979, and 7 days during November, 1983, primarily using helicopter support, and was responsible for reporting on all aspects of the Aja suite. Kellogg mapped the remaining Precambrian rocks during the first 10 days of May, 1983, using both helicopter and surface vehicle. Plutonic rock names follow the nomenclature of Streckeisen (1976).

Acknowledgments

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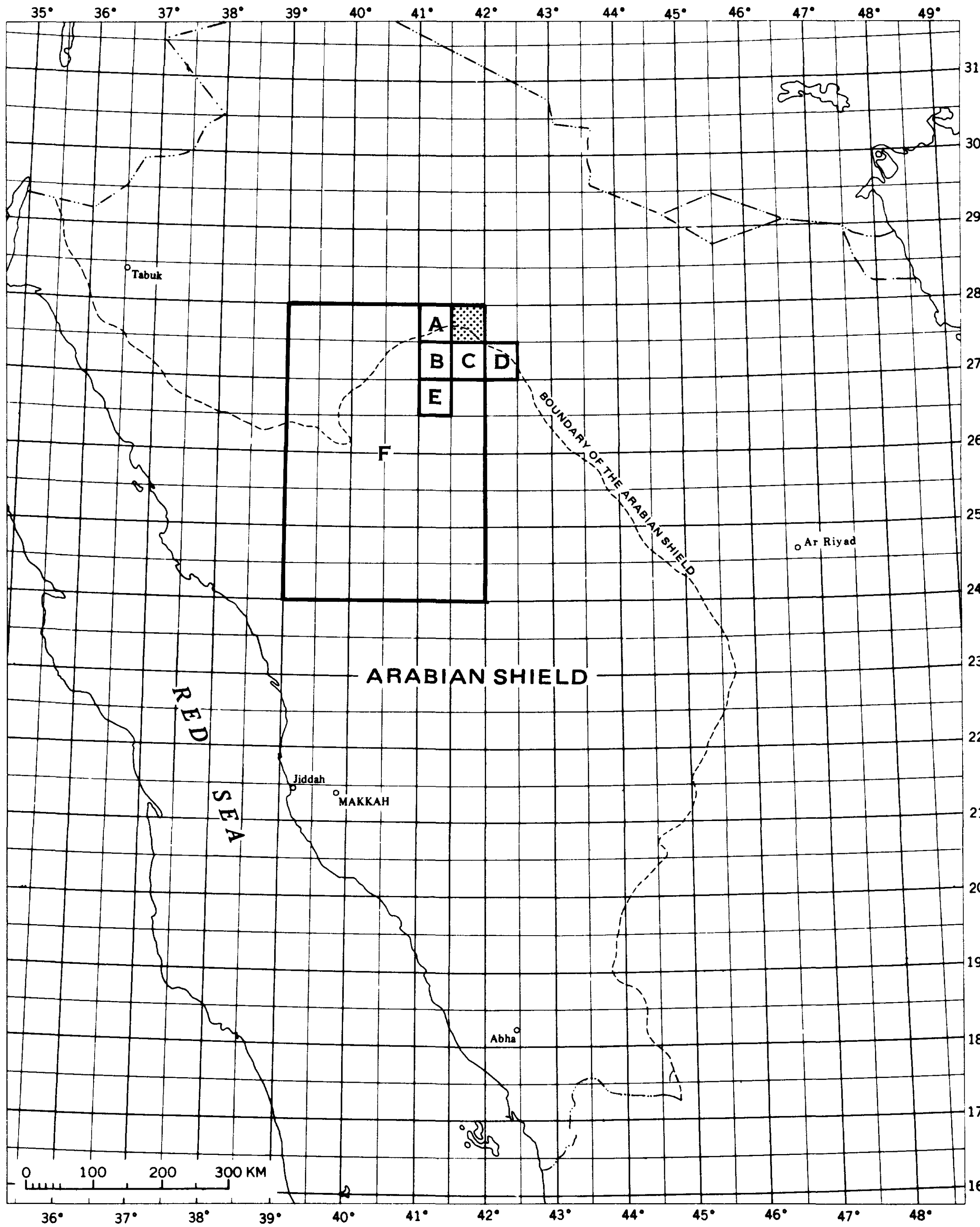

Figure 1.--Index map showing the location of the Ha'il quadrangle (patterned) and other quadrangles mentioned in this report: al Hufayr (27/41 A; duBray and Stoeser, 1984), al Qasr quadrangle (27/41 C; Stoeser and Elliott, 1985, unpub. data), Qufar quadrangle (27/41 D; Kellogg, 1983), Rak quadrangle (27/42 C; Kellogg, 1984), Ghazallah quadrangle (26/41 A; Quick, 1983), Northeastern Hijaz quadrangle (Brown and others, 1963).

GEOLOGICAL SETTING

Precambrian intrusive rocks crop out in the southern quarter of the quadrangle. The remainder of the quadrangle is underlain by nearly horizontally bedded Cambrian and Ordovician Saq Sandstone, the Ordovician to Devonian Tabuk Formation, and extensive deposits of Quaternary alluvium, dune sand, and playa silt.(see pl. 1).

The Precambrian intrusive rocks can be divided into two sequences. An older, partially deformed sequence consists of rocks ranging in composition from gabbro to syenogranite, and is predominantly monzogranite or granodiorite in composition. A younger postorogenic sequence comprises the Akash granite and the large elliptical granitic complex underlying Jabal Aja.

In a regional setting, the older intrusive sequence is part of a large, heterogeneous, and locally remobilized intrusive assemblage that extends at least 50 km to the southwest of the Ha'il quadrangle (Kellogg, 1983). Voluminous multiple intrusions within this assemblage, predominantly of calc-alkaline monzogranite and granodiorite (the Ha'il intrusive suite of this report), intruded and dismembered older gabbro and dioritic rocks (the Samra intrusive suite of Kellogg, 1983), and a predominently mafic assemblage of metamorphosed volcanic and hypabyssal rocks (the Nuf formation of Kellogg, 1983, and the Banana greenstone of Quick, 1983). A general chemical evolution is represented, as the more mafic rocks tend to be the oldest.

To the south of the Ha'il quadrangle, layered rhyolitic and minor dacitic volcanics and associated sediments of the Hadn formation (Quick, 1983; Kellogg, 1983; Stoeser and Elliott, 1984) represent subaerially equivalent rocks to at least some of the units of the Ha'il intrusive suite. These layered rocks are part of an assemblage of rhyolitic rocks that crop out extensively in the northern Shield and which has been referred to as the "Shammar rhyolite" (Brown and Jackson, 1960; Brown and others, 1963), and subsequently as the "Shammar group" (Hadley, 1973). These rocks are not represented in the Ha'il quadrangle, with one possible minor exception.

Predominantly north-trending gneiss zones are well-developed in the older intrusive rocks of the Qufar quadrangle (Kellogg, 1983), and extend into the Ha'il quadrangle. These zones represent a period of mobilization and metamorphism that occurred during emplacement of the earlier rocks of the Ha'il intrusive suite; some members of the suite are strongly foliated and deformed cataclastically, while younger members are essentially undeformed.

The rocks of the Ha'il intrusive suite are undated, although similar monzogranite and granodiorite from elsewhere in the northern Shield have yielded a consistent age of about 620 Ma (C. E. Hedge, oral commun. 1984).

The postorogenic granites of Jabal Aja were emplaced during a period of largely peralkaline magmatism about 580 Ma ago (Brown and others, 1978; Stacey and others, 1980) that produced numerous elliptical to circular, erosionally resistant granitic massifs throughout the northeastern and eastern part of the Shield (Stoeser and Elliott, 1980). These rocks are geochemically highly evolved and consist predominantly of metaluminous and peralkaline syenogranite and alkali-feldspar granite.

The Dhabi fault system (named in this report) is a generally north-northeast-striking, southeast-dipping set of imbricate thrust faults (Kellogg, 1983) that extend from the northern part of the Qufar quadrangle into the Ha'il quadrangle. The last period of thrusting apparently postdates the earlier stages of emplacement of at least some of the postorogenic granites.

INTRUSIVE ROCKS

The intrusive rocks of the Ha'il quadrangle belong to two major assemblages, both late Precambrian in age. In the south-central part of the quadrangle is an older assemblage composed of locally strongly foliated gabbro, diorite, quartz diorite, granodiorite and monzogranite. The younger assemblage consists of peralkaline rhyolite dikes, the Akash granite in the southeastern part of the quadrangle, and the Jabal Aja intrusive granite complex in the southwest.

Samra intrusive suite

Kellogg (1983) defined the Samra intrusive after Jabal Samra which lies immediately east of the city of Ha'il in the Ha'il quadrangle. Kellogg interpreted the suite as representing the oldest intrusive rocks of the Ha'il region. The suite consists of hornblende metagabbro, untramafic rocks, and diorite orthogneiss. Within the Ha'il quadrangle only the metagabbro (gb) is represented.

