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Petrography and Geochemistry of the Dariyah Granite, Central Arabian Shield

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ABSTRACT. The Dariyah granite, quarried for the use as a facade for the Holy Mosques in Makkah and Al-Madinah, belongs to the late-stage plutonics of the Arabian Shield (585 ± 8 Ma). It is a typical leucocratic equigranular coarse-grained 'trans-solvus' granite formed dominantly of perthite, both orthoclase and microcline, quartz and oligoclase. Plagioclase crystallized first followed by potash feldspar then quartz.

The granite is slightly peraluminous with low Ca, Mg, Fe and Ti contents. Its Ab-Qz-Or composition indicates a near minimum melt potassic granite. Compared to average abundance of granites, it is significantly depleted in the incompatible elements Ba, Sr, Zr, Ce, La, Y, and Nd. Thronton-Tuttle indices as well as Rb/Sr and K/Rb ratios suggest fairly evolved stage of differentiation. The initial $^{87}Sr/^{86}Sr$ ratio (0.7037 ± 0.0003) suggests derivation from mantle source with limited crustal contamination or by low degree partial melting of the lower crust. Petrochemical and geochemical features however, support a crustal melt origin.

Introduction

The objective of this paper is to present the petrographical and geochemical features of a granitic mass in the Dariyah area, central Arabian Shield, that is being quarried as ornamental stone for the use as facade for the two Holy Mosques in Makkah and Al-Madinah. The present quarry is located at the intersection of latitude 24 43′ 15″ N and longitude 42 55′ 30″ W. The mass is a part of Dariyah granitic complex, sometimes referred to as Miskah granite, which covers most of Miskah Quadrangle, sheet 24F, published by the DMMR, Kingdom of Saudi Arabia.

The general geology of the area and brief petrographic description of the granite complex is given by Pellaton (1985) based on few geological map reports by Brankamp *et al.* (1963), Dhellemmes (1982a, b) and Pellaton (1984).

General Geology

The Miskah quadrangle is underlain by late Proterozoic volcano-sedimentary succession wihch has a general northwest trend (Fig. 1). It is affected by a low-grade metamorphism of greenschist facies and intruded by different types of granitoids. Two main units are recognized in this succession, the lower Hulyfah Group which is formed of basic to silicic volcanic and pyroclastic rocks, greywackes and limestone, and the upper Murdama Group which is formed of basal polymictic conglomerate, greywacke, sandstone, and intermediate to silicic volcanic and pyroclastic rocks. Most of the exposed granitoids are post Murdama and comprise a wide variety of rocks ranging from diorites to alkali granites. Sheet-like alkali syenites and volcanic rocks striking north to northwest cut both the layered succession and granitoids.

The most important granitic intrusions in the area are the two composite batholiths, the Dariyah complex in the east and the Furayshah complex in the west (Fig. 1). The Dariyah complex is a batholith of about 50 km of width in the south and extends some 125 km in a northwest direction with narrower exposure (Pellaton 1985). It is intruded into both the Hulyfah and Murdama Groups, as well as into post Hulyfah Group plutonic rocks. Two Rb-Sr whole rock isochron ages are reported for the Dariyah granite, a 563 ± 71 Ma age by Fleck and Hadley (1982), and a more reliable 585 ± 8 Ma age with an initial $^{87}Sr/^{86}Sr$ of 0.7037 by Stuckless and Futa (1987).

The bulk of the Dariyah complex is biotite granite which outcrops as planar slabs and/or as inselbergs of beautiful rosy color. Grain size, textures, and mineral proportions are variable. Concentric zonation of the granite through the development of coarse and fine-grained facies to the south and west of Dariyah village is reported by Pellaton (1984). Quartz syenite intrusions cut the granite in several places and are believed to belong to the same magmatic cycle (Pellaton, *op. cit.*).

Petrography

Only five samples were collected from the quarry rather than the extended body of the batholith for the purpose of petrographic description. These samples represent the actual stones currently prepared for the Al-Madinah Mosque.

The rock is coarse-grained, dominantly equigranular (Fig. 2) but in some places pinkish potash feldspar and quartz may develop as larger (1-2 cm) phenocrysts giving the rock a local porphyritic texture. The main mineral constituents are quartz, K-feldspar, sodic plagioclase, biotite and some iron oxides. The granite is typically leucocratic with quartzofeldspathic phases > 90%.

