J. King Saud Univ., Vol. 6, Science (2), pp. 279–300 (A.H. 1414/1994).

Petrology, Zircon Mineralization and Granite-Basalt Interaction in the Safra Area, Northeastern Arabian Shield, Saudi Arabia.

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(Received 16 February 1993; accepted for publication 29 November 1993)

Abstract. Three successive episodes of plutonism occurred in the Safra-Musharikah area during the Proterozoic: first, the emplacement of the Kilab Monzogranite, which is a large granite batholith composed mainly of plagioclase (30-35%), K-feldspar (30-35%), and quartz (20-30%), with minor amounts of hornblende and biotite; second, the intrusion of the Laban Complex, which is a large mafic batholith and the emplacement of the Rack complex which is a granitic suite. The latest stage of plutonism in the area is the Shurmah ring dike which consists of alkali feldspar granite, composed mainly of potash feldspar (43-68%), quartz (25-50%), plagioclase (4-15%) and a minor amount of biotite. Basaltic flows and gabbroic intrusions of Cenozoic age are also common.

Zircon is abundant in the alkali feldspar granite associated with epidote, alanite, and opaque oxides. The interaction between the granitic rocks and basaltic magma resulted in assimilation and formation of hybrid rocks. The hybrid rocks exhibit an increase in mafic minerals (from about 3 to 26%) and in plagioclase content (from 6 to 50%) and caused a decrease in K-feldspar content (from 60 to 6%) and in quartz content (from 21 to 18%). This suggests a decrease in silica and potash content and increase in calcium, iron and magnesium content.

Introduction

An area covering about 660 square kilometers was chosen for detailed petrographic and mineralogical study that will be later followed by detailed geochemical analysis in order to delineate the chemical evolution of the different rock types present in the area (Fig. 1). This study area is in the As Safra - Musharikah region about 90 Km to the southeast of Hail city. The area is at the extreme northeast corner of the Saudi Arabian Shield between latitudes 26° 42′ N and 26° 59′ N, and longitudes 42° 08′ E and 42° 20′ E, immediately to the southeastern end of the well known Jabal Salma.

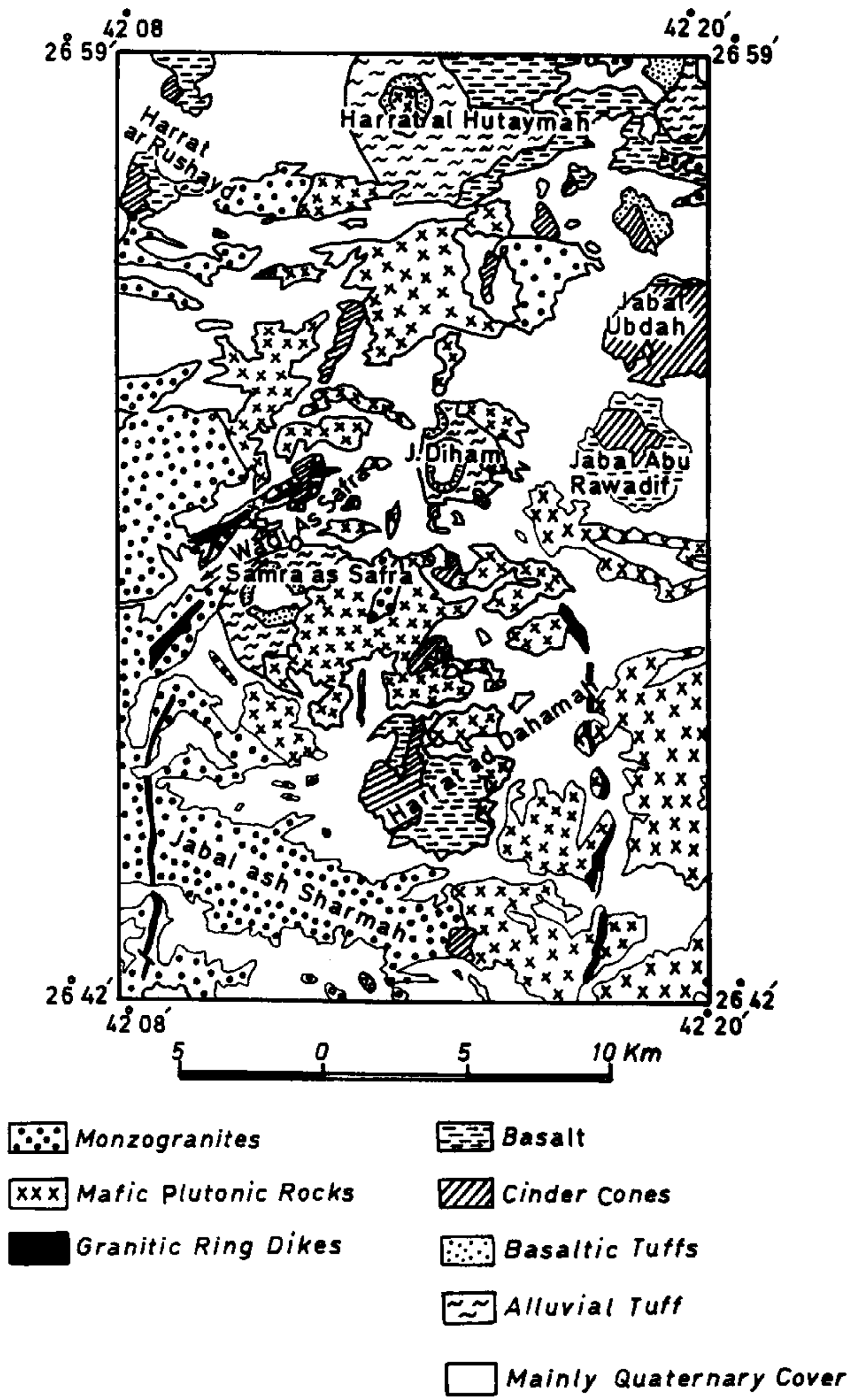

Fig. 1. **Geologic map showing location and types of igneous rocks in the study area, scale is 1:200,000. (Modified from the 1: 250,000 scale geologic map of the Jabal Habashi quadrangle by Williams *et al.*, 1986).**

The As Safra area (Fig. 2) occupies the northwestern corner of the Jabal Habashi quadrangle. A 1: 250,000 - scale geologic map of the quadrangle [1] was used as geological base map for this study. The importance of the area under investigation lies in the occurrence of at least three, more or less, successive episodes of plutonic activity during the Proterozoic followed by extrusion of Cenozoic basaltic magma. Throughout these episodes, a large variety of intrusive rocks was formed including quartz monzonites, alkali granites and gabbros [2-4; 5, p.5; 6, p.82 and 7, p.51]. Consequently, a large number of Proterozoic felsic and mafic dykes also occur in the area as well as Tertiary and Quaternary volcanic centers. Volcanic craters and vents and related cinder cones and flow rocks form several sparsely distributed volcanic fields or "Harrat". Basaltic extrusions are believed to be controlled by north-south trending fractures associated with rifting of the Arabian - Nubian Shield and the opening of the Red Sea during the Cenozoic [5, p.5 and 6, p.82]. The later Quaternary volcanic activity and extrusion of basaltic flows may be accompanied by melting and assimilation of the pre-existing felsic country rocks in several locations within the study area. Cu - Ni or platinum group element (PGE) mineralization may occur in some of the gabbroic rocks, inasmuch as contamination of the magma by assimilation of crustal rocks is so prominent [8-10].