The Samra is black to gray, medium to coarse grained, xenomorphic, inequigranular, and contains about 50 to 75 percent calcic plagioclase (An70 to An80), 15 to 50 percent light-green actinolite, 0 to 30 percent partially uralitized clinopyroxene, up to 1 percent opaque minerals, and trace amounts of apatite, and secondary epidote. A few shreads of altered (to chlorite and epidote) biotite were observed in one thin section. The plagioclase weathers white, producing a distinctive white-and-black mottled rock, and the high (greater than 65 percent) proportion of plagioclase in many of the rocks of this unit makes the name leucogabbro appropriate. This unit is intruded by numerous diabasic and basaltic dikes, and is strongly quartz-veined.

Most metagabbro in the quadrangle is foliated with a well-developed compositional banding. Many of the mafic dikes cutting the gabbro are also foliated. Clinopyroxene rarely occurs in the more strongly foliated rock, indicating that metamorphic grade during the major period of metamorphism probably reached only amphibolite facies. Foliation planes are complexely refolded into isoclinal to open folds in some localities, such as in a prominent roadcut just northwest of Jabal Samra.

Gabbro is clearly intruded by gneissic monzogranite of the Ha'il intrusive suite, and occurs in numerous small blocks, many too small to show on the plate, incorporated into both foliated and non-foliated granitic rocks. Two relatively large areas underlain by metagabbro are most of Jabal Samra, a prominent black mountain just east of Ha'il, and a low hilly region about 4 km west of Jabal Akash, in the southeast corner of the quadrangle. Metagabbro weathers to a dark-gray to black rock with a distinctive dark-gray to greenish-gray soil.

Quartz diorite gneiss

A few isolated inliers of quartz diorite gneiss (qd), including subordinate foliated trondhjemite and quartz-bearing diorite, occur scattered throughout the quadrangle. The largest body of quartz diorite underlies about 15 km^2 immediately north of the city of Ha'il. The rock is heterogeneous in composition, although it generally contains about 70 percent oligoclase or andesine (locally normally zoned), 5 to 15 percent biotite, 5 to 10 percent hornblende, 2 to 10 percent quartz, and trace amounts of sphene, opaque minerals, apatite, and rare clinopyroxene.

Quartz diorite gneiss is intruded by rocks of the Ha'il intrusive suite, and generally correlates with the diorite orthogneiss unit of the Qufar quadrangle.

Ha'il intrusive suite

Gabbro and quartz diorite gneiss is intruded by granodiorite and monzogranite of the Ha'il intrusive suite, a name proposed in this report to include voluminous intermediate to felsic calc-alkaline intrusive rocks that crop out extensively in the region around Ha'il. This suite includes rocks mapped in the Qufar quadrangle (Kellogg, 1983) as Ha'il granite, the Malayhah granite complex, 'Ishsh monzogranite, and syenogranite. The rocks of the Ha'il intrusive suite were probably emplaced during an extensive magmatic event in the northern part of the Shield that began sometime before 652 Ma and continued until about 610 Ma years ago (C. E. Hedge, oral commun.). During this event, numerous granitic plutons were feeders to extensive rhyolitic and dacitic volcanic rocks (the Shammar group of Hadley, 1973) that are well-exposed throughout the northern Shield, although none are mapped in the Ha'il quadrangle.

Many of the rocks of the Ha'il intrusive suite are strongly foliated and lineated, and cataclastic features such as augen texture and mylonitization are common.

Granodiorite and monzogranite gneiss

Granodiorite and monzogranite gneiss (ggn) is very heterogeneous in composition and texture, but is generally a light-grayish-pink, medium-grained, inequigranular, granoblastic to strongly foliated and lineated biotite-amphibole monzogranite or granodiorite gneiss. Plagioclase varies in composition from An6 to An20, and the total amount of mafic minerals is generally less then 5 percent. The amphibole in most cases is ferroedenite, and commonly occurs in small clots in association with magnetite, biotite and sphene. Trace minerals include zircon, allanite, apatite, and secondary calcite, epidote, and chlorite.

This unit defines a wide north- to northeast-trending zone in the southeastern part of the quadrangle. The Dhabi fault system is situated near the center of the gneiss zone, and is oriented approximately parallel to it. The foliation tends to have a more pronounced cataclastic texture towards the eastern part of the gneiss zone, where crush-structures such as augen texture and mylonite are common. However, everywhere within this unit at least some recrystallization features, such as secondary biotite flakes oriented parallel to foliation, are present. West of the Dhabi fault systen, the gneiss is more thoroughly recrystallized and compositional banding is common. Also to the west of the Dhabi fault system, numerous lenses of foliated diorite or quartz diorite, oriented parallel to foliation, are interlayered with the granodiorite and monzogranite gneiss. These lenses probably represent older pods of deformed diorite and quartz diorite contained in the granitic rock. Only a couple of the larger of these dioritic lenses (mapped as quartz diorite gneiss) are shown on the plate

Clotted granodiorite and monzogranite

Clotted granodiorite and monzogranite (mdc) is mostly the non-foliated equivalent to the granitic gneiss unit, and consists of a pinkish-gray, medium-grained, xenomorphic, inequigranular granodiorite or monzogranite. Monzogranite is the predominant rock type, and typically contains about 28-34 percent strongly undulatory quartz, 25-40 percent microcline, 30-37 percent oligoclase (An10-12), 0-4 percent ferroedenite, 0-2 percent partially altered biotite, and trace amounts of opaque minerals, sphene, allanite, and zircon. The mafic minerals, including sphene, commonly occur in small fine-grained clots. Granulated grain boundaries indicate that this unit has undergone some cataclastic deformation. The rock is not resistant to weathering, and crops out in yellowish-tan slabs and small craggy tors.

Non-deformed rocks of this unit intrude strongly foliated gneiss on the northwest side of the gneiss zone. The transition between foliated and non-foliated rocks appears to be gradual on the southeast side of the gneiss zone. On this basis, the clotted granodiorite and monzogranite unit probably represents at least two periods of intrusive activity.

This unit corresponds to non-foliated phases of the Ha'il granite as mapped in the Qufar quadrangle (Kellogg, 1983). It is intruded by the Akash granite and by numerous mafic to felsic dikes, and contains older blocks of quartz diorite and gabbro. Massive monzogranite of this unit intrudes strongly foliated granitic gneiss about 5 km northeast of Ha'il.

Monzogranite porphyry

Monzogranite porphyry (mgp) crops out in one area several km north of Ha'il, and is a distinctive light-pink, fine- to coarse-grained, xenomorphic, very inequigranular to porphyritic, leucocratic monzogranite that crops out in low relief. Pink microcline is easily distinguishable from white plagioclase (An12). As much as 2 percent partially altered biotite and 1 percent hornblende, and trace amounts of opaque minerals, sphene, and zircon occur in this rock. Phenocrysts as large as 7 mm include quartz, plagioclase and microcline. No contact relationships between this unit and others of the Ha'il intrusive suite were observed.

Biotite-sphene monzogranite

Biotite-sphene monzogranite (mgb) underlies most of the city of Ha'il, including the west end of the prominent dike-supported ridge in the north part of the city. The rock is gray to slightly pinkish-gray, medium to coarse grained, hypidiomorphic inequigranular and contains about 23-28 percent quartz, 29-34 percent microcline with numerous small inclusions of plagioclase, 40 percent oligoclase (An12-15), 3-4 percent biotite, 0.5 percent large (to 2 mm) sphene crystals, and trace amounts of opaque minerals, allanite and zircon. Biotite-sphene monzogranite shows good primary igneous textures, and generally has about a 50 percent higher scintillation count than other monzogranites of the Ha'il intrusive suite. The rock is extremely weathered and "grussy," at most localities, and is preserved only adjacent to large northwest-trending resistant granitic dikes.

Biotite-sphene monzogranite intrudes foliated gabbro in the ridge in the northeast part of the city of Ha'il, and is intruded by the rocks of the Aja intrusive complex.

Syenogranite

Syenogranite (sgr) is mapped in one area northeast of the city of Ha'il, adjacent to the Saq Sandstone. The rock is pink, medium to coarse grained, hypidiomorphic inequigranular, and leucocratic, and contains about 38-40 percent quartz, 43-49 percent strongly perthitic potassium-feldspar, trace to 1 percent biotite and opaque minerals, and trace amounts of sphene and zircon. The sparse mafic minerals are commonly clotted, and appear in hand specimen like small magnetite grains. Syenogranite crops out in low, reddish-brown slabs and tors.

Syenogranite intrudes strongly foliated and compositionally banded granitic gneiss of the granodiorite and monzogranite gneiss unit, and is intruded by the prominent northwest-trending granitic dike system.