Microscopically, the granite has a hypidiomorphic granular texture. Perthites are dominant, followed by quartz then plagioclase. Feldspars generally show incipient

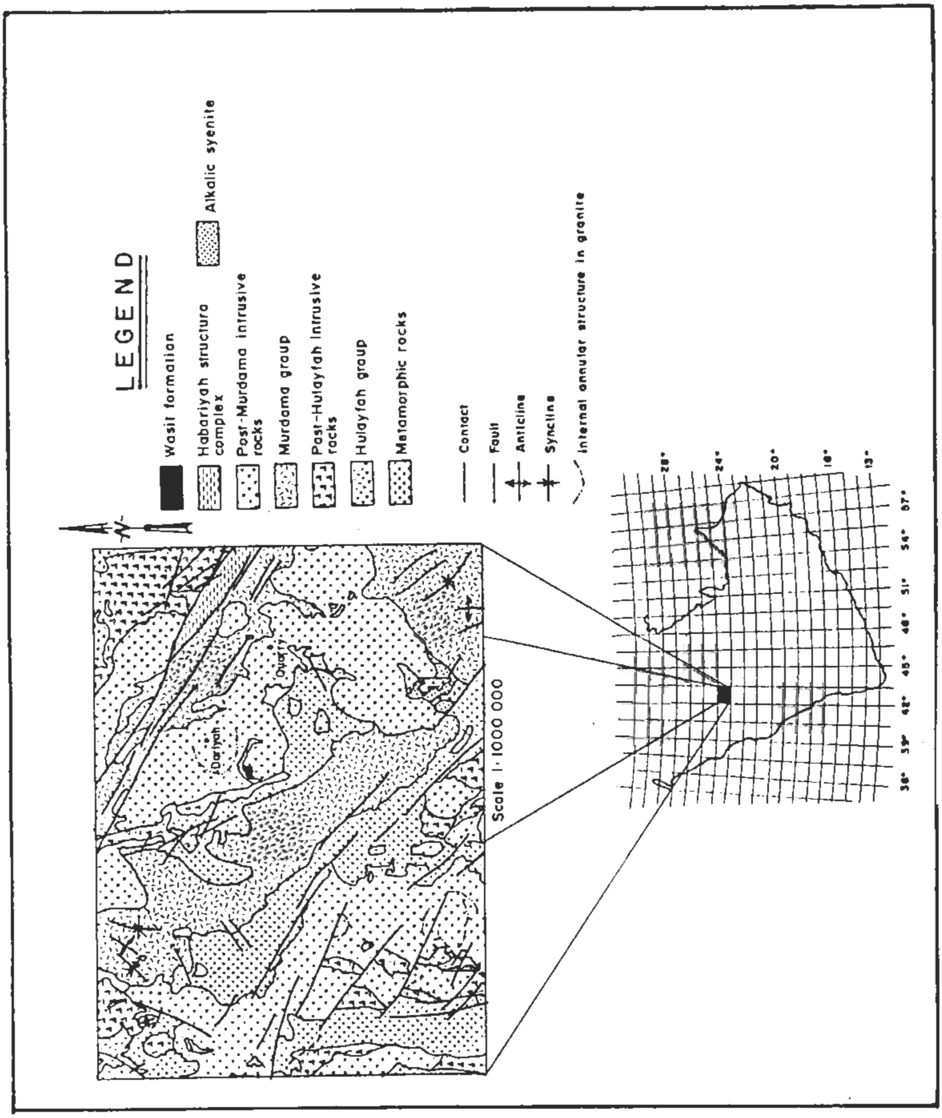

FIG. 1. Geologic map of the Miskah quadrangle. (After Pellaton 1985).