Approximately 70 samples were collected during two field trips to the study area. Many of these samples were taken from a north - south traverse along Jabal Al-Musharikah, while the remaining samples were selected from several outcrops to represent the various rock types present within the area. Sample locations are shown on the map (Fig. 3) which covers approximately an area of 36 square kilometers. The samples from Jabal Al-Musharikah represent the basaltic flows, volcanic products, and felsic intrusives. Several zones that may represent assimilation or xenolithic mixture of basaltic and felsic rocks were also sampled. Thin sections of most of these samples were prepared for study. The aim of this paper is to study the characteristics and the potential for mineralization related to the Proterozoic granitic rocks belonging to the younger episode of plutonism and their interaction with the Tertiary basaltic magmas. Study of the intrusive and extrusive mafic rocks and of the chemical evolution of the area will be the subject of a subsequent paper.

Petrography

The area under investigation contains a wide variety of igneous rocks of differing ages. Felsic plutonic rocks, mainly of granitic affiliation, are the most abundant types of igneous rocks in the area. Mafic volcanic extrusive rocks of basaltic composition are also abundant. Furthermore, mafic plutons of gabbroic - dioritic composition are also common. A variety of minor intrusions and mafic and felsic dikes populate the area. These include rhyolitic, granitic, dacitic, andesitic, and basaltic dikes; also, micrograniitic plugs, and quartz, calcite, and barite veins are present.

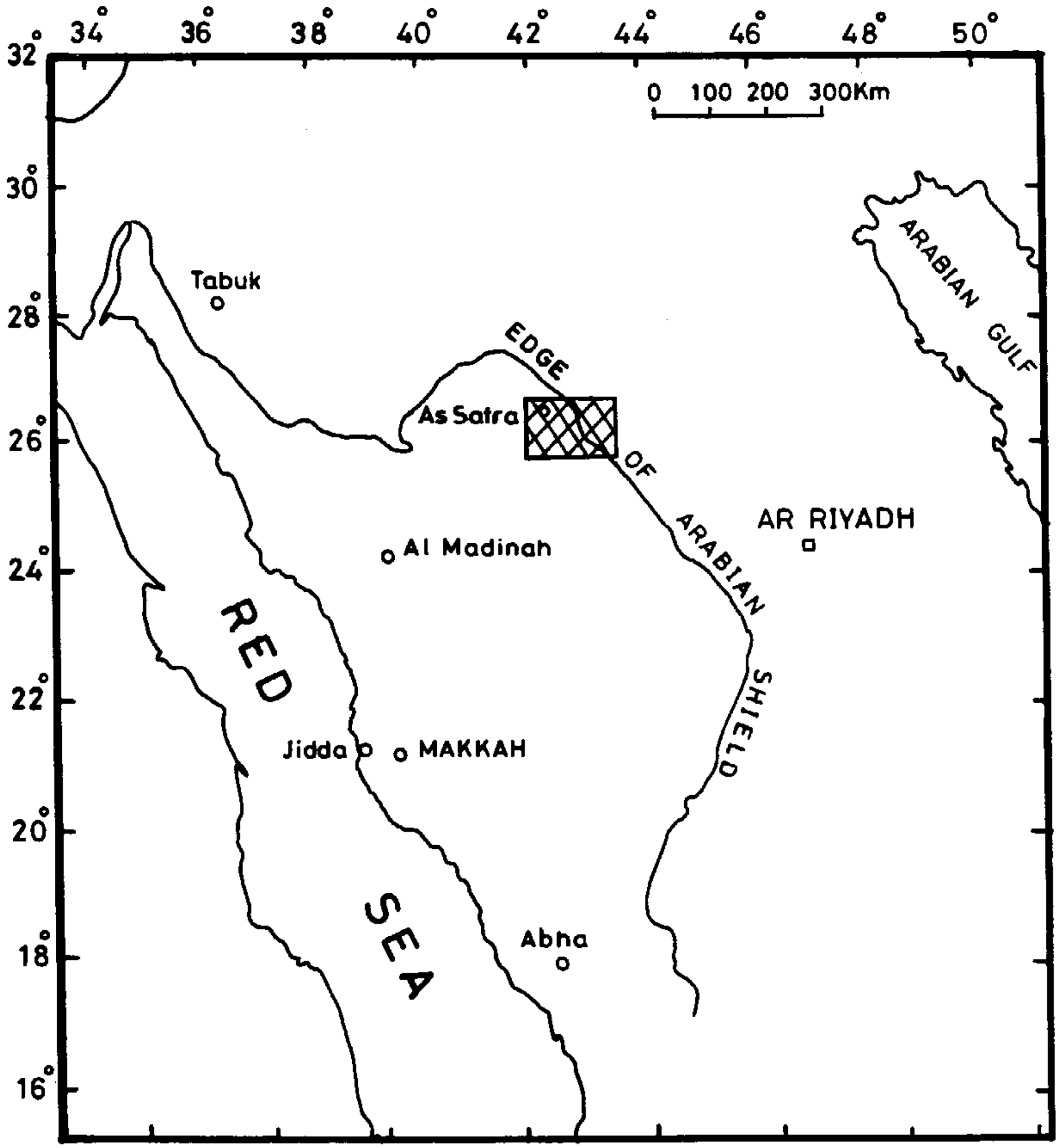

Fig. 2. Index Map showing the location of Jabal Habashi quadrangle (Hatched area), Kingdom of Saudi Arabia.

For the most part the felsic rocks intrude the mafic rocks with little effect except local baking, perhaps some low - grade metamorphism, and addition of hydrothermal solutions. However, the younger basaltic magmas have markedly affected both felsic and mafic plutonic rocks. Conspicuous in Jabal Al-Musharikah is the interaction between basalts and granites. Evidence of baking, alteration, assimilation of granitic material by basaltic magma, and formation of hybrid rocks is clearly present. The