Akash granite

The Akash granite (gra) crops out in the extreme southeastern part of the quadrangle, and extends into the quadrangles to the south and southeast (Kellogg and Smith, 1985, unpubl. data). This unit defines a 10 by 14 km elliptical-shaped pluton with long axis oriented approximately north. The northern portion is covered by horizontally bedded Saq Sandstone. The rock is a light-pink, medium-grained, xenomorphic to hypidiomorphic monzogranite or syenogranite, and in the Ha'il quadrangle, contains 30-35 percent non-undulatory quartz, 43-52 percent coarse-grained, cloudy and strongly perthitic potassium-feldspar, 12-24 percent sodic oligoclase (An11-16), 1-3 percent biotite, and trace amounts of muscovite, apaque minerals, fluorite, zircon, allanite, and apatite.

Adjacent to the older clotted granodiorite and monzogranite unit of the Ha'il intrusive suite, the northwest contact of the Akash granite is strongly altered, and, within several tens of meters of the contact along Jabal Akash, a well-developed zone of greisen occurs (referred to in the Economic Geology section).

The Akash granite appears to be slightly zoned. Modal mineralogy in the Akash granite to the south of the quadrangle boundary indicates that the rock is slightly less potassic (fig. 2). This may reflect mild potassic alteration peripheral to the greisenized zone on Jabal Akash.

Numerous reddish-brown, aphanitic to very fine grained, silicic rhyolite dikes, as much as several meters thick, are probably related to late stages of emplacement of the Akash granite. The rock is quartz-phyric, and spherulites are common. These dikes intrude older monzogranite of the Ha'il intrusive suite along the west side of the ridge which includes Jabal Akash, and have a strike which is parallel to the Akash granite contact. The dip is between 30^{o} and 50^{o} to the east. These dikes are not noticably greisenized.

Peralkaline granophyre dikes

A swarm of large peralkaline granophyre dikes, as much as 20 m wide, trends between N. 10^{o} W. and N. 35^{o} W. in the south-central part of the quadrangle. Fresh dike rock is dark gray, very fine grained to fine grained, inequigranular to porphyritic, with a well-developed graphic intergrowth of potassium feldspar and quartz. Albite, primarily as phenocrysts, forms as much as 20 percent of the rock. Mafic minerals form as much as 5 percent of the rock and include arfvedsonite and aegerine-augite. Opaque minerals compose as much as one percent of the rock, and trace minerals include zircon, secondary sericite, and epidote. The rock weathers to a yellowish-tan to reddish-brown color, and is relatively resistant to erosion, producing numerous long linear ridges.

The peralkaline granophyre dikes intrude all phases of the Ha'il intrusive suite, and possibly some early phases of the Jabal Aja intrusive complex. They are part of a group of north-northwest-striking dike swarms that occur throughout the Ha'il region (du Bray and Stoeser, 1984; Ekren, 1984; Stoeser and Elliott, 1985, unpub. data). Their relationship to the Aja intrusive complex is unclear. They represent a regional episode of peralkaline silicic magmatism and regional extension prior to the emplacement of the Jabal Aja intrusive complex, and may not be significantly different in age, although they do not intrude the rocks of the intrusive complex.

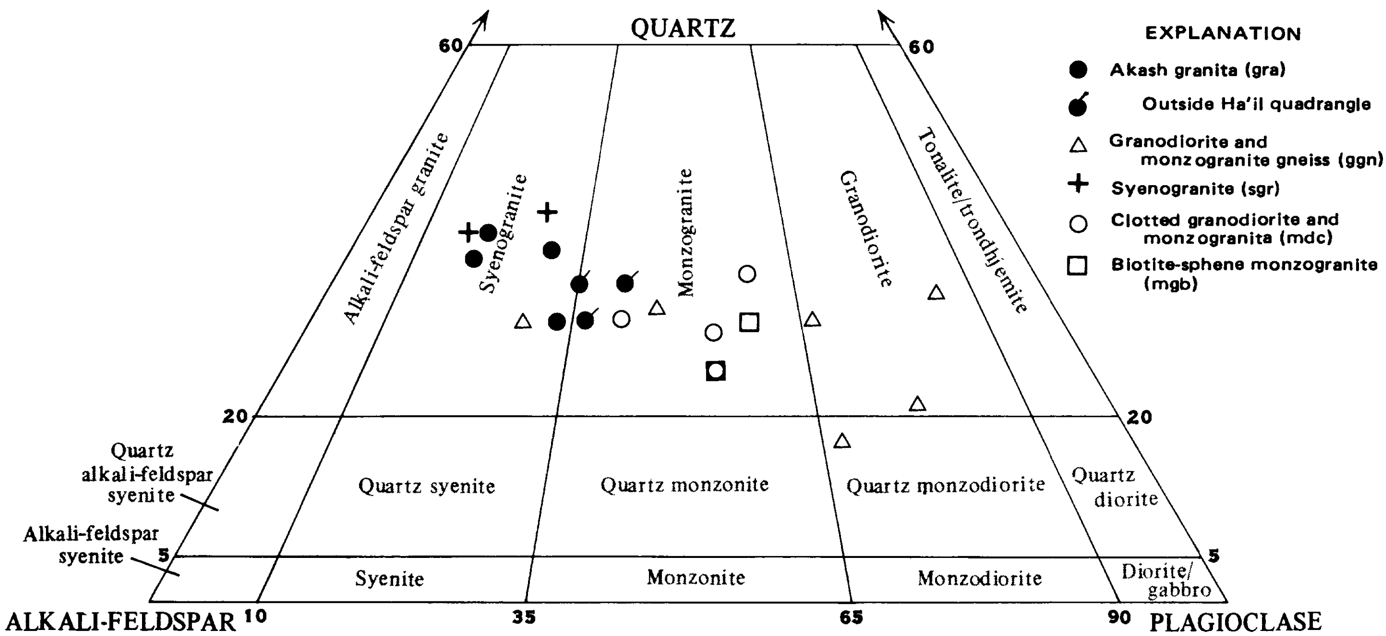

Figure 2.—Modal compositions of rocks of the Ha'il intrusive suite and the Akash granite, following the terminalogy of Streckeisen (1976). The symbols represent the Akash granite (gra), granodiorite and monzogranite gneiss (ggn), clotted monzogranite and granodiorite (mdc), monzogranite porphyry (mgp), biotite-sphene monzogranite (mgb), and syenogranite (sgr).

Jabal Aja intrusive complex

The Jabal Aja range forms the type area for the Aja suite, which includes the Jabal Aja intrusive complex and several other nearby plutons (du Bray and Stoeser, 1984; Stoeser and Elliott, 1985 unpub. data). The Aja suite is composed of a cogenetic suite of hypersolvus alkali-feldspar granite, porphyritic micrographic granophyre, and rhyolite porphyry.

The Jabal Aja intrusive complex, about 35 km by 85 km in area, was first named by Stoeser and Elliott (1980) as the Jabal Aja granite complex after Jabal Aja, a prominent ridge along the eastern margin of the pluton, west of the city of Ha'il. The Jabal Aja intrusive complex is divided into two main subunits, which are referred to in this report as the rim complex and the core complex. The rim complex, which almost completely encircles the core except on the southern margin, consists mainly of peralkaline hypersolvus granites. The core complex consists of granophyres, leucocratic alkali-feldspar granite and intrusive rhyolite porphyry. In the Ha'il quadrangle, the rim complex also contains at least seven large roof pendants. In addition to the units of the Aja intrusive complex, one other unit, the Nisiyah alkali apogranite, is assigned to the Aja suite. The map symbol for all map units which belong to the Aja suite (except the roof pendants) are prefixed with the letters "aj".

Rim complex

The rim complex consists of four units, three of which are peralkaline alkali-feldspar granites and one of which is a comendite porphyry.

Arfvedsonite-aegirine alkali granite: Grayish-orange-pink arfvedsonite-aegirine alkali granite (aje) forms the bulk of the rim of the Jabal Aja complex in the Ha'il quadrangle. Based on seven samples the unit appears to be rather inhomogeneous and it may actually represent several intrusive units which are inseparable with the present level of sampling. The outer rim granite contains a number of large roof pendants in the northern portion of the complex. The relative age of the outer rim granite to the other rim granite units and the core granophyres has not been established. du Bray and Stoeser (1984) report a similar unit, their aegirine-augite alkali granite, which occurs on the western flank of the Jabal Aja intrusive complex in the Hufayr quadrangle.

The rock is a dark-greenish-brown alkali-feldspar granite (fig. 3) with a coarse-grained hypersolvus texture and average grain sizes in the range 1 1/2 to 5 mm. The major minerals are perthite, quartz, aegirine or aegirine-augite and arfvedsonite or katophorite amphibole. The chief feldspar is a string-to-patch perthite that in most samples is rimmed and partially replaced by late fine-grained albite. The pyrobole minerals are paragenetically late relative to the feldspar and quartz and tend to occur in interstices between the felsic minerals. In samples that contain both amphibole and aegirine-augite, the pyroxene partly replaces the amphibole. Accessory minerals include (although the entire suite is not present in all samples) ilmenite, fluorite, zircon, anegmatite, and elpidite ($Na_2ZrSi_6O_{15}.3H_2O$).

