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PETROGRAPHICAL AND GEOCHEMICAL STUDIES OF THE AL-BAYDA GRANITES, SOUTH EASTERN SECTOR, YEMEN ARAB REPUBLIC

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ABSTRACT

The study of the Al-Bayda pluton comprises petrography and chemistry of the different granite varieties which are related to the basement rocks in the south eastern sector of the Yemen Arab Republic. According to the modal and chemical data, the present granite can be classified as syeno-granite and kali-granite, respectively. In the Al-Bayda granites, a perthitization had taken place through exsolution and replacement processes.

Generally, the investigated granites were crystallized from an acidic melt during a very limited differentiation stage. Finally, the Al-Bayda granites suffered greatly from metasomatism at a postmagmatic stage producing a type of granite related to the anomalous group.

INTRODUCTION

The present study deals with the behaviour of some major and trace elements in occurrence of Precambrian granitic rocks in the Yemen Arab Republic. The occurrence investigated in the present work is Al-Bayda, which constitutes with

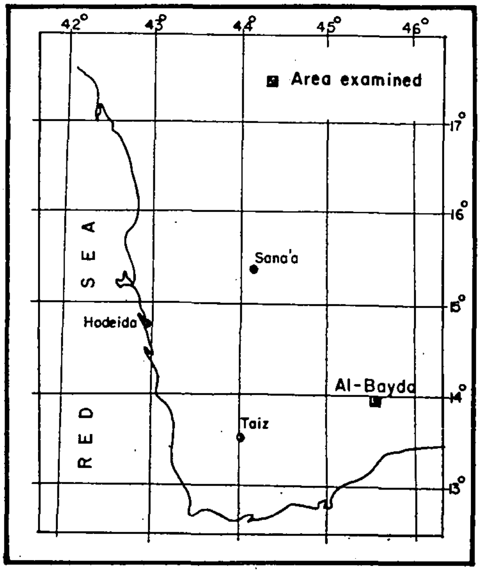

Fig. 1. Location map

others the main granitic outcrops of presumably Precambrian age in the Yemen Arab Republic *(Fig. 1)*.

Broadly, the Precambrian basement rocks cover about 1/4 of the total area of Yemen. These rocks, not yet systematically classified or studied, comprise metamorphics including gneisses, schists, amphibolites, marbles quartzites, intrusives represented mainly by minor mafic masses of diorites and gabbros, ultramafics typified by serpentinites, and finally large granitic massifs.

Generally, detailed studies on the basement rocks of Yemen are scarce. No previous work of significance has been carried out on these rocks in general and the granitic rocks in particular. However, recently, few investigations have been carried out on the Precambrian granitic rocks, as well as some Tertiary alkaline granites of Yemen, [KABESH *et al.* 1979a; KABESH *et al.*, 1979b; REFAAT and KABESH, 1980].

The granitic rocks of Al-Bayda form several hilly outcrops in the south-eastern sector of the Yemen Arab Republic. They are dominantly hard, massive, pink-red and medium-grained. The present work forms part of a research program devoted to the chemical characterisation of the Precambrian granitic rocks of Yemen to elucidate their petrogenesis.

PETROGRAPHY

The Al-Bayda granite rocks consist mainly of pink and red field types. Generally, both types show a slight difference in their mineralogical composition in which quartz, perthite, microcline perthite, orthoclase, plagioclase and biotite form the main minerals in the examined granites. Quartz forms interstitial anhedral crystals reaching up to 2.2 mm in length and 1.6 mm in breadth. Most quartz grains are clear. The alkali feldspars are mainly represented by perthite and microcline perthite in addition to little kaolinized orthoclase crystals. The perthite occurs as elongated crsytals usually with anhedral to subhedral margins reaching up to 2.1 mm in length and 1.21 mm in breadth. Some of the perthite grains enclose small grains of quartz and albite. The plagioclase crystals are mostly albite to oligoclase in composition.

Most of the plagioclase crystals are polysynthetically twinned according to the albite and Carlsbad laws. The albite crystals are characterized by broad uncurved lamellae. A great difference between the direction of lamellae and fractures in the albite crystals is observed. The present authors argue that these albites are characterized by primary twinning resulting from growth nucleation in a liquid magma [SMITH, 1974]. Green and brown biotite flakes are considered the main mafic mineral in the Al-Bayda granites. These biotites vary from short to long flakes. The pleochroic formulae of the green biotite is X=yellow and Y=Z=dark green, whereas the brown biotite is X=straw yellow and Y=Z=brown. Some biotite flakes of the pink granites are corroded by quartz and feldspar and occasionally contain large amounts of sphene. Replacement of biotite by adjacent feldspars and secondary quartz occurs. In one variety of the pink granite, the biotite is associated with little green hornblende crystals. Few primary and secondary muscovite is observed in some varieties of the red biotite granite in which the muscovite flakes are mainly enclosed in the perthite. In some varieties of the red granites, phenocrysts of microcline perthite and quartz are embedded in groundmass of quartz, feldspar and biotite forming porphyritic texture.