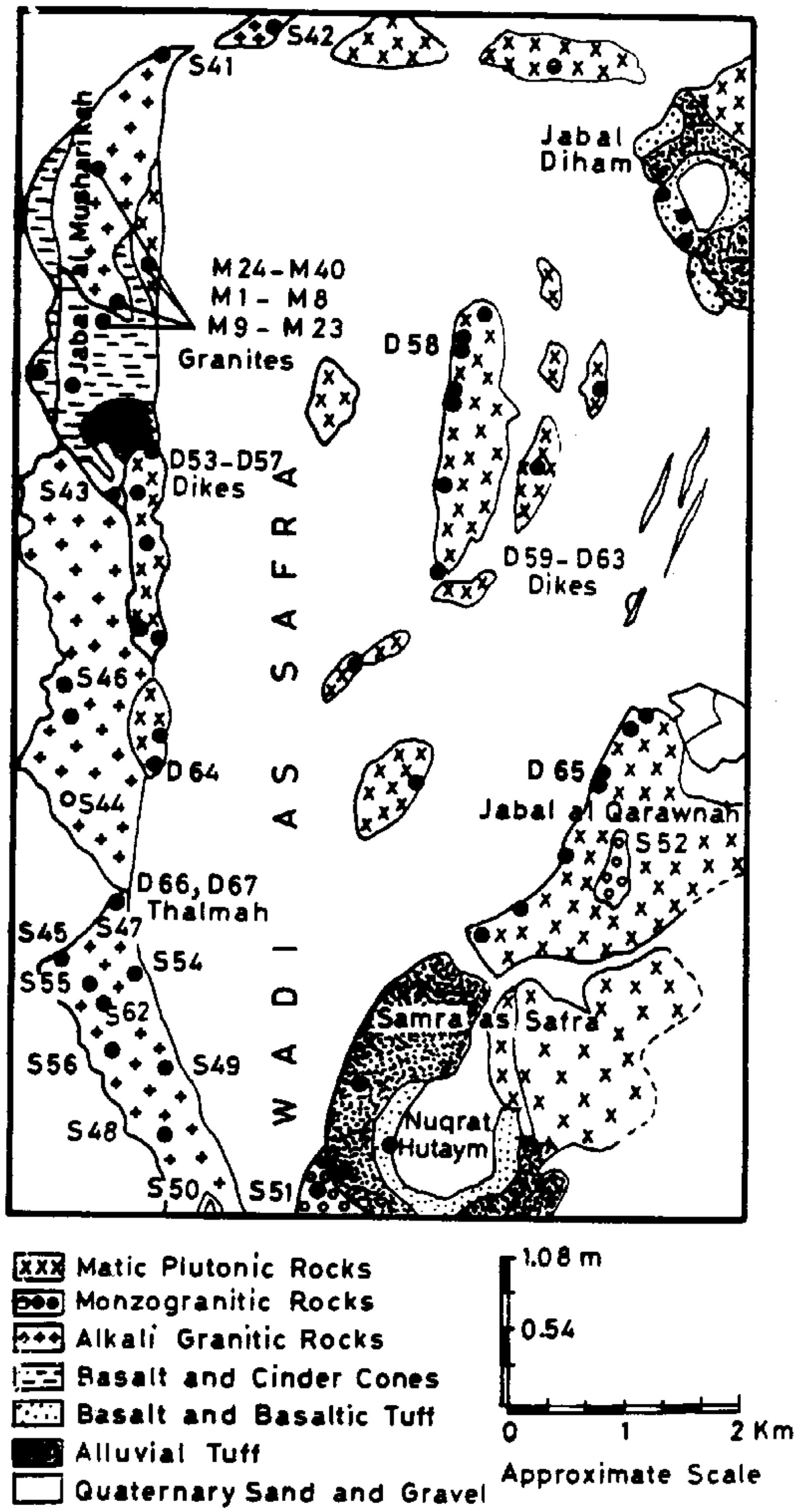

Fig. 3. **Map showing sample location. The vertical sclae is different from the horizontal scale, approximate scale is 1:38,000, the area covered by the map is about 36 square kilometers. Ages of the units are as follows: mafic plutonic rocks are Late Proterozoic = 650 ± 7 my [3]; monzogranitic rocks are Late Proterozoic = 651 ± 8 my [3]; alkali granitic rocks are Late Proterozoic = 579 to 565 my [7]; basalts, cinder cones, and basaltic tuff are Tertiary - Quaternary = 1.8 ± 0.05 [2].**

assimilation of granite by basaltic magma resulted in a hybrid granitic rock. This hybrid is dark-gray in color, and contains more mafic minerals than the adjacent alkali granite. The basaltic rocks at the hybrid - basalt contact also contain rock fragments belonging to the alkali feldspar granite. Details of the effects of interaction between the basaltic magma and granite will be discussed in later seection.

A. Granite mineralogy and textural relation

Two types of Proterozoic granites are present. The first is a light reddish - brown to pinkish - gray, granular, medium - to coarse-grained rocks. It contains mainly calcic plagioclase, Potash feldspar, and quartz, with minor amounts of amphibole and biotite (Table 1). The main accessory minerals in these granitic rocks are iron - titanium oxides, chlorite, muscovite, and epidote. These plutons belong to the Kilab monzogranitic batholith which intrudes rocks of the Laban Complex [4].

Plagioclase is the most abundant mineral in the granite and amounts to between 30 and 35 percent of the total volume of the rock. Plagioclase crystal are often large (about 1.0 mm diameter), elongated, twinned, zoned, and have euhedral to subhedral habit. The grains are generally altered to clay minerals and sericite giving the mineral surface a yellowish coat of tiny spots and grains. The plagioclase composition ranges between albite and andesine.

The potash feldspar amounts to between 30 to 35 percent of the total volume of the rock. The K-feldspar exhibit somewhat long, tabular, and euhedral to subhedral crystal habit. It is only slightly altered to sericite, however, the widespread alteration of K-feldspar to an unidentified clay, stained probably by iron oxide, gives the surface of the grain a reddish brown color which masks the original color and the optical properties of the mineral. Perthitic texture is common. K-feldspar crystals are often found enclosing grains of plagioclase. Microcline and/or orthoclase is the dominant K-feldspar mineral.

Quartz is the third most abundant mineral in the first type of granitic rocks. Its abundance ranges between 20 and 30 percent of the total volume of the rock. Quartz grains are essentially of medium size (0.3-0.5 mm in diameter), anhedral to subhedral, and generally are transparent, but sometimes the grains contain tiny inclusions of unidentified material (probably K-feldspar) giving the crystal a graphic habit. Vermiform quartz is often intergrown with sodium plagioclase to form a myrmikitic textural relation.

Hornblende is present in variable amounts ranging between 3 and 10 percent of the total volume of the rock. This amphibole is green to brownish-green and strongly pleochroic. It is formed of medium - sized anhedral grains, often interstitial to other major minerals and sometimes altered to chlorite, epidote, and iron oxides.

Table 1. Modal analysis of felsic intrusives and related rocks from the safra area

Sample Number	Amph.	Bio.	Plagio.	k-spar	Qz	Rock Name
M 1	-	4	6	58	32	Alkali granite
M 2	-	5	5	55	35	" "
M 3	3	1	4	59	33	" "
M 4	-	4	4	65	27	" "
M 5	-	3	7	60	30	" "
M 6	-	2	5	53	40	" "
M 7	-	1	5	68	26	" "
M 8	-	-	4	61	35	" "
M 9	17	10	50	5	18	Granite
M10	18	7	30	25	20	"
M11	24	1	20	35	20	"
M12	22	3	25	32	18	"
M13	25	5	55	10	5	"
M14	15	12	48	5	20	"
M15	14	9	50	10	17	"
M16	22	-	5	55	18	"
M17	20	4	4	52	20	"
M18	25	2	53	5	15	"
M19	35	-	52	8	5	"
M20	40	-	45	10	5	"
M21	18	2	14	46	20	"
M22	20	-	5	55	20	Granite
M23	20	5	10	43	22	"
M24	10	5	30	35	20	Monzogranite
M25	8	2	33	34	23	"
M26	3	3	33	31	30	"
M27	12	-	15	43	30	Granite
M28	-	4	10	51	35	Alkali granite
M29	2	2	8	56	32	" "
M30	5	-	10	55	30	" "
M31	-	2	7	61	30	" "
M32	-	8	15	45	32	" "
M33	-	5	5	55	35	" "
M34	-	1	7	67	25	" "
M35	-	4	6	60	30	" "
M36	8	3	30	34	25	Monzogranite
M37	6	4	30	35	25	"
M38	-	5	15	45	35	Granite
M39	-	5	10	50	35	Alkali granite

Table 1. (Cont.)