Katophorite alkali granite: This unit (ajk) only occurs within a small area on the western border of the quadrangle and is assumed to be an eastern extension of the kataphorite alkali granite unit of du Bray and Stoeser (1984) in the Hufayr quadrangle to the west. In the Ha'il quadrangle only one sample of this unit was examined in thin section. It is a coarse-grained, hypersolvus perthite granite (fig. 3) with an average grain size of approximately 5-6 mm. The feldspars are weakly oxidized string perthites with very fine grained albite along the grain boundaries. Quartz show a minor amount of strain with suturing of the grain boundaries. Clinopyroxene is the earliest pyrobole and is weakly pleochroic from medium green to olive green. Amphibole tends to subhedral, averages 1-2 mm in length, is pleochroic pale olive green to dark green and typically includes pyroxene and abundant opaque minerals. The identification of the pyroboles is uncertain, but they are assumed to be ferrohedenbergite and ferroedenite hornblende. A trace amount of late dark-red-brown to black biotite is also found. Accessory minerals include magnetite, ilmentite, apatite, zircon and a deep-red mineral (allanite?).

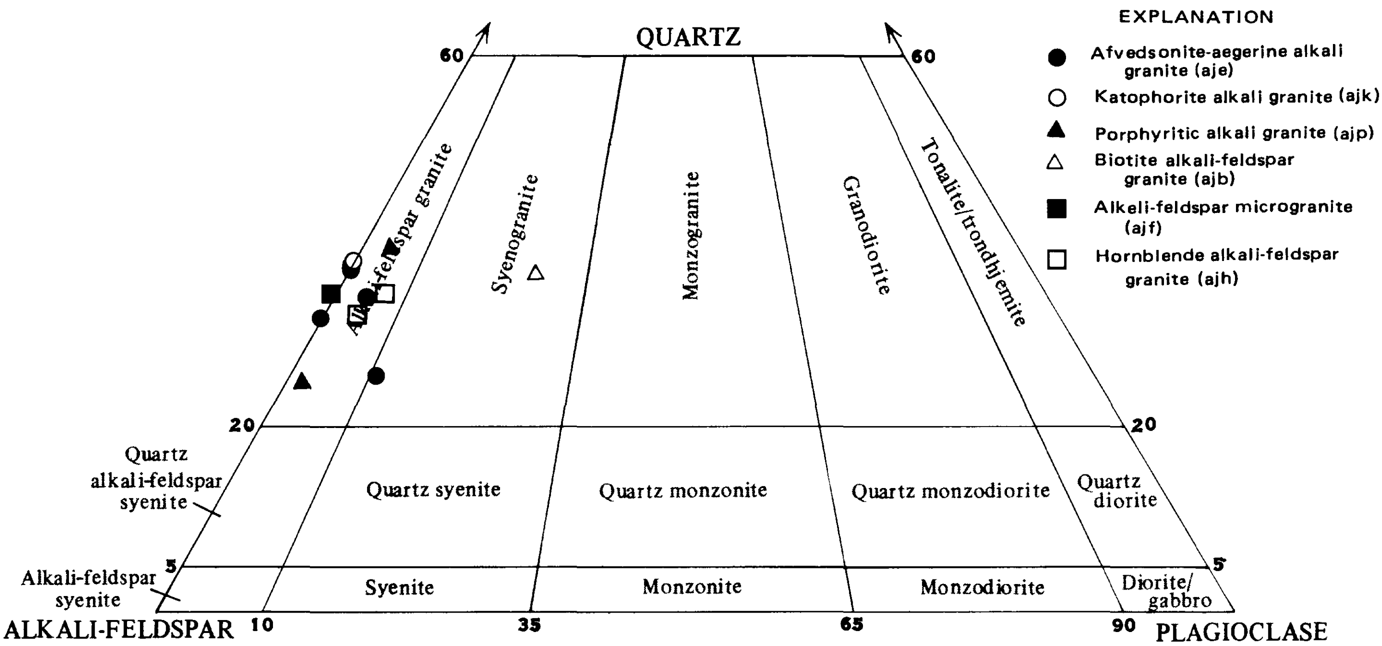

Figure 3.—Modal compositions of rocks of the Jabal Aja intusive complex. Field boundaries same as figure 2. The symbols represent the arfvedsonite-aegirine alkali granite (age), katophorite alkali granite (agk), porphyritic alkali granite (ajp), biotite alkali-feldspar granite (ajb), alkali-feldspar microgranite (ajf), and hornblende alkali-feldspar granite (ajh).

Porphyritic alkali granite: This unit (ajp) occurs only along the western margin of the quadrangle and is an extension from the al Hufayr quadrangle of the porphyritic alkali granite unit of du Bray and Stoeser (1984). Only two samples were examined in thin section. Both consisted of about 50-60 percent alkali-feldspar (as much as 1 cm) and quartz phenocrysts (less than 0.5 cm) in a fine-grained microgranitic groundmass (fig. 3). In one sample the alkali-feldspar is extensively replaced by albite. Fine-grained aegirine (3-7 percent) and alkali amphibole (1-3 percent) occur in the groundmass with aegirine in greater abundance than the amphibole. The amphibole is pleochroic olive green to dark brownish green and is assumed to be katophorite. Accessory minerals are sparse and include zircon, ilmenite, anegmatite, fluorite, and an unidentified decomposed brown mineral.

Comendite porphyry: A grayish-green comendite (peralkaline rhyolite) porphyry (ajt) is mapped at two localities in the northern part of the rim complex. The northern unit is small, underlying an area of approximately one square kilometer; whereas, the southern unit includes an area of about 3 by 11 km and occurs along the southern margin of the rim complex. The southern unit appears to form a cap over the pink core granophyre and the highest summit within the Jabal Aja complex occurs on the comendite porphyry. The unit may be a finer-grained equivalent of the porphyritic alkali granite. At the contact with the leucogranite roof pendant along the northern margin of the main unit, the porphyry has a dense, very fine grained, flow-foliated, phenocryst-poor quench zone. The comendite porphyry is typically two to four times more radioactive than the rim granite units.

The comendite porphyry contains approximately 35 to 50 percent alkali-feldspar (5 mm) and quartz (0.3 mm) phenocrysts in a very fine grained, inequigranular groundmass. The proportion of alkali-feldspar to quartz phenocrysts ranges from 2:1 to 4:1. The pyrobole content of the groundmass is highly variable and ranges from about 6 to 45 percent with an average content of approximately 15 percent. The proportions of pyroxene to amphibole is also variable and either may be dominant in any particular sample. Aegirine ranges from very fine grained to 1 to 2 mm in diameter and is commonly zoned with pale-yellow-green cores and dark-green rims. The larger grains tend to be relatively equant, but the smaller grains are lath-shaped to acicular. Although in part coeval with the amphibole, aegirine is also locally rimmed by amphibole. The pleochroisim of the amphibole, which is assumed to be arfvedsonite, is highly variable from sample to sample and includes pale slate gray green to bright apple green, medium olive green to deep grayish blue, and deep brownish red to deep olive green. The habit of the arfvedsonite varies from fine-grained nonpoikiolitic laths to very poikiolitic grains as large as 2 mm in diameter. Accessory minerals are sparse and none were observed in the majority of the samples examined in thin section. They include aenigmatite, apatite, elpidite (northern unit only), fluorite, and zircon (?) (opaque minerals were not observed).

Roof pendants in rim complex

Seven roof pendants comprising five different lithologies are mapped in the rim complex. They range in size from 2 to 10 kilometers in length. The roof pendants have been treated as separate map units from those recognized outside of the Jabal Aja intrusive complex.

Leucogranite: The leucogranite (grl) occurs as two roof pendants within the arfvedsonite-aegirine alkali-feldspar rim granite. The larger is approximately 4 by 10 km and the smaller 1 1/2 by 4 km (the smaller roof pendant is exposed in two isolated outcrops which are separated by cover and it is assumed that they are part of a single block). The blocks are cut by rhyolite and diabase dikes which are restricted to the blocks and therefore older than the host granite. A third roof pendant of leucogranite was tentatively identified within rim granite along the eastern margin of the Jabal Aja complex near the south boundary of the quadrangle. This block was not visited in the field.

Two samples of the larger block were examined in thin section. One sample was a seriate leucomonzogranite with alkali-feldspar (patch perthite) and quartz as large as 5 mm in a fine-grained microgranitic groundmass composed of microcline, quartz, and plagioclase. No mafic minerals other than a trace of opaque oxide minerals were observed. Trace secondary, fine white mica was also present. The second sample was a medium-grained muscovite-biotite leucosyenogranite with a hypidiomorphic equigranular texture. Mica totalled less than 2 percent. Accessory minerals included sparse opaque oxide minerals and zircon.

