Origin of the Rare-metal-bearing Peraluminous Albite Granite of the Umm Al Suqian Pluton, Asir Region, Kingdom of Saudi Arabia

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Abstract. The Umm Al Suqian albite granite, in the southern Asir region, Kingdom of Saudi Arabia, is a late Proterozoic post-collisional peraluminous granite that hosts greisens and disseminated rare metal-bearing minerals. It was emplaced at shallow crustal levels into a metasedimentary and dioritic rock. The rocks of the Umm Al Suqian albite granite pluton consist of four petrographic facies: i) quartz-pegmatite, ii) a mixed layer of conglomerate, quartz-diorite xenoliths in albite granite, and iii) greisenized zone and iv) albite granite. Mineralization consists of small veins and lenses of fluorite and dessiminated minerals such as ixiolite, monazite and bastanesite. Field observations strongly suggest a comagmatic origin of the albite granite, greisens and the associated mineralization.

Geochemical data indicate that the albite granite is enriched in SiO^{2-}, Na_2O^-, F^-, Rb^-, Nb^-, Sn^-, and depleted in MgO^- CaO^-, and TiO^2 and can be termed specialized felsic granite. It is characterized by low K/Rb ratios (49 - 16), high Rb/Sr ratios (76 - 8) and less fractionated REE patterns. The albite granites show geochemical variation indicating their generation by extensive fractional crystallization of major phases such as feldspars and biotite. Subsequent fluorine complexing is assumed to have scoured and transported the HFSE as soluble components. Fractional crystallization of the evolving F-rich peraluminous granitic magma was accompanied, particularly at later stages by fluid fractionation, which plays an important role in the genesis of the greisenized rocks and the associated mineralizations. The parent magma of this granite pluton was formed by dehydration melting of lower crustal rocks. The melting was related to crustal thickening associated with continental collision at the end of the Pan-African orogeny.

Introduction

Present ideas on the geotectonic evolution of Arabian Shield points to the preponderate role of converging plate boundaries, through the formation of intra-oceanic island arc systems, subsequent ocean closure, amalgamation of the arc complexes and continental accretion [1], [2], [3]. These processes took place during the Pan-African orogenic event between 950 and 600 Ma [2], [3]. Towards the end of the Pan-African event (at about 600 Ma), the Arabian Shield witnessed the abundant emplacement of post-orogenic and anorogenic alkaline granites, which intruded the subduction-related Pan-African

basement rocks [4], [5]. The granitoid rocks are broadly grouped into two plutonic assemblages [6], [7]. The older granite assemblage (900 and 680 Ma) comprises syn-tectonic deformed calc-alkaline diorite-tonalite-trondhjemite-granodiorite-granite. The younger plutonic assemblage (680 – 570 Ma) includes post-orogenic monzogranite, alkali feldspar granites and syenites.

In recent years, the younger granite assemblage attracted interest because many plutons, known as specialized granites (Fig. 1), are typically associated with high concentrations of rare metals such as Sn, W, U, Th, REE, Be, Nb, Ta, and Mo [7]. These specialized plutons typically form small stocks or cupolas associated with larger intrusions. Knowledge of the processes involved in the generation and evolution of the specialized granites are essential for understanding the tectonic evolution of the Arabian Shield, and also for the formation of metallic ore deposits. The Umm Al Suqian granite pluton (Fig. 1), is one of the known Nb, Ta, Sn, REE-bearing specialized granites in the Arabian Shield [8]. This paper presents field and geochemical data on this granite pluton aiming at evaluating the processes involved in its geochemical evolution and specialization.

2. Geological setting

2.1 General setting and previous work

Models for the evolution of the Arabian Shield [1] indicate its development through a series of orogenesis associated with collisional events along suture zones between five microplates. Two microplates in the eastern Shield (the Afif and Ar Rayn terranes) are of continental affinity and have been dated at 2000 – 1600 Ma [9]. The other three microplates (Asir in the south, Hijaz in the center and Midyan in the north) are ensimatic island arc terranes of 940 – 700 Ma age [1]. The studied pluton is a part of Jabal Ishmas Quadrangle [10], which lies within the Asir ensimatic microplate. According to [10], four principal rock units crop out in the Jabal Ishmas quadrangle. From the oldest to youngest, these are: (1) tonalite and granodiorite suite; (2) metagabbro-diorite; (3) meta-sediments of the Halaban Group; and younger granite assemblage of monzogranite and alkali feldspar granite. The Umm Al Suqian specialized granite belongs to the younger granite assemblage. Recent sands that cover large areas around the pluton conceal its contact with the surrounding country rocks. However, the presence of abundant metasediment xenoliths within the outer margin of the granite mass indicates that it was emplaced in the metasedimentary rocks of the Halaban Group [11].The albite granite intrusion is thought to be a cupola on the roof of a buried intrusion of alkali feldspar granite [11].