Review of perthite mechanism

The microcline perthite and perthite are considered the common feldspars in the pink granite. The microcline perthite originated mainly from exsolution at high temperature and partly from replacement at low temperature. The plagioclase of the pink granites occurs in a coarse interlocking pattern with the microcline, this is ascribed to simultaneous crystallization [ANDERSEN, 1928; BARTH, 1930]. Generally, the simultaneous crystallization of potassium- and sodium-rich feldspar is much less likely and this process is not supported by the crystallization relationships in synthetic feldspar systems [DEER *et al.*, 1966; SMITH, 1974]. As a result, the interlocking texture in the microcline perthite most probably originated through exsolution process. Hair perthite is recognized in the pink granites. ESKOLA [1952] stated that the plagioclase threads, which in the perthites of common granites are comparatively thick and often have curved and tapering flame like forms, are here like extremely thin short hairs. The plagioclase threads in the perthite show that the infiltration of plagioclase into a potash-feldspar involves solution penetrability along directions of weakness or crackes of the host K-feldspar. Also, a replacement is probable, i.e. perthitisation is post-kinematic and metasomatic [AUGUSTITHIS, 1973].

The replacement of microcline by albite produces chessboard albite in which the lamellar lattices of albite and microcline are quasi-parallel [FISHER, 1971]. This process shows that numerous transitions and degrees of replacement had taken place through the formation of chessboard albite texture [MEHNERT, 1968]. In the red granites, the dominant feldspar is the microcline perthites which mainly enclosed small grains of quartz, muscovite and albite along their cracks. The present authors suggest that deposition from external solutions had taken place, *i.e.* the remaining magmatic solutions are communicated with the bulk rocks through the ubiquitous contraction cracks. Initially, these solutions dissolve microcline, and then albite and quartz inclusions are trapped during primary crystallization. Microcline is recrystallized from the solution, facilitating its replacement by albite and forming microcline perthite.

CHEMISTRY

A total of 5 representative samples were analysed from Al-Bayda granite pluton. Two field granite types are recorded in the pluton comprising pink and red granites. The analysed samples were chosen on the basis of petrographic variations in each field type. The major elements of the granite were determined by using the volumetric and gravimetric methods of BENNETT and REED [1971]. These major elements and their normative minerals are listed in Tables 1 and 2, respectively. Some trace elements were detected from the 5 granite samples (Table 3) in which the trace elements were determined by using spectrographic and spectrophotometric methods.

The chemical data show that the pink granites are characterized by SiO_2% ranging from 72.86 to 73.67, whereas the red granites have SiO_2% varying from 73.29 to 74.67.

The SiO_2 values could be used as well as a measure of degree of differentiation in the granites, *i.e.* the drop of SiO_2 between the pink and red granites is caused by internal differentiation within the pluton.

The ternary relation between the Rb, Ba and Sr in granitoid rocks was discussed by EL-BOUSEILY and EL-SOKKARY [1975]. They stated that this relation could be used in tracing differentiation trends in acidic suites. The plots of Rb, Ba and Sr for the

TABLE 1

Chemical analysis of Al-Bayda granites

	1	2	3	4	5
SiO_2	73.67	72.86	74.50	73.29	74.67
Al_2O_3	12.46	11.78	12.56	13.32	12.90
Fe_2O_3	0.85	0.72	0.95	0.95	0.67
FeO	1.26	1.63	1.43	1.41	1.01
MgO	0.83	0.85	0.91	0.99	0.62
CaO	1.61	2.53	1.41	1.32	1.02
Na_2O	1.98	1.51	1.99	2.11	1.36
K_2O	5.51	5.87	5.02	5.11	6.21
P_2O_5	0.21	0.25	0.20	0.22	0.18
TiO_2	0.35	1.21	0.23	0.19	0.11
H_2O	0.82	0.71	0.68	0.55	0.75
Total	99.55	99.92	99.88	99.46	99.50

examined granites on this diagram are shown in *Fig. 2.* All samples are grouped in the anomalous granite zone. The group of anomalous granites cover types that suffered from metasomatism. Generally, most of the investigated granites are clustered near the Ba apex showing that the different varienties of these rocks are crystallized from a limited differentiated acidic magma. Moreover, these granite types are affecte greatly by a metasomatic process at a late stage giving rise to perthitic intergrowths to a large extent.