Diabase: This unit (di), which, along with a granitic rock, appears to be part of a composite roof pendant within the eastern rim granite, was not examined in the field. It was interpreted to be diabase on the basis of observation from the air because of its similar appearance to diabase associated with granitic roof pendants in the Al Qasr quadrangle to the southeast (Stoeser and Elliott, 1985, unpub. data).

Hornblende-biotite monzogranite: The hornblende-biotite monzogranite unit (mgh) occurs as two roof pendants hosted by the porphyritic alkali granite in the northern part of the rim complex. The northwestern block is 1 by 1.8 km and the southwestern block is tear-drop shaped with a length of 4 km and a maximum width of 1.5 km. Both are cut by felsic and diabasic dikes that are older than the host granite. A third roof pendant that lies north of both of these blocks and which was not visited is also tentatively assigned to this unit.

One specimen from each of the sampled blocks was examined in thin section. The sample from the northwestern block is a fine-grained hornblende-biotite monzogranite with an inequigranular, hypidiomorphic texture and an average grain-size of about 3/4 mm.

The feldspars are very oxidized and the quartz shows considerable resorption. The mafic minerals total about 3 1/2 modal percent with about 3 percent biotite and 1/2 percent hornblende. The biotite is pleochroic yellow ochre to chestnut brown, and has decomposed rims that have been replaced by fine-grained opaque minerals. The hornblende is pleochroic light to medium olive green. Accessory minerals include opaque oxides minerals, zircon, apatite and sparse sphene.

The sample from the southeastern block is a medium-grained hornblende-biotite monzogranite with an inequigranular, hypidiomorphic-granular texture and an average grain-size of about 1 1/2 mm. Quartz is considerably strained and quartz-quartz contacts are highly sutured. The rock contains about 2 percent biotite and less than one percent hornblende. The biotite is pleochroic pale ochre yellow to brown and partially replaced by chlorite. The hornblende is pleochroic pale yellow to medium olive green to medium apple green. Accessory minerals include opaque oxide minerals, and sparse sphene, apatite, and zircon.

Rhyolite tuff: One small area of pinkish-red rhyolite tuff (rt) overlies the southernmost hornblende-biotite monzogranite roof pendant. It exhibits a well-preserved, eutaxitic texture in the field, and was altered and brecciated. The tuff was not examined in thin section. It is not known whether this tuff is older than the rocks of the Aja suite and should be assigned to the Hadn formation (Stoeser and Elliott, 1985, unpub. data) or is coeval with or younger than the Aja suite and represents a relic of a volcanic carapace that used to overlie the Jabal Aja intrusive complex.

Alkali granite: The alkali granite unit (ag) is represented by two roof pendants within the arfvedsonite-aegirine alkali-feldspar rim granite in the northeastern part of the Jabal Aja complex. The northern block is approximately 2 km^2 and the southern 22 km^2. The alkali granite roof pendants are heavily diked by the peralkaline rhyolite (comendite) dikes. These dikes appear to be an extension of the intense north-northwest-striking dike swarm which cuts the Ha'il granite north of the city of Ha'il. Since these dikes do not cut the rocks of the Jabal Aja intrusive complex, it seems clear that the alkali granite roof pendants predate the complex and the diking. du Bray and Stoeser (1984) report a similar large, diked, roof pendant of alkali granite in the rim complex to the west in the Hufayr quadrangle. It is not clear whether these pre-dike alkali granites represent an early intrusive phase of the Aja suite or are an earlier unrelated phase of alkali granite plutonism that has been incorporated into the Jabal Aja intrusive complex. du Bray and Stoeser (1984), and Stoeser and Elliott (1985 unpub. data) report older alkali granites that occur outside of the Jabal Aja intrusive complex and which are also diked by peralkaline rhyolites in the Hufayr and al Qasr quadrangles.

Two samples of the southern block were examined in thin section. It consists of a medium-grained alkali granite. The samples show evidence of recrystallization and the pyroboles have been extensively oxidized to fine-grained aggregates of opaque oxide and felsic minerals. The rock contains about 3 percent amphibole and 1 percent pyroxene. The amphibole is pleochroic olive green to dark slate gray blue and assumed to be arfvedsonite. The pyroxene is weakly pleochroic yellow green and is presumed to be aegirine. Accessory minerals are opaque oxides, zircon(?) and an unidentified brown mineral.

Core complex

The core complex contains a wider range of lithologies than the rim complex and in general these units are metaluminous, not peralkaline like the rim granites. The core units include three granophyre units, four granite units, and a rhyolite porphyry.

Pink core granophyre: The pink core granophyre (ajc) is the most widespread unit within the core complex. It forms pink to pink-red massive outcrops which typically have considerable relief and weather with smooth rounded faces. Observations throughout the core complex suggest that the pink core granophyre consists of multiple cooling units, but due to the lithologic similarity of these units it is not possible to map them on a reconnaissance basis (du Bray and Stoeser, 1984). An area of about 7 km^2 is also mapped within the rim complex where it cuts a monzogranite roof pendant. It is not known whether the granophyre is part of the roof pendant and therefore older than the rim granites or is intrusive into the rim complex.

The core granophyre has a very fine grained miarolitic micrographic groundmass and approximately 35 to 50 percent alkali-feldspar (5 mm) and quartz (1-3 mm) phenocrysts. The proportion of alkali-feldspar and quartz phenocrysts varies from about 1:1 to 5:1. The alkali-feldspar phenocrysts are generally oxidized, resulting in their being clouded by fine hematitic(?) particles. The pink core granophyre appears to have been pervasively oxidized such that mafic silicates have been destroyed in most samples. In samples where they have been preserved, the granopyre is leucocratic and only contains one or two percent biotite. Accessory mineral are sparse and include fluorite, opaque oxides, allanite, and zircon.

Biotite alkali-feldspar granite: The biotite alkali-feldspar granite (ajb) occurs along the eastern margin of the core between the pink core granophyre and the aegirine-augite alkali-feldspar granite. It weathers pinkish red to brick red and is very well exposed, forming extremely rough terrane with considerable relief. Its appearance in the field is very similar to that of the pink core granophyre and it may be directly related to that unit. Although both the pink core granophyre and the biotite alkali-feldspar granite units extend into the Qufar quadrangle, Kellogg (1983) did not differentiate these units and only recognized one unit, his leucocratic syenogranite member.

Only two samples of the biotite alkali-feldspar granite were examined in thin section (fig. 3). It is medium grained (approximately 3 mm average grain size) with a somewhat seriate hypidiomorphic-granular texture. The alkali-feldspar is a string perthite with a maximum diameter of 5 mm and is moderately oxidized with some unaltered patches within grains. Quartz ranges from euhedral to anhedral and appears to have grown cotectically with the alkali-feldspar. One to two percent ochre-yellow to dark-brown biotite occurs in the interstices between the felsic minerals. Accessory minerals include abundant fluorite and zircon that mainly occur intergrown with biotite and sparse opaque oxide minerals.

Hornblende granophyre: In outcrop the hornblende granophyre (ajw) has a brownish-pink cast, but is very similar in appearance to the pink core granophyre and completely contained within it. The hornblende granophyre occurs mainly in the southwestern part of the Ha'il quadrangle, but extends into the Hufayr quadrangle to the west. The age relationship between the hornblende granophyre and pink core granophyre has not been established, but it is assumed that the hornblende granophyre is intrusive into the pink core granophyre on the basis of the hornblende granophyre outcrop distribution and that it does not appear to be as altered as the pink core granophyre.

Three samples of this unit were examined in thin section. The hornblende granophyre is fine grained, with a microgranitic seriate texture. Alkali-feldspar and quartz grains range as large as 4 mm in diameter, and average less than 1 mm. The alkali-feldspar is typically somewhat oxidized causing it to be clouded with fine hematite(?) particles. As much as a few percent plagioclase occur in two samples. The rock is leucocratic with less than 2 percent fine-grained pale-yellow to olive-green hornblende. Accessory minerals include red-brown biotite, fluorite, zircon, opaque oxides, and allanite(?).

Hornblende alkali-feldspar granite: The hornblende alkali-feldspar granite (ajh) occurs in the central part of the core complex in the southwestern part of the quadrangle. It weathers brownish pale red and has somewhat subdued relief relative to the pink core granite and biotite alkali-feldspar granite units. It is the northern extension of Kellogg's (1983) hornblende syenogranite unit of the Qufar quadrangle. The hornblende granophyre abuts it to the north and lies on its strike extension suggesting that the two units are related.

Four samples of the hornblende alkali-feldspar granite were examined in thin section. It is medium grained (average grain size 2.5 to 5 mm) with a typical hypersolvus texture. The alkali-feldspar is a string perthite that is moderately to heavily oxidized. The granite is leucocratic and contains about 3 to 4 percent pale-yellowish-olive-green to deep-olive-green hornblende and less than one percent biotite in one sample. Accessory minerals include zircon, apatite, opaque oxide minerals, and allanite.