Sample Number	Amph.	Bio.	Plagio.	k-spar	Qz	Rock Name
M40	-	6	12	52	30	" "
M41	-	-	4	66	30	" "
M42	-	1	8	65	26	" "
S43	-	2	7	64	27	Alkali granite
S44	-	4	6	62	28	" "
S45	-	-	5	55	40	" "
S46	6	-	5	55	34	" "
S47	-	-	5	60	35	" "
S48	-	3	7	60	30	" "
S49	2	2	8	58	30	" "
S50	5	6	32	33	24	Monzogranite
S51	7	3	30	32	28	"
S52	-	3	5	60	32	Alkali granite
D53	4	1	30	40	25	Rhyodacite
D54	45	-	51	2	2	Andesite
D55	40	-	53	5	2	Andesite
D56	-	-	10	50	40	Rhyolite
D57	-	2	8	40	50	Rhyolite
D58	45	-	51	1	3	Andesite
D59	-	10	10	50	30	Rhyolite
D60	8	5	7	40	40	"
D61	10	5	35	30	20	Rhyodacite
D62	5	10	55	15	15	Dacite
D63	-	5	50	5	40	"
D64	20	5	65	-	10	Quartz andesite
D65	2	8	10	55	52	Alkali rhyolite
D66	-	-	-	-	5	Calcite vein.
D67	-	-	-	-	5	" "

Note:

Amph = amphibole, Bio = biotite, Plagio = plagioclase, K-spar = K-feldspar, Qz = quartz.

Samples M24 - M26, M36, M37, S50 and S51 are from the kilab monzogranite.

Samples M1-M8, M28 - M35, M38-M40, S41-S49, S52 are from the Shurmah alkali feldspar granite.

Samples D53, D56, D57, D59, D60, D61 and D65 are felsic dikes.

Samples D54, D55, D58, D62, D63, D64 are from mafic dikes.

Samples M9 - M23 are from mixed granite.

Biotite forms 2 to 6 percent of the granitic rock. This biotite is in the form of pale-brown, pleochroic, elongated, and subhedral crystals. Biotite grains are commonly interstitial to other minerals and are often embayed by hornblende and appear to be replaced by the latter mineral.

To classify the granitic rocks, the QAP ternary diagram of [11] for plutonic rocks is used [12, p. 732]. The modal compositions of this type of granite (Samples M 24-26, M 36, M 37, S 50 and S 51) on the triangular diagram (Fig. 4) show that the rock generally plots in the lower right cornor of the granitic field and may be named hornblende-biotite monzogranite (shown on figure 4 as open circles with central dots).

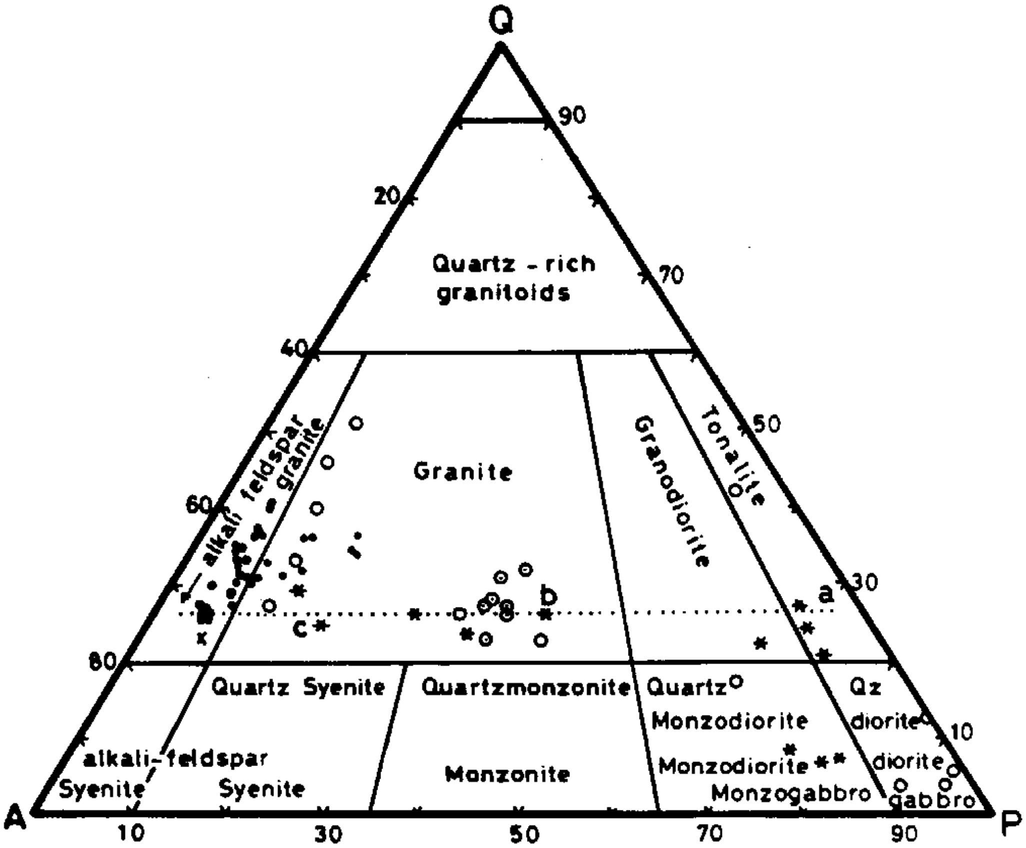

Fig. 4. **QAP ternary diagram showing the classification of the felsic igneous rocks in the study area (o = monzogranites, • = alkali feldspar granites, o = dike rocks, and * = mixed granites).**

The second type of granite is pinkish gray to deep reddish brown, fine - medium - to coarse - grained, granular to granophyric, porphyritic rock. This rock belongs to the Shurmah alkali - feldspar granite that forms a vertical or slightly outward - dipping ring structure or ring dike distributed in an oval pattern. The ring dike intrudes the Kilab Monzogranite and the Laban Complex [2; 4]. The rocks can be divided into two distinct sub-varieties, on the basis of texture or K-feldspar grain size, although the two varieties have approximately the same mineralogy. The first variety is light pinkish - brown, medium - to coarse - grained, equigranular composed mainly of potash feldspar, quartz, and calcic - sodic plagioclase with accessory amounts of epidote, allanite, hornblende, iron oxides, zircon, and calcite (Table 1).

K-feldspar is the most abundant mineral in the rock amounting to about 50 - 68% of the total volume of rock. The K-feldspar crystals are large (3 mm in diameter), elongated, anhedral, and highly altered to sericite and clay minerals.

Quartz forms between 26 and 35% of the rock. Quartz grains are medium sized (0.5 mm in diameter) and often polycrystalline or, quartz and alkali feldspar intergrow together forming a sieve structure or a graphic (granophyric) intergrowth.

Plagioclase crystals are tabular, elongated, twinned, zoned, and often altered to sericite and clay minerals. Plagioclase forms between 5-10% of the rock and its composition is of the albite - oligoclase type. Biotite is also present, forming 1-5% of the rock.

Calcite is abundant in this granitic rock generally as veins filling the cracks between K-feldspar and quartz. The rock also contains abundant opaque oxides often as part of a close association of allanite, epidote, Fe-oxides, and zircon.

On the QAP diagram, the rock plots in the field of granite close to/or within the alkali feldspar zone and can thus be called alkali feldspar granite. (Fig. 4).

The second variety of granite is inequigranular, porphyritic rock, having a light-pink to deep pinkish or reddish brown color. It is a K-feldspar - quartz - plagioclase - phyric granite having generally two distinct sizes of K-feldspar crystals visible in hand samples. As shown by the photograph (Fig. 5) potassium feldspar (pink) exhibits large, elongated, more than 1 cm long and more than 0.5 cm wide crystals and small grains of about 1 mm diameter.