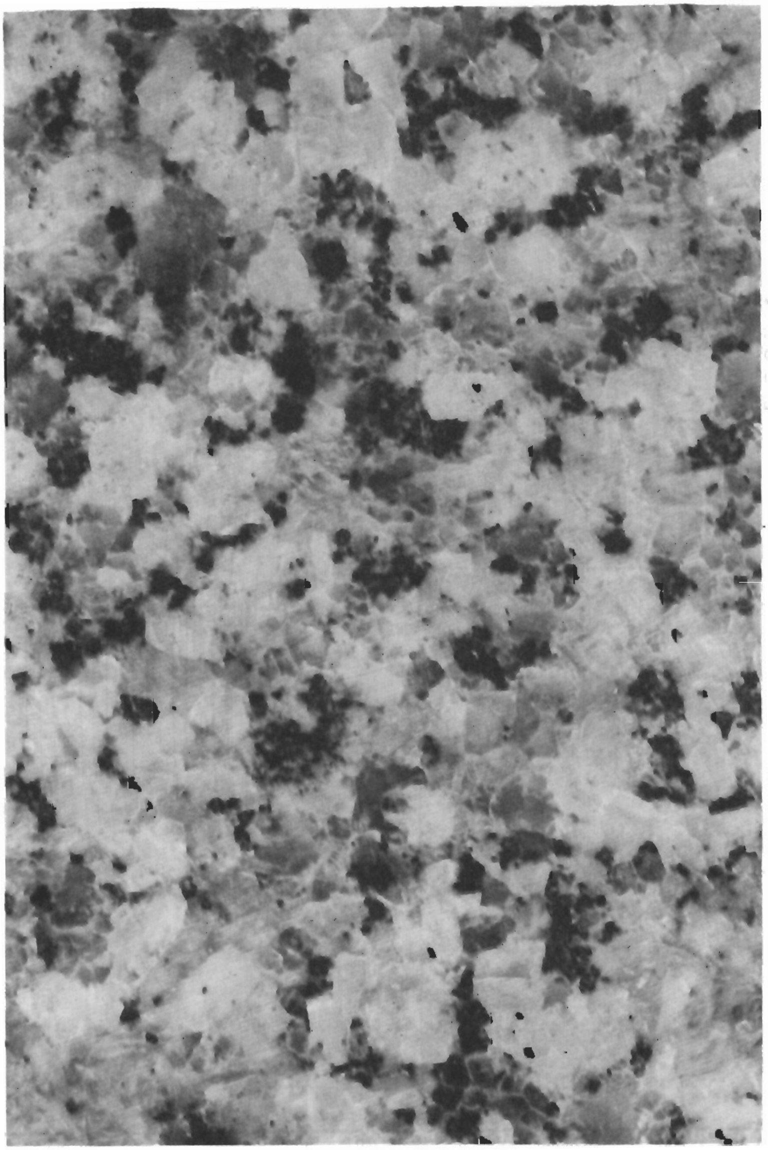

FIG. 2. Photograph of polished slab of the Dariyah granite showing the equigranular texture (scale × 2).

alteration. Table 1 gives the modal composition of the studied five samples. On Streckeisen (1966) diagram they plot mostly within the syenogranite field (Fig. 3).

TABLE 1. Modal composition of Dariyah granite.

	DG1	DG2	DG3	DG4	DG5
Quartz	30.6	22.3	37.3	49.4	32.8
Plagioclase	6.6	8.7	8.2	13.3	10.2
K-feldspar	57.3	66.3	48.2	37.1	52.9
Biotite	6.0	2.5	6.0	0.2	3.9

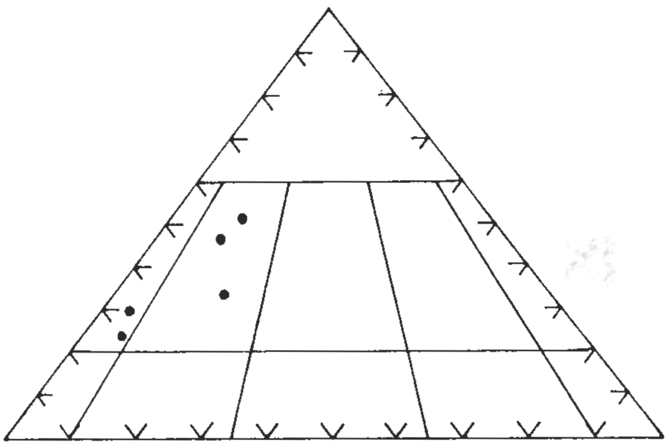

FIG. 3. Modal composition of the Dariyah granite plotted on Streckeisen (1976) diagram.