Granophyre dike: The granophyre dike unit (ajd) is located between the hornblende alkali-feldspar granite and the pink core granophyre. It extends southwards into the Qufar quadrangle where it is part of a small group of arcuate dike-like bodies which occurs in the pink core granophyre or separate the pink core granophyre from the hornblende alkali-granite unit. In addition, one small intrusion of granophyre of about 1/4 Km^2 about 3 1/2 km north of the main unit was included in this unit. In the Ha'il quadrangle the granophyre dike unit is 200 to 400 m wide and over 3 km wide. No samples of this unit were taken from the Ha'il quadrangle. Rocks belonging to these granophyric intrusions in the Qufar quadrangle consist of leucocratic micrographic granophyre containing 2 to 3 percent biotite and(or) hornblende.

Aegirine-arfvedsonite micrographic granite: The aegirine arfvedsonite micrographic granite unit (ajg) occurs as a single mappable unit in the northeastern margin of the core complex. It lies between the pink core granophyre on the west and the biotite alkali-feldspar granite on the east, and is intruded by stocks of alkali-feldspar microgranite. Its age relative to adjoining units is uncertain but assumed to be younger than them on the basis that the feldspars and pyroboles of the aegirine-arfvedsonite micrographic granite are less oxidized than those of the adjoining units.

Three samples of this unit were examined in thin section. The rock is a micrographic granite with 40 to 70 percent phenocrysts of alkali-feldspar and quartz (approximate proportions of 3:1) in a very fine grained micrographic groundmass. Two of the samples are only weakly oxidized such that the alkali-feldspar is only slightly turbid and the pyroboles are fresh. The third sample is strongly oxidized such that the alkali-feldspar is clouded with hematitic dust and no pyroboles were observed. The fresh samples contain about 4 percent amphibole and pyroxene. In one sample the amphibole is pleochroic grayish olive green to dark green blue and assumed to be arfvedsonite, and in the other sample is medium olive green to deep apple green and assumed to be katophorite. In both samples the pyroxene is moderately pleochroic from bright yellow green to deep emerald green and is either aegirine or aegirine-augite. Accessory minerals include zircon, opaque oxide minerals, fluorite, apatite, an unidentified neutral gray low relief mineral, and an unidentified deep-yellow mineral with moderate relief.

Alkali-feldspar microgranite: The alkali-feldspar microgranite (ajf) occurs as two small oval stocks in the northeastern part of the core complex. The southern stock intrudes the aegirine-arfvedsonite micrographic granite and the pink core granophyre, and is 0.7 by 1.6 km. The northern stock is emplaced in the aegirine-arfvedsonite micrographic granite and is 1.5 by 2 km. One thin section from the southern stock and two thin sections from the northern stock were examined.

The sample from the southern stock is a microgranite with an equigranular groundmass with an average grain size of about 0.2 mm and about 5 percent alkali-feldspar phenocrysts (as much as 6 mm). The rock has been strongly oxidized such that the feldspar is heavily dusted with very fine hematitic particles and all mafic silicates destroyed. Accessory minerals include zircon, opaque oxide minerals, and sparse fluorite.

The two samples taken from the northern stock were distinctly different. One was very similar to the sample of the southern stock and the other was a leucocratic medium-grained arfvedsonite aegerine-augite biotite alkali-feldspar hypersolvus granite. The rock contains about 1 percent biotite and less than one percent of pyroxene and amphibole. The biotite is pleochroic ochre yellow to brown and appears to be the earliest of the mafic minerals. The pyroxene (aegirine-augite?) is granular and non-pleochroic dark yellow green and rimmed by very fine grained amphibole. The amphibole is pleochroic gray green to slate gray blue and is assumed to be arfvedsonite. Accessory minerals include abundant fluorite and zircon.

Rhyolite porphyry: The rhyolite porphyry unit (ajr) is part of a widespread series of late intrusive rhyolite porphyries which occur throughout the Jabal Aja complex (du Bray and Stoeser, 1984; Stoeser and Elliott, 1995, unpubl. data). They are generally sill-like sheets in the core complex granophyres but small bodies of rhyolite porphyry also occur in the rim complex. Two units of rhyolite porphyry are mapped in the Ha'il quadrangle, a large sheet within the hornblende granophyre and a small plug-like body within the arfvedsonite-aegirine alkali-feldspar rim granite.

One sample from the rhyolite porphyry sheet was examined. It is a brick-red rhyolite porphyry with approximately 20 percent euhedral alkali-feldspar and quartz phenocrysts in about equal amounts. No pyrobole minerals were observed. Accessory minerals included zircon, fluorite, and abundant opaque minerals. The sill is approximately 3 to 6 m thick. Its relatively large area on the map is due to an exposed dip-slope surface, on the top of the sill.

One sample from the rhyolite porphyry stock was examined in thin section. It consists of coarse-grained highly altered alkali-feldspar phenocrysts (as large as 1 cm) in a very fine grained highly altered miarolitic groundmass.

Nisiyah alkali apogranite

The Nisiyah alkali apogranite (ajn) occurs as a 0.7 km diameter circular stock in the Ha'il granite, approximately 5 km north of the city of Ha'il and 1 1/2 km east of the Jabal Aja complex outer contact. It is informally named here after Sha'ib al Nisiyah, a wadi which passes along the western margin of the intrusion and the farming village of An Nisiyah to the north of the stock (plate). Although the stock lies within the dike swarm north of the city of Ha'il, it is not diked and therefore is younger than the swarm. In addition, a 60-70 km diameter alkali apogranite plug, which was too small to show on the plate, occurs about 300 meters east of the main stock. The Nisiyah alkali apogranite is tentatively assigned to the Aja suite on the basis of its relative age, alkali granite composition, and physical proximity to the Jabal Aja complex. The petrography of samples from these two intrusions is similar to other alkali apogranites found in the northern Hijaz and at Jabal Sayid (Drysdall and others, 1984). The economic geology of the Nisiyah alkali apogranites is discussed later in this report.

Two samples of the main stock were examined in thin section. They are virtually identical and are fine-grained alkali microgranite with an estimated average grain-size of about 0.4 mm and an equigranular granitic texture. The rock consists of about 40 percent quartz, 50 percent albite, and 10 percent pyrobole and opaque oxide minerals. The feldspar has been heavily oxidized and is clouded with a fine hematitic dust. The pyrobole has been largely converted by oxidation to a fine-grained mixture of opaque oxide and felsic minerals and only a trace amount of primary aegirine has survived. Accessory and minor minerals are opaque oxides and zircon.

Only one sample of the plug was examined in thin section. It is a miarolitic inequigranular alkali quartz-rich granitoid with an estimated average grain size of about 1/2 mm. The rock consists of about 65 percent medium-grained quartz (1-3 mm), 30 percent fine-grained late albite (0.1-0.6 mm), 3 percent opaque oxide minerals, 2 percent zircon(?), a trace of residual aegirine, and a minor amount of interstitial calcite. The quartz occurs as rounded grains with relatively inclusion-free cores and an outer zone that is filled with feldspar and opaque oxide inclusions. Some late quartz also shows growth rings as marked by well-defined zones of fine hematitic(?) dust. The bulk of the primary pyrobole has been altered to a very fine grained aggregate of opaque oxides and felsic minerals, but on the basis of pseudomorphs and relic aegirine is assumed to have all been aegirine. Zircon occurs as somewhat equidimensional disseminated granular aggregates 0.3-1.5 mm in diameter. The individual crystals have brown cores and clear outer rims. The cores may be thorite and the rims thorium-zircon. Other minor and accessory minerals include a bladed opaque mineral (ilmenite) and a trace amount of fluorite.

PALEOZOIC ROCKS

Saq Sandstone

According to Powers and others (1963), the Saq Sandstone (O€s) was named by H. L. Burchfiel and J. W. Hoover in 1935 for Jabal Saq, about 150 km southeast of the Ha'il quadrangle. The Saq Sandstone is Cambrian and Ordovician in age, and consists of reddish-brown, buff and yellowish-tan, commonly cross-bedded, poorly indurated, well-sorted, locally ferruginous quartz sandstone. Well-rounded pebbles and cobbles, predominantly of Precambrian quartz and red rhyolite, fill shallow channels at the base of the section. Thin olive and red shale lenses occur in the upper part of the section (Brown and others, 1963). Detailed petrography of the Saq Sandstone was not performed for this report.

Most of the outcrop surface of the Saq Sandstone is a rough, hummocky plain of low relief, containing sand pockets and low, slabby bluffs.

Tabuk Formation

The rocks of the Tabuk Formation (DSOt) underlie the prominent peaks of Jabal at Tawil and Jabal Humaymah in the northern part of the quadrangle, and were not investigated for this report. The contact between the Tabuk Formation and the Saq Sandstone on the plate is taken from Brown and others (1963), who state that in the area of the Ha'il quadrangle, the Tabuk formation consists predominantly of brown to tan and buff, black weathering, massively crossbedded sandstone.