Table 1 indicates that the most abundant mineral in this granite is K-feldspar which constitutes between 43 and 67% of the total volume of the rock. Large, elongated phenocrysts of K-feldspar are characteristic of this rock. In addition, there are other small K-feldspar phenocrysts together with abundant fine grains of K-feldspar in the groundmass. The phenocrysts are euhedral to subhedral and appear to be composed of two kinds of K-feldspar. The first is long, tabular, subhedral, highly altered to clay mineral so that a reddish brown to copper red coat of iron oxide stains the mineral surfaces. Microcline or orthoclase is the likely structural state of the feldspar. The other population of abundant K-feldspar crystals in this rock (possibly sanidine) consists of transparent, equidimensional, euhedral, unaltered crystals having no inclusions (Fig. 6). The only evidence of reheating that can be seen in the granite is

Fig. 5. Photograph showing the two distinct sizes of K-feldspar in alkali granite (photo by the author, ASA 100).

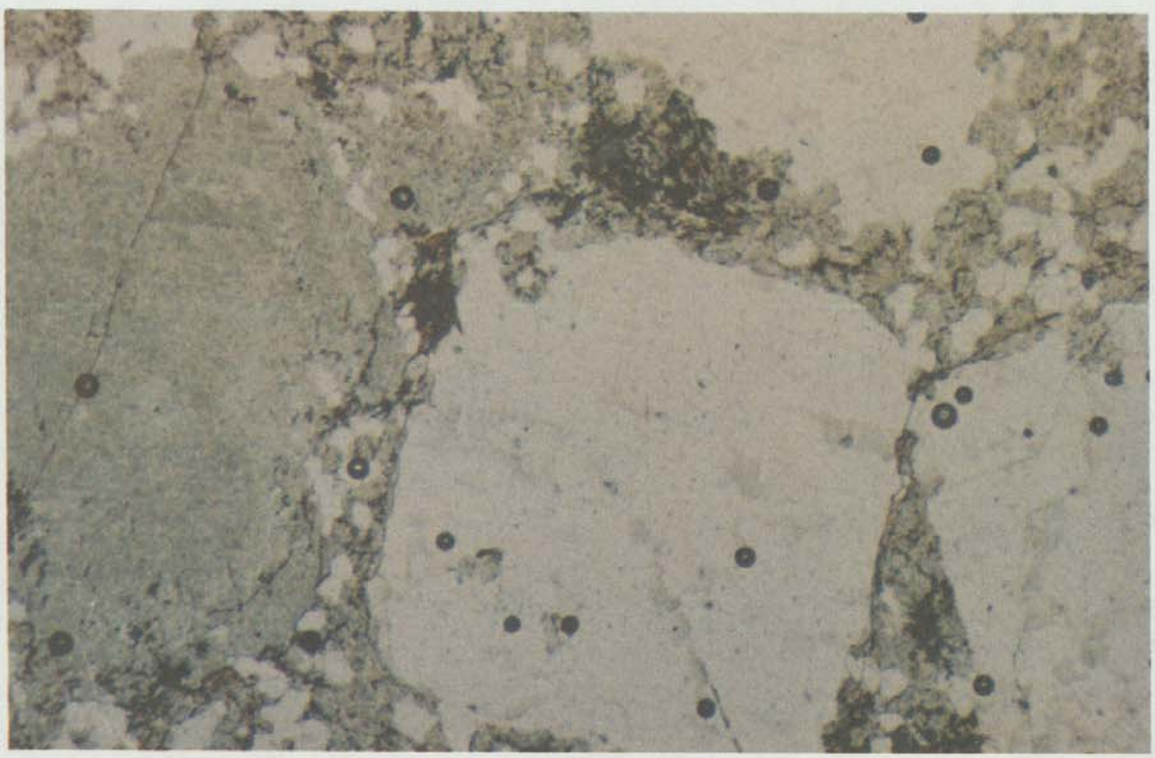

Fig. 6. Photomicrograph showing clear, euhedral, and unhedral crystals of sanidine (White euhedral crystal in the middle) in granites (PL, × 10).

baking, reduction in the grain size, and an increase of the mafic content in the granite as the contact with the basaltic rocks is approached (see the discussion of the felsic - mafic interaction in a later section). Perthitic intergrowths of potassium feldspar and alkali plagioclase is conspicuous in this rock. Sometimes sanidine grains are enclosed in orthoclase, and in other instance the K-feldspar grains are fractured and regularly arranged in a brick-and-mortar structure indicating a stress release. The characteristic microcline tartan structure is frequently found and zoned K-feldspar crystals are not uncommon.

Quartz is the second most abundant constituent in the present granite forming between 25 and 40% of the rock. Quartz is present as phenocrysts and in the groundmass. The quartz phenocrysts are large (0.5 mm), equidimensional, clear white, unaltered, and anhedral to subhedral. Sometimes the grains are polycrystalline or clustered indicating stress. Vermicular quartz and plagioclase intergrowth forming graphic texture is present and quartz - alkali feldspar association in a sieve - like structure is also found.

Plagioclase abundance varies between 4 and 15% of total rock volume. It is frequently present as medium - sized, tabular and subhedral phenocrysts which are twinned, zoned and altered to sericite and clay minerals. In some samples plagioclase may be found enclosed in K-feldspar.

The groundmass of the granite is fine-grained (less than 0.1 mm in diameter) composed of variable amounts of different minerals including orthoclase, microcline, quartz, Ca-Na plagioclase, hornblende, biotite, and calcite. Furthermore, the accessory minerals are also variable in abundance and occurrence including calcite, epidote, allanite, muscovite, opaque oxides, zircon, tourmaline, and apatite. Vein - filling calcite is present in most of the samples. However, calcite may be found as discrete twinned grains.

Plot of the modal analyses of this type of rock on the ternary diagram shows it to be located in the lower left side of the granite field and mostly within the alkali granite field. Therefore, it can be named alkali - feldspar granite (solid dots on Fig. 4).

Characteristics of unusually abundant zircon

One of the most characteristic features of the second type of granitic rocks is the abundance of zircon and iron oxides and the invariable presence of the association allanite - epidote - opaque oxides - zircon. Sometimes hornblende is also present in the association. The unusual abundance of zircon is noticeable. For instance in a thin section of about 3 cm long and 1.5 cm wide between 25 and 35 zircon grains can be counted (Samples M2, M4, M22, M28, M31 and S41). Many of the zircon crystals are sufficiently large to be clearly identified by a 2.5 $\times$ 8 objective so as to obtain their characteristic interference figures. The grains vary from euhedral to irregular in shape (Fig. 7). Most of the zircon grains are colored, cloudy, and have a reddish earthy surface due to the formation of hydrozircon overgrowths suggesting high U and Th content during magmatic crystallization [13], and also suggesting a fairly high concentration of radioactive elements in the granitic rock [14]. Some varieties of zircon grains are clearly altered to a metamict state caused by the structural damage from self - irradiation. This irradiation is due to the presence of variable quantities of radioactive elements, transforming the mineral into an amorphous mineraloid (malacon) or an isotropic glass [15, p. 492]. Furthermore, allanite is also widley altered or inverted to the typical amorphous substance or metamict state [16, p. 532] as a result of self-irradiation, thus releasing a fairly large quantity of iron oxides (Fig. 8). No other reaction products can be seen except clay minerals which are common alteration products in these granitic rocks.