Both microcline and orthoclase perthites are present in variable proportions constituting over 50% of the rock (Fig. 4). Most perthite occurs as subhedral elongated crystals up to 15 mm long, occasionally with corroded margins. Braid and batch intergrowth of albite with microcline is common while rod and vein intergrowth is more common with orthoclase (Fig. 5). Corsshatched twinning of microcline and carlsbad twinning in orthoclase are well developed. In some samples, perthite shows local brittle deformation in the form of spherulitic cracks (Fig. 6) most probably due to strain effect. Inclusions of plagioclase and biotite are common in both microcline and orthoclase. Most of the perthite crystals show incipient alteration and have light buff tan due to iron staining.

Quartz is the second most abundant mineral typically forming 30-50% of the rock. It is present as clear subhedral to anhedral grains, 3 to 5 mm in diameter, mostly occupying interstitial sites. Some quartz crystals are fractured but not dislocated and undulatory extinction is not common. Spherulitic cracking is well developed also in quartz but restricted in the vicinity of perthite grains exhibiting the same phenomenon thus confirming a localized induced stress. Inclusions of euhedral plagioclase crystals and corroded biotite flakes are not common.

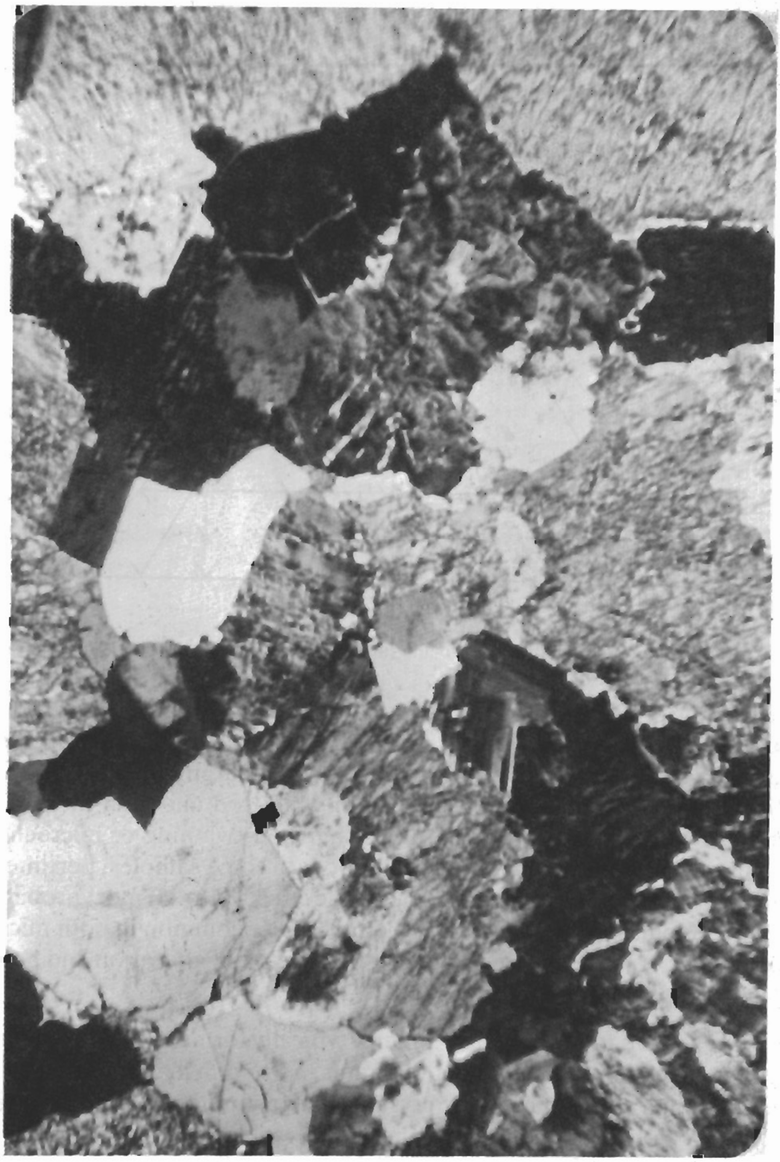

FIG. 4. Photomicrograph showing the dominance of perthites in the Dariyah granite (scale × 25).

FIG. 5. Vein perthitic intergrowth within orthoclase (scale × 25).