MIOCENE OLIVINE BASALT

One small plug of olivine basalt (Tba) occurs in the south-western part of the quadrangle within the Aja core complex. This plug, which was not sampled, belongs to a small field of volcanic necks and plugs that occur throughout the 27/41 one-degree sheet, but are concentrated in the al Qasr quadrangle (Kellogg, 1983; du Bray and Stoeser, 1984; Stoeser and Elliott, 1985 unpub. data). Rocks from these intrusives are typically porphyritic hyalopilitic basalts with 5 to 15 percent euhedral to fragmental olivine phenocrysts and xenocrysts. Stoeser and Elliott (1985 unpub. data) report whole rock major element chemistry and K-Ar ages for two alkali olivine basalts from plugs in the al Qasr quadrangle which give preliminary ages of 15 and 19 Ma. Kellogg (1983) reported a whole rock K-Ar age of 23.4 $\pm$ 0.2 Ma for one of two small basaltic flow remnants in the Qufar quadrangle.

QUATERNARY DEPOSITS

Predominantly alluvial deposits

Sediment mapped as predominantly alluvial deposits (Qal) consist of sand and silt in currently active alluvial channels and flood plains. Minor low-lying dunes and eolean sheet sand are included in this unit.

Dune deposits

The southern edge of the Great Nafud, an extensive sea of stabilized seif dunes (Whitney and others, 1983), extends into the northwest part of the quadrangle. These dune deposits (Qd) are composed of light-tan, fine-grained, well-sorted, predominantly quartzose sand.

Playa deposits

Several closed depressions within the Ha'il quadrangle are underlain by playa deposits (Qp), composed of light-tan silt that accumulates during periods of heavy rainfall. Shallow lakes occupy these depressions after such rainfalls.

STRUCTURE

The obvious structure within the older rocks of the quadrangle is the north- to northeast-trending gniess zone which is approximately centered on and parallel to the Dhabi fault system. The foliated and lineated rocks of the gneiss zone include many of the older units of the Ha'il intrusive suite, and older, more mafic rocks.

Ruwayyah gneiss antiform

The gneiss zone is thought to represent a gneiss antiform that is truncated on the west by post-tectonic granites of the Ha'il intrusive suite. Numerous large blocks of foliated rock, dismembered pieces of the antiform, are embedded within the post-tectonic granites. The core zone of the antiform trends northeast and is centered approximately on Jabal Samra. The name Ruwayyah gneiss antiform, after a small hill in the central part of this feature, is proposed for this structure.

Metamorphic intensity generally increases from east to west across the Ruwayyah gneiss antiform. In the southeast part of the quadrangle the rock is essentially non-foliated granodiorite and monzogranite, containing numerous large gabbroic and dioritic inclusions. Towards the west, the grain boundaries within these rocks become progressively more granulated, and a slight foliation, dipping 30° to 50° consistently to the east, is induced. Further west, towards the Dhabi fault system, strongly lineated and foliated, east-dipping augen gneiss and mylonite are developed. The well-developed lineation is characterized by aligned augen trains and by small crenulations in the planes of cleavage. The presence of non-deformed flakes of biotite indicate post-deformational recrystallization. West of the Dhabi fault system, the rock is compositionally banded and strongly recrystallized; cataclastic textures are generally obscured. This region probably represents the core zone of the antiform.

The numerous gabbroic and dioritic inclusions in the granitic rocks of the Ha'il intrusive suite are progressively more elongated and foliated towards the core of the antiform. A cross section through the gneiss west of the Dhabi fault system reveals a complex interlayering of banded granitic, dioritic, and gabbroic gneiss.

The foliation and lineation directions are remarkably uniform throughout the eastern part of the gneiss antiform. Foliation generally dips between about 30° and 50° to the east, and a strong cataclastic lineation plunges between about 0° and 30° to the south. This same southerly lineation direction is evident within foliated rocks at least 30 km south of the quadrangle boundary (Kellogg, 1983).

Variations in the amount and direction of dip on foliation do occur, however, and become more varied within the more strongly foliated and recrystallized rocks in the core zone of the antiform. Complex minor folds and recrystallized mylonitic shear zones with small (as much as several 10s of cm) offsets are common, just east of Jabal Samra.

Non-foliated granitic rocks that intrude and truncate the west side of the antiform resemble many of the non-foliated granitic rocks to the east of the antiform that probably predate the formation of the antiform. Apparently, the deformational (and metamorphic) event that produced the Ruwayyah gneiss antiform did not mark a change in the geochemical nature of magmatism in the region.

Dhabi fault system

The Dhabi fault system is a much younger feature than the metamorphic rocks of the Ruwayyah gneiss antiform. The Dhabi fault system offsets the peralkaline granophyre dikes by apparent right-lateral movement along fault zones that dip about 50° east in the southernmost part of the quadrangle. The zones are between several centimeters to several meters thick, and consist of red to brown oxidized rock that is both mylonitized and brecciated. The Dhabi fault system defines numerous imbricate, generally east-dipping, thrust surfaces to the south of the Ha'il quadrangle. (Kellogg, 1983). Evidence from the Qufar quadrangle (Kellogg, 1983) strongly suggests that last movement along the Dhabi fault system also postdates deposition of the lower Saq Sandstone. Small wedges of Saq Sandstone are bounded by large northeast-trending faults within the area of outcropping Precambrian rock, and are cut by low-dipping faults of the Dhabi fault system. Within the Ha'il quadrangle, a small northwest-trending fault with apparent left-lateral offset and possibly related to the Najd fault system (Delfour, 1981) is also truncated by the Dhabi fault system.

GEOCHRONOLOGY

No radiometric ages are available for rocks of the Ha'il quadrangle and the only unit which has been dated is the Jabal Aja intrusive complex. Aleinikoff and others (1985) obtained an U-Pb zircon age of 566±19 Ma for the arfvedsonite-aegirine alkali granite unit in the Āl Qsar quadrangle. Stuckless and others (in press), using whole rock samples of the complex from the al Qasr and al Hufayr quadrangles, obtained a Th-Pb isochron age for the complex of 570±19 Ma. Brown and others (1978) report Rb-Sr whole rock ages for two unspecified localities from Jabal Aja of 580±18 Ma and 492±15 Ma. These ages indicate that the Jabal Āja intrusive complex was emplaced about 566-580 Ma ago.

Ages of older rocks in the quadrangle can only be inferred by comparison with dated rocks from elsewhere in the northern part of the Shield. For example, quartz diorites and tonalites from the northeastern part of the Shield give preliminary zircon ages that cluster around 680 Ma, although a quartz diorite which underlies the layered rocks on Jabal Hibshi, 50 km to the south of the quadrangle, gives an age of 643 Ma (C. E. Hedge, oral commun. 1984). This suggests that the quartz diorite of the Ha'il quadrangle may be between about 640 and 680 Ma old.

Calc-alkaline granites and granodiorites of the northern part of the Shield yield zircon ages that group around 620 Ma (Stuckless and others, in press; C. E. Hedge, oral commun. 1984), which suggest that at least some rocks of the Ha'il intrusive suite, as well as the Ruwayyah gneiss antiform, may also be about this age.

PRECAMBRIAN GEOLOGICAL HISTORY

The oldest rocks of the Ha'il quadrangle are metagabbroic and foliated dioritic rocks. Kellogg (1983) has inferred that similar rocks to the south of the quadrangle may have formed in the root zone of an island arc system that existed some time before about 650 Ma ago. These older mafic rocks were largely dismembered during the emplacement of the voluminous calc-alkaline plutons of the Ha'il intrusive suite. This large magmatic event produced a structurally complex batholith composed of multiple intrusions of granodiorite and monzogranite, which incorporate large blocks of gabbro and dioritic rock.

The formation of the large north- to northeast-trending Ruwayyah gneiss antiform involved the earlier units of the Ha'il intrusive suite, and older more mafic rocks. The antiform is truncated in the west by post-tectonic granitic intrusives of the Ha'il intrusive suite. Kellogg (1983) suggests that deformation may be associated with the forceful emplacement of the batholith-size Malayhah monzogranite about 25 km south of the quadrangle boundary. While this possibility has strong geological support (Kellogg, 1983), the gneiss antiform may also be the result of a more regional, generally west-directed compressional stress. Stoeser and others (1984), for example, have suggested that the southeastern part of the Arabian Shield was subjected to a major west-directed compressional event (Nabitah orogeny) about 680-640 Ma ago, produced by a collision of the young crustal rocks of the proto-Shield with a continental mass to the east. Several north-trending mobile belts, encompassing numerous synorogenic plutons, gneiss antiforms and domes, were formed at this time. Possibly, the gneiss zones in the region near Ha'il represent a small mobile belt of Nabitah age, "feathering out" into undeformed rocks to the south (just north of the Qufar quadrangle's southern boundary). Any model for the deformation in the Ha'il quadrangle, however, must take into account the widespread south-plunging lineation. This consistant lineation direction extends to 30 km south of the quadrangle, to Jabal Malayhah in the Qufar quadrangle (Kellogg, 1983).