The present authors argue the K enrichments in the Al-Bayda granites to the strong effect of the metasomatic process in which a solution richer in K than in Na attacked the feldspars particularly the sodic type forming microcline perthits and

TABLE 2

Norm values of Al-Bayda granites

	1	2	3	4	5
q	36.50	36.07	39.23	37.09	39.87
or	32.58	34.71	29.69	30.22	36.72
ab	16.73	12.75	16.81	17.83	11.49
an	6.62	7.97	5.69	5.12	3.88
c	0.79	—	1.75	2.42	2.49
di	—	2.32	—	—	—
hy	3.10	1.41	4.1	3.95	2.66
mt	1.23	1.04	1.37	1.37	0.96
il	0.66	2.29	0.43	0.36	0.20
ap	1.65	1.96	1.57	1.73	1.41
Total	99.86	100.52	100.64	100.09	99.68
or %	58.2	62.6	63.8	62.8	70.4
ab %	29.9	23.0	36.1	37.1	22.0
an %	11.9	14.4	0.1	0.1	7.6
An= =an100/an+ab	28.3	38.4	25.2	22.3	25.2
DI=q+or+ab	85.81	83.53	85.73	85.14	88.08

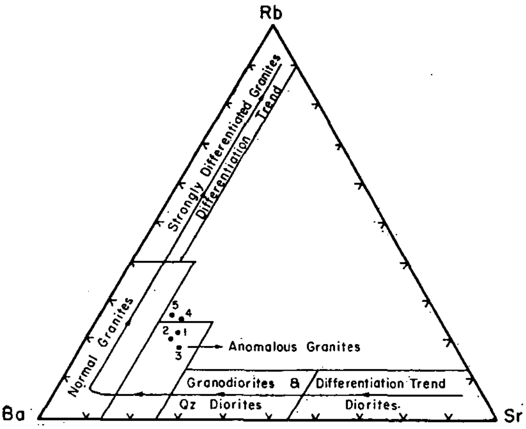

Fig. 2. Relation between Rb, Ba and Sr in granitic rocks [after EL-BOUSEILY and EL-SOKKARY, 1975]

Legend

Pink granites	Red granites
1. Biotite hornblende granite	3. Biotite granite
2. Biotite granite	4. Porphyritic biotite granite
	5. Biotite muscovite granite

orthoclase perthite as a dominant feldspar in the Al-Bayda granite pluton. The granite varieties have low values for K/Rb (166.5—235.5) ratios relative to those (K/Rb 620) in the granites of Kongsberg area [KAYODE, 1974]. KAYODE [1974] suggests that the Kongsberg granites could have been formed by a normal crystallization from a granitic melt. It can be concluded that the low K/Rb ratio in the investigated granite is due to the effect of postmagmatic processes (exsolution and metasomatism) which had taken place after the differentiation of the primary granite melt. The low K/Rb ratios in some varieties (samples No. 10, 11 and 17) are mainly due to the enrichment of these varieties in biotites which have large Rb ions [DE ALBUQUERQUE, 1971].

TABLE 3

Trace element analysis in Al-Bayda granites (ppm)

	1	2	3	4	5
Ba	499	550	520	532	575
Sr	146	165	150	147	142
Rb	198	194	180	239	290
Ba/Ca	0.043	0.03	0.052	0.053	0.079
Sr/Ca	0.012	0.009	0.015	0.014	0.019
K/Rb	216.6	235.5	217.2	166.5	166.8
Ba/Rb	0.011	0.012	0.013	0.013	0.011
Ba/Sr	3.41	3.33	3.46	3.61	4.04
Rb/Sr	1.35	1.17	1.21	1.62	2.04
Ba/Rb	2.52	2.83	2.88	2.22	1.97
Ba %	59.1	60.5	61.1	57.9	57.1
Sr %	17.3	18.1	17.6	16.0	14.7
Rb %	23.6	21.4	21.3	26.1	28.2

The norm values of all the examined granites are peraluminous with normative corundum except sample No. 8 in which the diopside exists due to the excess of Ca relative to residual Al. The presence of high amounts of sphene (5%) in addition to the high An content of the plagioclase (88.4%) reflect the cause of enrichments in Ca content in sample No. 8. The short range of differentiation index [THORNTON and TUTTLES, 1960] in the granite rocks (83.53—88.08) reflects that these granites were formed through a very limited differentiated process in which little chemical variations in their major and trace elements had taken place. From Tables 2 and 3, the Ba/Ca, Sr/Ca, Ba/Sr and Rb/Sr ratios increase with differentiation, whereas Ba/Rb shows opposite relation.