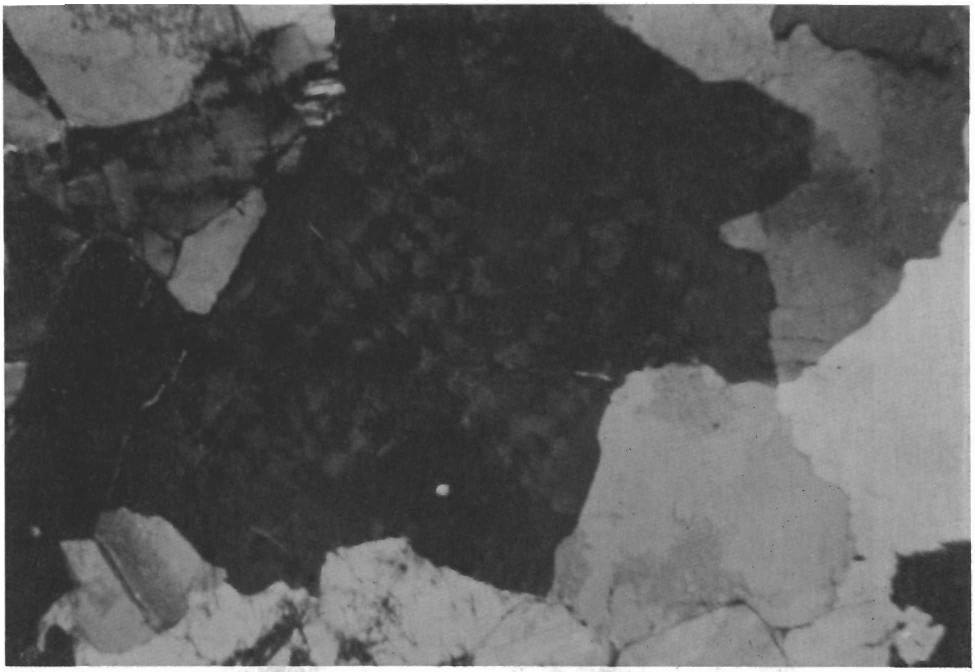

FIG. 6. Spherulitic crack in the Dariyah granite (scale × 25).

Plagioclase constitutes about 10% of the rock. It is present as elongated to equant euhedral to subhedral crystals, 5-8 mm (up to 15 mm) along their maximum dimension. It is strongly zoned with more altered cores. Albite and combined carlsbad albite twinning are well developed but often masked by the clouded altered cores. No inclusions are observed suggesting that plagioclase crystallized first. Minor myrmekitic intergrowth with quartz and orthoclase is rarely observed.

Biotite is the only mafic mineral and constitutes less than 5% of the rock. It is present as small flakes up to 5 mm in length. It is partly broken, corroded and altered to chlorite and iron oxides. No bending or wavey extinction is noted suggesting minimum deformation. Biotite flakes often host minute euhedral zircon crystals which develop pleochroic halos as a result of radiation damage caused by emitted alpha particles. Muscovite is also present but in minor amounts (< 1%).

Zircon is the dominant accessory mineral, occurs mostly as euhedral crystals less than 1 mm in diameter and often concentrated near biotite and or iron oxides. Euhedral to subhedral opaques and sphene are the only other accessories. Sericite is the dominant alteration product in the rock while chlorite is restricted to some biotite flakes.

The high abundance of perthite classifies the rock as hypersolvus, but the presence of plagioclase implies a 'trans-solvus' nature suggested by Bonin (1972) for low-Ca granites having two discrete feldspars one of which is perthite. The sequence of crystallization is most probably plagioclase-perthite-quartz. Inclusions of biotite in perthite and quartz in biotite suggest that biotite may have formed in both the early and late phases of crystallization. Early biotites usually host zircons and are more altered to chlorite compared to late biotites.

Geochemistry

Five representative samples of the Dariyah granite were analyzed for major oxides and 15 trace elements including 3 REE. Analyses were carried out in the laboratories of the Royal Holloway and Bedford New College, University of London. Accuracy is estimated as better than 2% for major elements and 5 to 10% for trace elements depending on encountered concentration ranges.