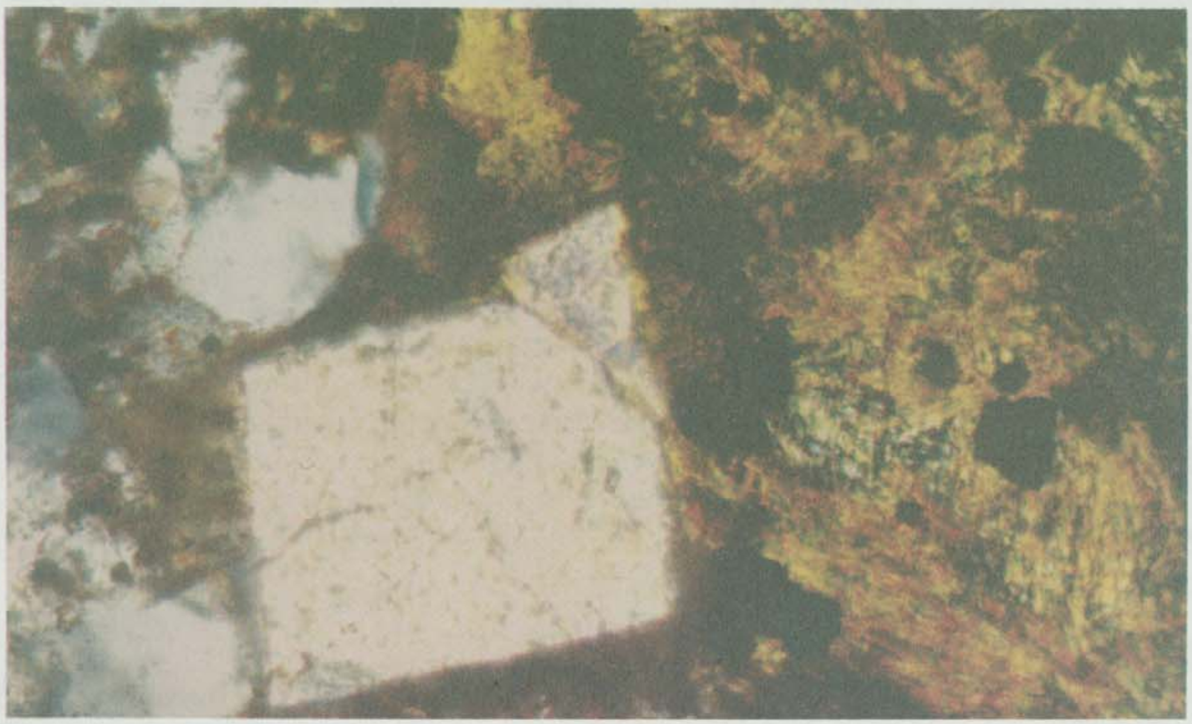

Fig. 7. Photomicrograph showing large, euhedral, tetragonal crystals of zircon in alkali granites (XN, X25).

In 1982 [17] stuckless *et al.* have made a preliminary report on the geochemistry and uranium favorability of the postorogenic granites of northeastern Arabian Shield, Kingdom of Saudi Arabia. Chemical analysis of 176 samples shows that the uranium content of the post kinematic granites is anomalously high, although they did not find any uranium minerals and they judged the potential for secondary uranium mineralization to be low [4]. Furthermore, [18] Stuckless *et al.* studied the

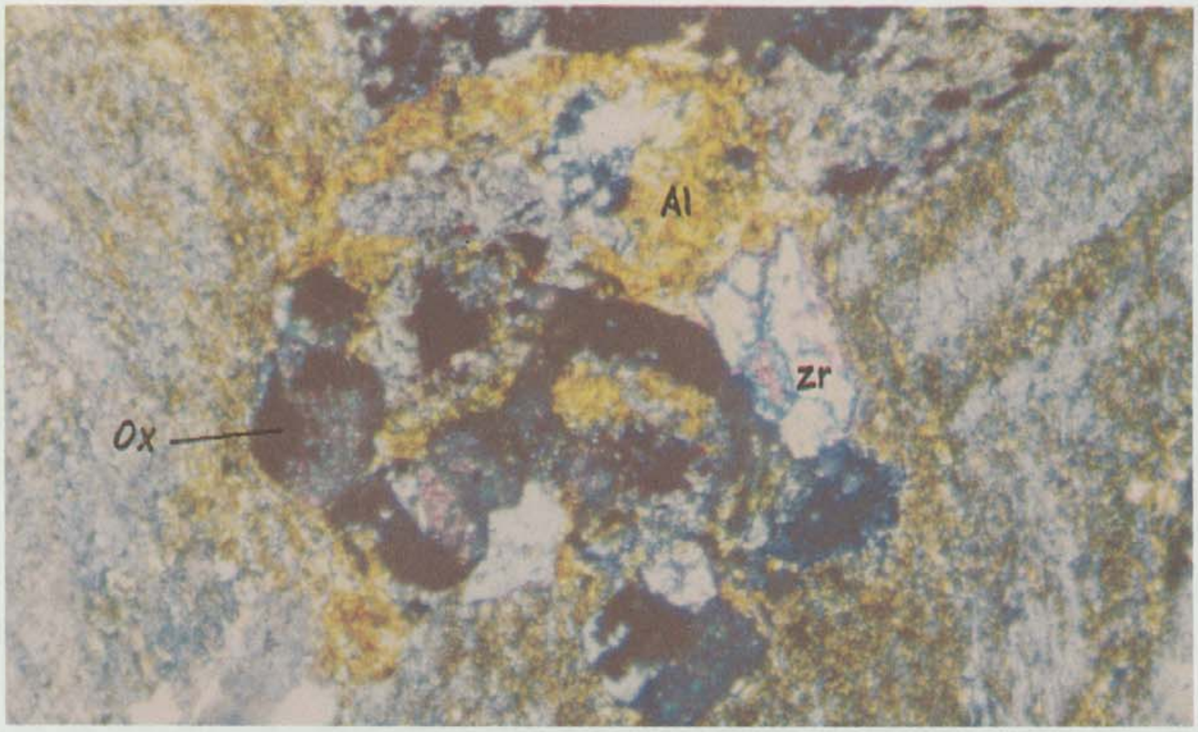

Fig. 8. **Photomicrograph showing the association of opaque oxides (op) with allanite metamict (al) and zircon (zr) in alkali granite (XN, X10).**

trace element geochemistry of postorogenic granite from the same area. They concluded that there is some possibility for potentially economic uranium and thorium in granitoids formed toward the end stage of postorogenic magmatism. However, in regard to the high abundance of zircon and allanite in the area under investigation, and the obvious widespread self-irradiation of these two minerals, further investigation is warranted in order to more thoroughly investigate the potential for uranium mineralization.

B. Felsic and mafic dike rocks of proterozoic ages

These rocks consist mainly of rhyolitic and granitic dikes having the same pinkish - brown color as the alkali granite with which they are associated. Their texture varies from equigranular, very fine-grained, microcrystalline to unequigranular, porphyritic. Andesitic dikes are also common in the area together with some dacite dikes and calcite veins.

The equigranular rhyolitic dike rock is slightly altered and is mainly composed of quartz, potash feldspar, and plagioclase with abundant amounts of opaque oxides, and allanite, epidote, and variable amounts of zircon. Calcite occurs as vein - filling material and some xenolithic rock fragments are also found, but no glass is present. Quartz forms between 40-50% of the rock, K-feldspar forms about 40%, and plagioclase forms between 7 and 8 percent of the total volume of rock. The Porphyritic rhyolite is chiefly composed of quartz, orthoclase, plagioclase, muscovite, rock fragments, and some perlitic glass. Quartz content ranges between 25 and 40, K-feldspar between 50 and 55, and plagioclase forms about 10 percent of the total volume of rock. Accessories include muscovite, opaque oxides, zircon, and allanite. Sanidine phenocrysts are transparent, large, euhedral, equidimensional, and have no alteration. Some quartz phenocrysts are clear white, euhedral, equidimensional but most of the quartz in the rock is in the matrix or tied up in a variety of intergrowths including granophyric, micrographic, and vermicular relationships with plagioclase, K-feldspar, and other minerals. Some skeletal crystals, spherulites, and sieve structures are also encountered in this rock. Plagioclase and K-feldspar are both altered to sericite and clay minerals.