CLASSIFICATION

The proposed schemes of classification are based on the modal analysis and chemical composition.

Modal classification

The modal distribution of the mineral constituents of 5 granites varieties was determined using a point counter. A total of 15 thin sections were made 1000 points were taken for each section (Table 4).

The mineralogical variations in the Al-Bayda granite pluton are reflected corresponding differences in their concentrations of major and trace elements.

The increase in the K_2O contents (5.02—6.21%) shows an increase in orthoclase, microcline, microcline perthite and orthoclase perthite. Generally, the examined granite pluton is characterized by low amount of orthoclase (8.7—12.1%) and plagioclase (8.1—11.5%) in which most of the feldspars are concerned in the perthitic type as a result of the metasomatic and exsolution processes.

TABLE 4

Modal analysis of Al-Bayda granites

Modal %	1	2	3	4	5	Explanation
Quartz	37.3	33.3	32.4	36.0	31.4	Pink granite
Perthite	27.1	19.5	22.4	25.3	17.3	1-Coarse-grained
Microcline	—	10.2	11.5	—	14.0	biotite hornblende
Orthoclase	11.2	8.7	9.2	12.1	10.2	granite
Plagioclase	11.5	10.0	8.1	10.1	9.1	2-Coarse-grained
Biotite	6.5	11.2	10.6	12.3	8.5	biotite granite
Muscovite	—	—	—	—	6.4	Red granite
Hornblende	3.0	—	—	—	—	3-Coarse-grained
Accessories	3.4	7.1	5.8	4.2	3.1	biotite granite
Quartz %	42.8	40.7	38.7	43.1	38.2	4-Porphyritic biotite
Alk. Feld. %	43.9	47.0	51.5	44.7	50.6	granite
Plag. %	13.3	12.3	9.8	12.2	11.2	5-Coarse-grained biotite muscovite granite

N. B. Sample numbers referring to various granites are the same throughout the present Tables.

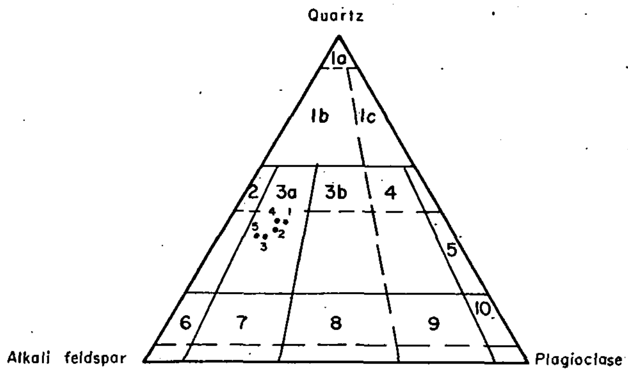

Fig. 3. The investigated granites plotted according to classification scheme by STRECKEISEN [1967]

1a Quartz rocks
1b Quartz granite
1c Quartz granodiorite
2 Alkali granite
3a Syeno-granite
3b Monzo-granite
4 Granodiorite
5. Quartz diorite
6. Alkali syenite
7. Syenite
8 Monzonite
9 Monzo-diorite and Monzo-gabbro
10 Diorite and gabbro

(Index of numbers as in *Fig. 2*)

Fig. 3 illustrates the classification given by STRECKEISEN [1967]. It is obvious that the investigated granite falls within the field of syeno-granite (zone 3a). STRECKEISEN [1967, p. 167] stated that rocks which fall in zone 3b *(Fig. 3)* are granite rocks which are mostly crystallized from a magmatic solution. The present authors argue the unfalling of the investigated granites in zone 3b to the strong suffering of these granites owing to the metasomatic and exsolution processes.