Analytical data indicate a rather narrow range of major element composition (Table 2). Average SiO_2 content (74.8%) is within the narrow range displayed by most normal granitic rock types. Alumina is slightly high giving the granite a mildly peraluminous affinity (molar $Al_2O_3/CaO + Na_2O + K_2O = 1.09 - 1.14$), also expressed in sparse amounts of normative corundum (0.55-0.83) in the calculated CIPW norms (Table 2). This is quite normal for granites poor in dark minerals (Debon and Le Forte 1982).

TiO_2, FeO^*, MgO and CaO are generally low reflecting the leucocratic nature of the granite and reasonably evolved stage of differentiation. In all samples K_2O predominates over Na_2O. The average K_2O/Na_2O ratio is 1.90 with a standard deviation of 1.13.

Thornton-Tuttle differentiation indices range between 91.1 and 94.2 with an average of 92.8 (Table 2) thus indicating a fairly evolved stage of differentiation. On the normative Ab-Qz-Or plot (Fig.7), the five samples lie near, or within the field where most granites concentrate, they are slightly more potassic than the isobaric minima or ternary eutectic at various pressures. This indicates that the Dariyah granite is not saturated with water (Tuttle and Bowen 1958). The Dariyah granite thus has a near minimum melt composition.

The granite also shows a distinctly wide range of FeO^*/MgO ratios (3.4-8.9) with a rather high average of 6.5. A high FeO^*/MgO ratio and high K_2O are considered by Anderson (1983) to indicate magma generation by partial melting of primitive crust, but the low Ca, Mg, Fe and Ti contents of the granite suggests limited or low degree of such mechanism.

When the ratio $FeO^*/FeO^* + MgO$ is plotted versus silica on the tectonic discrimination diagram of granitoids (Miniar and Piccoli 1989) the Dariyah granite is categorized in group I that includes island arc granitoids, continental arc granitoids and continental collision granitoids. The molar ratios $Al_2O_3/CaO + Na_2O + K_2O$ of the five samples fall however within 1.09-1.14 range which, although does not allow

TABLE 2. Major elements composition (water-free basis) and estimated norms for Dariyah granite samples.

	DG1	DG2	DG3	DG4	DG5
SiO_2	74.09	74.32	75.07	74.79	73.49
TiO_2	0.18	0.16	0.14	0.12	0.32
Al_2O_3	14.21	13.69	13.55	13.90	14.01
Fe_2O_3	1.42	1.86	1.48	1.19	1.84
MnO	0.06	0.04	0.04	0.04	0.07
MgO	0.38	0.20	0.15	0.14	0.39
CaO	1.21	0.94	0.72	0.76	1.06
Na_2O	4.05	3.74	3.79	3.72	3.94
K_2O	4.33	5.00	5.02	5.32	4.83
P_2O_5	0.05	0.04	0.03	0.03	0.07
Total	100.00	100.00	100.00	100.00	100.00
Ap	0.11	0.09	0.07	0.07	0.15
Il	0.13	0.08	0.09	0.09	0.11
Or	25.44	29.46	29.50	31.21	28.45
Ab	34.23	31.57	31.91	31.26	33.26
An	5.67	4.41	3.36	3.55	4.78
Hy	0.62	0.32	0.24	0.23	0.64
C	1.50	0.99	1.28	1.44	1.09
Q	30.76	31.11	31.98	30.91	29.41
Hm	1.42	1.86	1.48	1.18	1.84
Ru	0.11	0.11	0.09	0.07	0.27
Total	100.00	100.00	100.00	100.00	100.00
D.I.	91.11	92.9	94.23	94.21	91.78

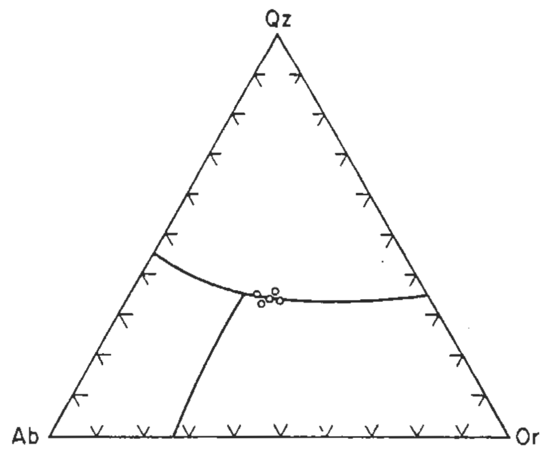

FIG. 7. Normative Ab-Qz-Or diagram showing all the samples of the Dariyah granite plotting near the ternary eutectic point at a confined pressure of 3000 kg/cm^2 (Tuttle and Bowen 1958).

definite discrimination of the three types according to Miniar and Piccoli (1989) scheme, yet it strongly suggests a continental setting.