The ternary composition of the two types of rhyolite (open circles on Fig. 4) lies within the field of the alkali granite, which may indicate a genetic relation to the alkali granite. Other criteria also genetically relate the rhylite to the alkali granite including the pink color and the presence of the association Fe - oxides - zircon - allanite.

Andesite dike rocks are slightly altered and composed mainly of plagioclase (51-65%), amphiboles (20 -45%), and quartz (2-10%). Dacitic dike rocks are composed of plagioclase (50-55%), quartz (35-40%) K-feldspar (5-15%), and biotite (5-10%). Another variety of dike rocks common in the area is composed of K-feldspar (30-40%), plagioclase (30-35%), quartz (20-25%), amphibole (4-10%), and biotite (1-5%). This rock when plotted on the QAP diagram lies within the field of rhyolite not far from the dacite field. Thus, it may be named rhyodacite (open circles on (Fig. 4).

C. Felsic - Mafic Interaction

Preliminary observation shows that the Tertiary basalt in the study area is mainly composed of calcium plagioclase (about 45%), pyroxene (about 30%), and olivine (about 25%). The basalts are porphyritic, vesicular, and contain abundant peridlotite xenoliths. The rocks at the contact between the granite and basalt resulting from the granite-basalt reaction have inherited many of the same minerals and textural relations as noted in the granitic rocks, although they differ in several regards such as:

1) The hybrid rock which resulted from melting of granite by basaltic magma contains minerals of granitic provenance and minerals of mafic provenance.

2) All samples contain the assemblage of opaque oxides zircon - allanite characteristic of the granite.

3) The color of the hybrid rock in hand samples varies from dark - gray at the hybrid - basalt contact to light pinkish - gray away from the contact (as found in the 3 - meter outcrop and represented by the line a - c shown on Fig. 4).

4) There is only small variation in the amount of free quartz (15-22%) in the rocks along the 3-meter outcrop a-c, while the K-feldspar content varies greatly from very low (5%) near the hybrid - basalt contact to relatively high (55%) away from the

contact. Similarly the plagioclase content varies greatly from very high (53%) near the contact to relatively low (4%) away from the contact.

Therefore, the local name "mixed granite" is given to such hybrid rocks and a description of selected rock samples is given following the line a - c (Fig. 4). Rock a, from near the basalt contact (Samples M9, M14, M15, and M18), is equigranular, dark - gray and contains white and light - pinkish grains in the hand sample. It is medium - grained and composed mainly of plagioclase (48-53%), quartz (15-20%), K-feldspar (5-10%), green amphibole (14-25%), and brown biotite (2-12%). Accessory minerals include opaque oxides, apatite, zircon, epidote, allanite, and muscovite. Plagioclase grains are large, tabular, subhedral and altered to sericite with several K-feldspar grains enclosed in plagioclase crystals. The amphibole is green (slightly sodic) and brown, pleochroic, anhedral, irregular in shape, and of variable size. It appears to be of variable chemical composition variety. Some amphibole 'hornblende' appears to enclose relic grains of pyroxene. Hornblende is often found to embay, replace, or intergrow with brown biotite. Unidentified Fe-oxide minerals often occur along the biotite-hornblende reaction rim. Fe-oxides may be found also enclosed within biotite which is surrounded by a fine fibrous rim of amphibole. Chlorite, as an alteration product of amphibole, is common in the rock.

A plot of this rock on the ternary diagram (Fig. 4) lies within the field of tonalite near the granodiorite field (point a) and may be called granodioritic tonalite.

Rock b is dark gray with white and pink grains (Sample M10, M11, and M12). It is medium to coarse - grained, equigranular, composed essentially of plagioclase (20-30%), K-feldspar (25-35%), quartz (18-20%), amphibole (18-24%), and biotite (1-7%) with a variable abundance of accessories such as opaque oxides, zircon, apatite, and allanite. Samples a and b have similar characteristics, crystal forms, and crystal habits including the presence of relic pyroxene enclosed in amphibole, the hornblende - biotite - iron oxide association and intergrowths, and hornblende - biotite altered to chlorite.

A plot of rock b on the diagram (Fig. 4) lies in the field of granite close to the quartzmonzonite field. Therefore, the rock (Samples M10, M11, and M12) can be named hornblende - biotite monzogranite.

Rock c is light - gray containing abundant pink grains. It is coarse - grained, equigranular, and composed mainly of K-feldspar (43-46%), quartz (20-22%), amphibole (18-20%), plagioclase (10-14%), and biotite (2-5%) with accessory minerals such as opaque oxides, zircon, allanite, and epidote, but no apatite is present. Amphibole including the blue variety is present. Relic pyroxene enclosed in hornblende is also found. Other characteristics, such as crystal forms and habits of minerals again resemble these of rocks a and b except as discussed earlier, for mineral abundance and color of the rock.

Plot of the rock c on the diagram (Fig. 4) reveals it to be in the granite field near from the field of quartz syenite and thus it may be named hornblende granite. (Samples M21, and M23).

The compositional extrapolation of line a-c reaches the alkali granite field in which the samples M16, M17, and M22 are real alkali feldspar granites with increased amounts of mafic minerals. These rocks consist mainly of K-feldspar (52-55%), quartz (18-20%), amphibole (20-22%), plagioclase (4-5% and biotite (0-4%).

Mass transfer and mass balance

The preceding systematic study of modal composition of the three rock types (a, b, and c) reveals that:

1. The original "prototype" for these rocks is alkali - feldspar granite composed mainly of K-feldspar and quartz with a small proportion of plagioclase and mafic constituents.

2. The emplacement of basaltic magma as a lava flow in contact with the alkali granite caused digestioin and assimilation of variable quantities of the granitic material. This is shown by increased felsic minerals in the basaltic magma near the contact that probably caused an increase in the silica content of the rocks.

3. Material of basaltic composition was transferred to the granite probably by diffusion or by partially melting the granite adjacent to the contact without assimilation followed by introduction of basaltic material into the melted granite. The extent of mass transfer could be determined by whole rock chemical analysis and quantitative mass calculation. That is not possible here due to lack of chemical analysis. However, supposing that there is no variation in the volume of the newly formed rocks, an estimate of mass balance may be done using the modal information (Table 2, and Fig. 9).

The original granitic rock (alkali - granite) contains: 31% quartz, 6% plagioclase, 60% K-feldspar, and 2% mafics. The basaltic lava flow rock contains: 25% olivine, 30% pyroxene, 45% plagioclase, and no free-quartz.

Rock c contains: 21% quartz, 12% plagioclase, 45% K-feldspar, and 22% mafics.

Rock b contains: 19% quartz, 25% plagioclase, 31% K-feldspar, and 25% mafics.

Rock a contains: 18% quartz, 50% plagiocalse, 6% K-feldspar, and 26% mafics.