Postorogenic plutonic rocks of the Ha'il quadrangle consist of the Akash granite and the rocks of the Aja suite. The Akash granite may be about the same age as the granites of Jabal Aja. Dated tin-bearing granites from elsewhere in the Shield have yielded dates of about 580-590 Ma (Stacy and Stoeser, 1983; Stacy and others, 1984; Stuckless and others, in press).

The Ha'il region underwent regional extension along a north-northeast axis during which numerous peralkaline rhyolite and granophyre dikes were emplaced. These dikes cut large roof pendants of alkali granite in the Jabal Aja intrusive complex, which indicates that an episode of peralkaline granitic magmatism preceded extension. The relationship of these older alkali granites to the dikes and to the younger Aja suite of alkali granites is unclear.

The last major phase of plutonism in the Ha'il region was the emplacement of the plutonic rocks of the Aja suite from about 580-566 Ma. The Aja suite belongs to widespread group of postorogenic peraluminous to peralkaline alkali-feldspar granites that were emplaced throughout the northern part of the shield from about 600 to 560 Ma (Stoeser and Elliott, 1980; Stuckless and others, 1982a; Aleinikoff and others, 1985).

After this episode of postorogenic plutonism, magmatism and tectonic activity waned throughout the region and the Cambrian-Ordovician epicontinental Saq Sandstone was deposited over the Shield as the region slowly subsided (Powers, and others, 1966). Faulting along the east-dipping Dhabi fault system, which strikes approximately parallel to the Ruwayyah gneiss antiform, was active after emplacement of at least the early rocks of the Jabal Aja intrusive complex, and there is evidence that at least some movement occurred after the deposition of the basal units of the Saq Sandstone.

ECONOMIC GEOLOGY

No ancient mines and no evidence for base or precious metal mineralization was found. Tin associated with the Akash granite was discovered during the mapping of the Ha'il quadrangle, and niobium, thorium, and rare earth elements are associated with the Jabal Aja intrusive complex and the Nisiyah alkali apogranite.

Akash granite

The Akash granite is identified as a tin-, tungsten- and zinc-anomalous granite. Extensively greisenized zones crop out along the northwest boundary of the Akash granite, within several tens of meters of the contact (MODS locality 03362). The greisenized rock is black to dark greenish gray, and is composed almost entirely of about 90 percent quartz, as a medium-grained mosaic, 5-6 percent muscovite, as much as 4 percent hematite, 0-2 percent altered biotite, as much as 1 percent fluorite, and trace amounts of cassiterite and topaz. Numerous west-trending, strongly hematitized quartz veins penetrate both greisenized rock and relatively unaltered phases of the Akash granite, and are found for at least several km from the eastern contact. These quartz veins penetrate only a few meters into the surrounding country rock to the west. The silicic rhyolite dikes along the west side of Jabal Akash, correlated with late stages of emplacement of the Akash granite, are barren.

Preliminary spectroscopic analysis (I. M. Naqvi, written commun.) of two grab samples from greisenized rock from the the top of Jabal Akash indicate the following results: sample 204005 - greater than 1000 ppm Sn, 50 ppm W, and 300 ppm Zn; sample 204088 - greater than 1000 ppm Sn, 50 ppm W, and 5000 ppm Zn. Other elements analyzed were not appreciably anomalous. A more detailed investigation of the greisenized zone on and near Jabal Akash is currently underway (Kellogg and Smith, 1985, unpub. data).

Jabal Aja intrusive complex

The 1966-1967 aerial scintillation counter survey of the Arabian Shield revealed a number of radiometric anomalies (2x to 3x background) within the Jabal Aja intrusive complex. Additional interpretative work was done by Irvine (written commun., 1976). Followup work, however, failed to detect any mineralization associated with these anomalies (Meissner and Petty, written commun., 1970; du Bray and Stoeser, 1984; Stoeser and Elliott, 1985 unpub. data) and it is assumed that these anomolies are mainly due to mass effect coupled with non-altitude corrected data related to the irregular topography of the Jabal Aja complex. The only known mineralization is shown by sparse niobium-thorium enriched veins in the arfvedsonite-aegirine, alkali-feldspar rim granite west of Ha'il (Meissner and Petty, written commun., 1970; Matzko and Naqvi, 1978). A regional study of the post-orogenic granites of the northeastern shield, which included the Jabal Aja intrusive complex, by Stuckless and others (1982a) revealed that ".... uranium-concentrating processes have not yet acted on the granites. Thus, although the region is anomalous in terms of uranium concentration, the potential for finding uranium deposits seems low." In general, pegmatites and veining in the Jabal Aja intrusive complex are very sparse and the potential for economic mineral deposits appears low.

Nisiyah alkali apogranite

The Nisiyah alkali apogranite was first visited by Hummel and Hakim (1972). They took one sample of the Nisiyah apogranite and one sample from the eastern rim of the Jabal Aja complex, and the analytical results were reported by C. R. Meissner and A. J. Petty (written commun., 1970), and subsequently by Matzko and Naqvi (1978). The one sample of Hummel and Hakim, and three additional samples of Meissner and Petty, from a "plug" in the vicinity of the Nisiyah stock, contained 0.04 to 0.15 percent Nb_2O_5 and 0.005 to 0.028 percent equivalent U_3O_8 (Matzko and Naqvi, 1978). The identity of this plug is not clear because the location shown on Meissner and Petty's map suggests they sampled the small plug east of the Nisiyah stock; however, they also describe it as being approximately 1/2 km in diameter which would indicate they sampled the Nisiyah stock itself. An attempt to identify specific ore minerals in these samples failed due to the altered and fine-grained nature of the samples (Matzko and Naqvi, 1978). In addition to the sampled plug, the above sources reported the existence of radioactive veins in the vicinity of the plug.

The Nisiyah stock and plug and several nearby veins were sampled by D. B. Stoeser and J. E. Elliott during 1978 (unpublished data). The analytical results for these samples are shown in table 1. Except for the one vein sample, the niobium values are less than those determined by earlier workers. Given that these results are semiquantitative, they only suggestive. In any case, it is clear that niobium-enriched alkali granite similar to those found elsewhere in the northern shield (Drysdall and others, in press) exist in the Ha'il area. Reconnaissance work to date is only adequate to indicate that niobium and probably thorium, uranium, and rare-earth-element potential exists in the Ha'il-Jabal Aja region and that further work is in order, if only to properly document further occurrences of this type of mineralization in the Arabian Shield.

DATA STORAGE

Base field and laboratory data contributing to this report are filed in the Jiddah office of the U.S.Geological Survey Saudi Arabian Mission as USGS-DF-04-14.

Only one entry in the Mineral Occurrence Documentation System (MODS) resulted from this project. This is the tin greissen (MODS 03362) associated with the Akash granite that was described in the previous section.

Table 1.--Selected geochemical data for the Nisiyah alkali apogranite and associated rocks. The two quartz vein samples were taken from veins in the Ha'il granite near the Nisiyah stock.

[All results in parts per million. L indicates less than the limit shown. n.d. indicates not determined. cps refers to total-count radioactivity measured in counts per second]

sample no.	128524	128525	128526	128527	128528	128529
sample source	quartz vein	Nisiyah pipe	quartz vein	rhyolite dike	Nisiyah stock	Nisiyah stock
Lat 27° N.	36'20"	36'20"	36'25"	36'25"	36'25"	36'30"
Long 41° E.	41'45"	42'00"	41'55"	42'00"	41'35"	41'40"
Ba[1]	100	20	386	53	235	33
Be[2]	100	50	5	20	30	30
Ce[1]	1435	268	8173	686	807	655
Cu[2]	50	10	70	20	L5	L5
F[3]	388	128	5040	776	1280	840
La[1]	900	53	4482	375	373	349
Li[4]	7.5	5.0	7.5	10.0	88.8	15.0
Nb[2]	150	200	2000	100	200	100
Nd[1]	470	120	3417	302	364	271
Pb[2]	100	30	150	50	100	30
Sn[1]	18	30	32	19	54	22
Y[2]	150	>2000	200	1000	200	50
Zn[2]	300	L10	300	300	500	300
Zr[2]	L10	L10	L10	500	L10	L10
cps	500	800	1400	n.d.	350	300

1. X-ray fluorescence (USGS Mission Kevex laboratory, Jiddah)
2. Semiquantative spectrography (DGMR/USGS Chemical Laboratory, Jiddah)
3. Selective-ion-electrode method (DGMR/USGS Chemical Laboratory, Jiddah)
4. Atomic absorption analysis (DGMR/USGS Chemical Laboratory, Jiddah)

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