Trace elements abundance in the Dariyah granite (Table 3) shows a rather narrow

TABLE 3. Trace elements (ppm) composition of Dariyah granite.

	DG1	DG2	DG3	DG4	DG5	Mean
Nb	8	24	30	16	10	17.6
Zr	87	87	157	73	141	109
Y	8	32	32	21	14	21.4
Sr	295	108	62	75	199	147.8
Zn	39	45	42	34	41	40.2
Cu	6	5	5	4	4	4.8
Ni	7	6	4	6	5	5.6
Rb	171	324	335	306	107	248.6
Cr	9	7	5	7	5	6.6
Ce	38	62	43	34	109	57.2
Sc	3	3	2	2	3	2.6
Nd	13	24	18	15	10	16
Ba	541	349	187	276	425	355
V	16	14	7	7	19	12
La	23	30	20	16	61	30

range of variation for most elements reflecting the close similarity of mineral compositions. Comparison of the Dariyah granite average with world average abundance of granites (Krauskopf 1979) indicates a significant depletion in most of the incompatible elements such as Ba, Sr, Zr, Ce, La, Y, Nd, and Sc as well as pronounced enrichment in Ni and to less extent Cr (Fig. 8). All samples fall in the field of crustal melts delineated by Pearce and Gale (1979) in a Nb vs. SiO_2 diagram (Fig. 9). The en-

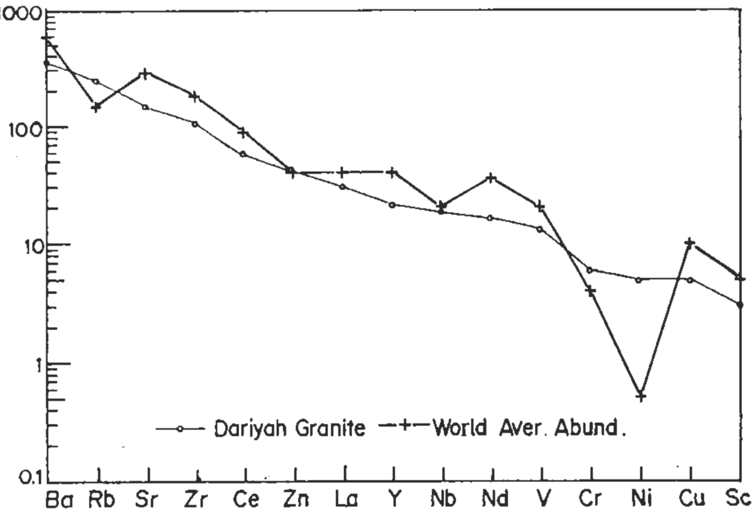

FIG. 8. Comparison of trace elements abundance in Dariyah granite with world average abundance of granite (Krauskopf 1979).