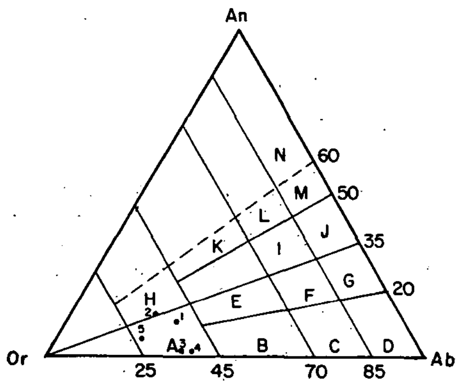

Fig. 4. Triangular diagram for An, Ab, Or normative ratio in the investigated granites [after HIETANEN, 1963]

A Kali-granite
B Granite
C Granite trondhjemite
D Trondhjemite
E Quartz monzonite
F Monzonite
G Tonalite
H Calci-granite
I Granodiorite
J Quartz diorite
K Calci-monzonite
L Granogabbro
M Gabbro
N Mafic gabbro

(Index of numbers as in *Fig. 2*)

Chemical classification

Fig. 4 shows the chemical classification of the investigated granites which are presented on the basis of their normative minerals (orthoclase, albite and anorthite). According to the scheme of HIETANEN [1963], the Al-Bayda granites fall within the kali-granite field due to its low plagioclase contents. One sample only falls in the calci-granite field assuring its enrichment in CaO (2.53%) content due to the high value of An content (38.4) in the plagioclase and also to the presence of fair amounts of sphene (5%) in this rocks (coarse-grained red biotite granite sample No. 8).

PETROGENESIS

The present authors suggest that the Al-Bayda granites were formed through two main stages comprising differentiation and metasomatism. Firstly, the bulk of the Al-Bayda pluton was crystallized early from magma formed due to the melting of salic rocks in the crust as a result of a palingenetic process [KLEEMAN, 1965]. The short range of the DI (83.53—88.08) reflects that the Al-Bayda granites had been crystallized from acidic melt through a very limited differentiation stage.

BOETTCHER and WYLLIE [1968] have observed that albite is converted to a jadeite and quartz assemblage at a depth reaching up to 50 km and under a pressure of 17 kbar. FYFE [1970] remarked that sillimanite is stable in granites formed at a depth less than 30 km in the crust.So the A-Bayda granites are completely free from jadeite and sillimanite, therefore, these granites could have been originated at a depth much less than 30 km and under low pressure.

The normative Or-Ab-An proportions of the present granites have been plotted in a ternary diagram *(Fig. 5)*. All the plots are shown to fall nearer to the Or apex. Most of the plotted points follow the isobaric univariant curve, indicating that crystal-liquid equilibrium was the dominant mechanism involved in the genesis of these granites [JAMES and HAMILTON, 1969].

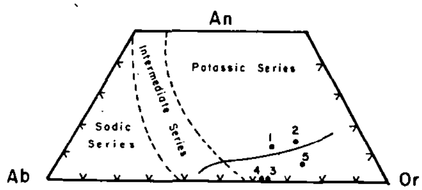

Fig. 5. Triangular diagram for An, Ab and Or normative ratio in the investigated granites. The solid line represents the two feldspar boundary curve for the quartz saturated ternary feldspar system at 1000 bars water-vapour pressure [after JAMES and HAMILTON, 1972]. Sodic and potassic sectors from IRVINE and BARAGAR [1971].
(Index of numbers as in *Fig. 2*)

The variation trend of the Al-Bayda granites fall close to the potassic zone assuring their enrichments in potassium contents. Sodic and potassic sectors in *Fig. 5.* are made by IRVINE and BARAGAR [1971].

Exsolution and replacement are the common process which are responsible for the formation of different types of perthites. Finally, it can be concluded that most of the examined granites had suffered from metasomatism by the action of K-fluids at a postmagmatic stage. As a result, some chemical variations in the Al-Bayda granites took place producing a type of anomalous granite richer in potassic content.

CONCLUSION

The Al-Bayda granites are related to the basement rocks of the south eastern sector of the Yemen Arab Republic. Generally, there are great similarities between the modal and chemical classifications of the examined granites in which both classifications assure their enrichment in microcline perthite (syeno-granite) and their poverty in albite (kali-granite). Microscopically, the perthite intergrowths show different types comprising interlocking, hair and chessboard textures. It can be concluded that a perthitisation had taken place as a result of exsolution and replacement processes.

The short range in the DI (83.53—88.08) indicates that the Al-Bayda granites had been crystallized from acidic melt through a very limited differentiation stage.

The examined granites had suffered from metasomatism. They are therefore, related to the anomalous granite group. The low values of K/Rb ratios in some granite varieties reflect their enrichment of biotite relative to the other types of high K/Rb ratios. But generally, the Al-Bayda granites have low K/Rb ratios. But generally, the Al-Bayda granites have low K/Rb ratios compared to those in the Kongsberg granites [KAYODE, 1974] due to the effect of postmagmatic processes such as metasomatism.

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