Table 2. Mass balance showing the amount of variation in oxide content in rock a, located at the granite-basalt contact

Minerals	alkali-granite	rock a granite	decrease volume %	increase volume %	amount of change
Quartz (SiO_2)	31	18	13	-	1.7 times
Plagiocalse (CaO)	6	50	-	44	8.3 times
K-feldspar (k_2O)	60	6	54	-	10 times
Mafic minerals (MgO, FeO, CaO)	3	26	-	23	8.7 times

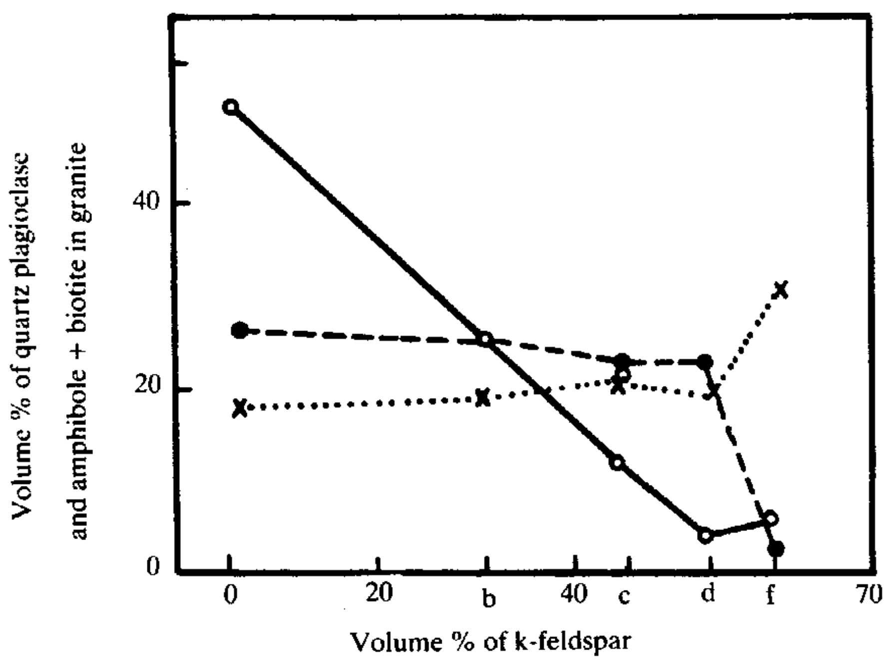

Fig. 9. Qualitative diagram, showing the variation in mafic content, Ca-plagioclase, and quartz content in function of K-feldspar content in the granitic rocks (a = rock a, b = rock b, c = rock c, d = samples M16, M17, and M22 "alkali granites", and f = prototype rock "alkali feldspar granite").

Therefore, from point c, 3 - m away from the contact, toward point a, at the contact, the mass exchange of the hydrid rock (a) at the basalt - hydrid contact is as follows:

Quarts has decreased 1.7 times.

Plagioclase has increased 8.3 times.

K-feldspar has decreased 10.0 times.

Mafic content has increased 8.7 times.

These variations in mineral abundance reflect the difference in abundances of SiO_2, CaO, K_2O, MgO and FêO.

In conclusion, by transfer of material from the basaltic magma to the alkali granite, the resulting hydrid has changed into a more mafic rock with minimal loss of granitoid textural relations, crystal shapes and habits, and mineralogy. Alkali granite, the country rock, is only partially melted, forming a magma that remained immobile. The originally felsic magma received an appreciable amount of material of basaltic origin injected by the ascending mafic melt. Eventually the hybrid magma, cooled and solidified.

Estimation of chemical changes indicates a gradual and consistent increase in CaO, MgO, and FeO contents in contrast to a decrease in the SiO_2 and K_2O content in granitic wallrock as the basaltic dike contact is approached. Other microscopic observations confirm this hypothesis;

1. Careful examination of the hybrid - basalt contact reveals it to be diffuse, gradational, and of limited extent, (about 3 m in width). This indicates that a reaction between the granitic rocks (alkali-granite) and the basaltic magma occurred but the extent of interaction is quite limited [12, p. 732]. It is likely that the ascending magma was of limited volume (mass) with respect to the country rock so that a relatively rapid cooling of the basaltic magma occurred as it contacted the cool granitic rocks.

2. The grains decrease gradually in size within the mixed rocks as the contact with basaltic rock is approached. Decrease in grain size occurs as the granitic rocks become more mafic toward the contact, and formation of the small grains indicates a large temperature difference between the original granite and the produced rock type.

Acknowledgement. I would like to thank Dr. M.E. Al-Dabbagh and Dr. A.M. Al-Bassam for reading the manuscript. Thanks are also due to Mr. H.S. Awad and Mr. H.F. Othman of the Geology Department, K.S.U., for their valuable help. I would also thank two anonymous referees whose remarks have greatly improved this manuscript.

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البترولوجية وتمعدن الزركون وتفاعل الجرانيت مع البازلت في منطقة الصفراء شمال شرقي الدرع العربي في المملكة العربية السعودية

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(سُلِّمَ في ٣٢٥ شعبان ١٤١٣هـ، وقُبِل للنشر في ١٦ جمادي الثانية ١٤١٤هـ)

ملخص البحث. لقد حدثت ثلاثة أحداث متتابعة من التداخل الجوفي في منطقة الصفراء ـ المشاركة وذلك في أثناء دهر الحياة العتيقة (البروتيروزوي). بداية هذه الأحداث كان تكوّن كلاب منزوجرانيت وهو عبارة عن تداخل ناري جوفي كبير (باثوليث) يتركب بشكل رئيسي من معادن البلاجيوكليز بحجم يتراوح بين ٣٠ و ٣٥ بالمئة من إجمالي حجم الصخر أي (٣٠ـ٣٥٪)، والفلسبار البوتاسي (٣٠ـ٣٥٪) والكوارتز (٢٠ـ٣٠٪) إلى جانب مقادير صغيرة من معادن الهورنبلند والبيوتايت. بعد ذلك تكون معقد اللبن وهو عبارة عن تداخل ناري جوفي عميق ضخم ذو تركيب ماحي (قاعدي) ثم تكوين معقد الراك وهو عبارة عن سلسلة (مجموعة) من الصخور الجرانيتية متقاربة الأصل. وآخر مراحل التداخل الناري في المنطقة كان تكوين قاطع حلقي (قاطع الشرمة الدائري) وهو عبارة عن جرانيت فلسباري قلوي يتركب بشكل رئيسي من فلسبار بوتاسي (٤٣ـ٦٨٪)، وكوارتز (٢٥ـ٤٠٪)، وبلاجيوكليز (٤ـ١٥٪) مع كمية قليلة من البيوتايت. وفي المنطقة نفسها يشيع أيضًا وجود الفيوض البازلتية ومتداخلات الجابرو النارية.

ويوجد معدن الزركون في صخور الجرانيت القلوي بكميات وافرة وغالبًا ما يكون مصحوبًا بمعادن الأبيدوت والالنايت وأكاسيد الحديد (الأكاسيد المعتمة). ومن الجدير بالذكر أن معدن الزركون والالانايت قد تعرضا إلى نوع من التدمير الإشعاعي التلقائي نتيجة فعل العناصر المشعة كاليورانيوم والثوريوم الموجودة داخلها في الأصل ولكن الدراسة الحاليّة كما هي الحال في دراسات سابقة لم تثبت وجود معادن خامات اليورانيوم والثوريوم في صخور الجرانيت التي تمت دراستها.

وقد نتج عن التفاعل بين الصخور الجرانيتية والصخور البازلتية زيادة في المحتوى الماحي (القاعدي) ضمن صخور جرانيت الفلسبار القلوي حيث إزداد ذلك من حوالي ٣٪ إلى ٢٦٪ وزيادة في محتوى البلاجيوكليز (من ٦ إلى ٥٠٪) هذا إلى جانب إنخفاض في محتوى الفلسبار البوتاسي (من ٦٠ إلى ٦٪).

وانخفاض في محتوى الكوارتز (من ٢١ إلى ١٨٪). كل هذا يقود إلى اقتراح حدوث انخفاض في محتوى كل من السيليكا والبوتاس وزيادة في محتوى كل من الكلسيوم والحديد والمغنيسوم ضمن الجرانيت القلوي.