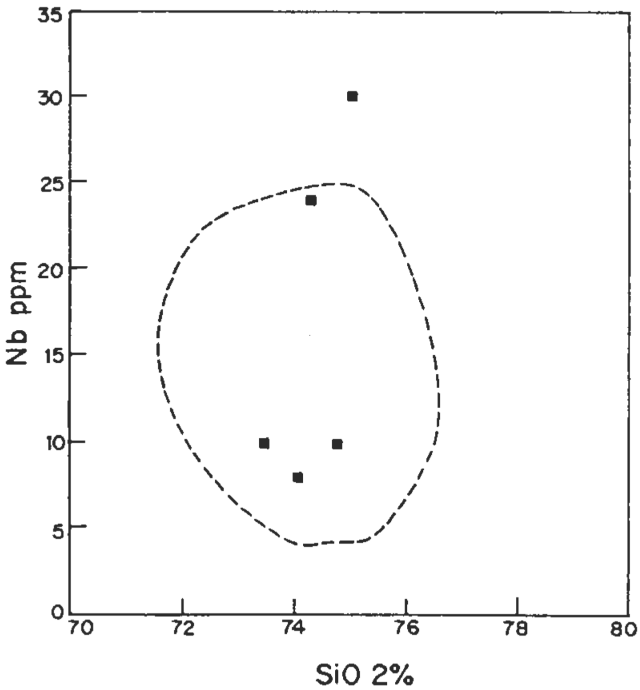

FIG. 9. Niobium (ppm) versus silica (wt %) diagram. The dashed line encircles the field of crustal melts, after Pearce and Gale (1979).

richment in Ni may indicate involvement of crustal component with oceanic affinity. The Rb/Sr ratios (range 0.5 to 5; average 1.7) and K/Rb ratios (range 134 to 400; average 211) indicate a fairly evolved granite in agreement with other differentiation indice .

Stuckless and Futa (1987) reported Rb-Sr isotopic data for eight samples that cover the full length of Miskah batholith, a part of which is the studied Dariyah granite. In spite of the large geographic area represented by the samples, they yielded a perfectly colinear isochron with an age of 585 ± 8 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7037 ± 0.0003. This ratio suggests derivation from a mantle source with limited crustal contamination, or derivation from not too old crustal source of oceanic affinity. We favor the second possibility because of its concordance with inferences drawn from major and trace element data.

Conclusion

The Dariyah granite is a part of Dariyah granitic complex formed at the final stages of plutonism (585 ± 8 Ma) in the development of the Arabian Shield. No distinctive petrographic features characterize the granite. It is a typical leucocratic 'trans-solvus' granite being formed dominantly by perthite, both orthoclase and microcline, quartz and oligoclase. The sequence of crystallization is plagioclase, perthite then quartz. Biotite may have formed in both the early and late phases of crystallization.

The granite is slightly peraluminous with low Ca, Mg, Fe and Ti contents. It is significantly depleted in most of the incompatible elements. It has initial $^{87}Sr/^{86}Sr$ ratio which suggests a higher radiogenic component in the magma source than usually reported in the mantle. Therefore, we suggest derivation of the Dariyah granite by low degree partial melting of a crust with oceanic affinity; or less probably derivation from mantle source with limited crustal contamination.

Acknowledgement

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دراسـة صخريـة وجيـوكيميائيـة لجرانيت ضريـة ، وسـط الدرع العربي

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المستخلص . ينتمي جرانيت ضرية الذي يجري تنقيبه لاستخدامه كواجهات للحرمين الشريفين في مكة المكرمة والمدينة المنورة إلى المرحلة المتأخرة للمحقونات في الدرع العربي (585 ± 8Ma) . وهو جرانيت انتقالي من النوع الفاتح اللون متساوي التحبب مكون أساسًا من البيرثيت (الأورثوكليز والميكروكلين معا) وكذلك من الكوارتز والبلاجيوكليز . ولقد تبلور البلاجيوكليز أولا ثم تبعه الفلسبار البوتاسي ثم الكوارتز .

وهذا الجرانيت تركيب فائض القلوية إلى حد ما بمحتوى منخفض من الـ Ti, Fe, Mg, Ca ، وتركيب الـ Ab - Oz - Or لجرانيت ضرية يدل على صهار جرانيت بوتاسي قريب إلى الحد الأدنى لدرجة الانصهار وبالمقارنة مع التركيب المتوسط لصخور الجرانيت الشائعة فإن جرانيت ضرية يعتبر صخرا مستنزفا بصور واضحة بالنسبة للعناصر غير المتوافقة مثل الـ Nd, Y, La, Ce, Zr, Sr, Ba .

إن معـامل Thronton-Tuttle وكذلك نسب الـ Rb/Sr والـ K/Rb تشير إلى مرحلة متقدمة من التمايز . نسبة الـ $^{87}Sr/^{86}Sr$ (0.7037 ± 0.0003) تشير إلى اشتقاق من مصهور وشاحي مع قليل من التلوث بالقشرة أو درجة منخفضة من الإذابة الجزئية للجزء الأسفل من القشرة . وعلى كل حال فإن الملامح البتروكيميائية والجيوكيميائية تدعم النشأة من صهير قشري .