2.2 Geology of the Umm Al Suqian granite pluton

The Umm Al Suqian granite pluton (Fig. 2) forms a dome-shaped topographic feature (about 700 m in diameter) rising about 200 m above the surrounding peniplained
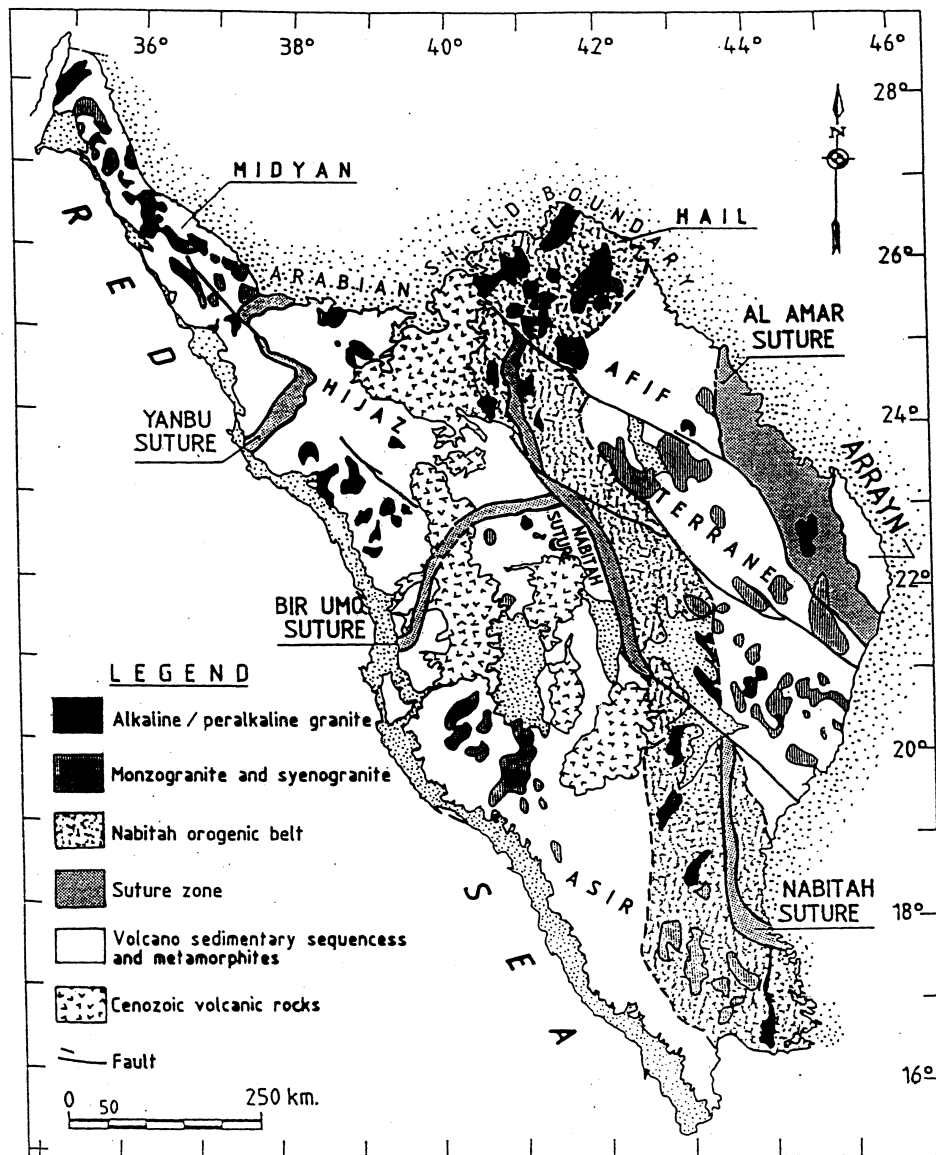
Fig. 1. A map showing the location of Jabal Umm Al Suqian and other specialized felsic plutons (monzogranites, alkali feldspar granites and alkaline/peralkaline granites)of the Arabian Shield (modified from Ramsay, 1986).

sandy area. Four distinct lithologic units have been encountered within the granite mass. From top to bottom (Fig. 2) these are: quartz-pegmatite, greisen zone and albite granite and a mixed layer of conglomerate and quartz-diorite.
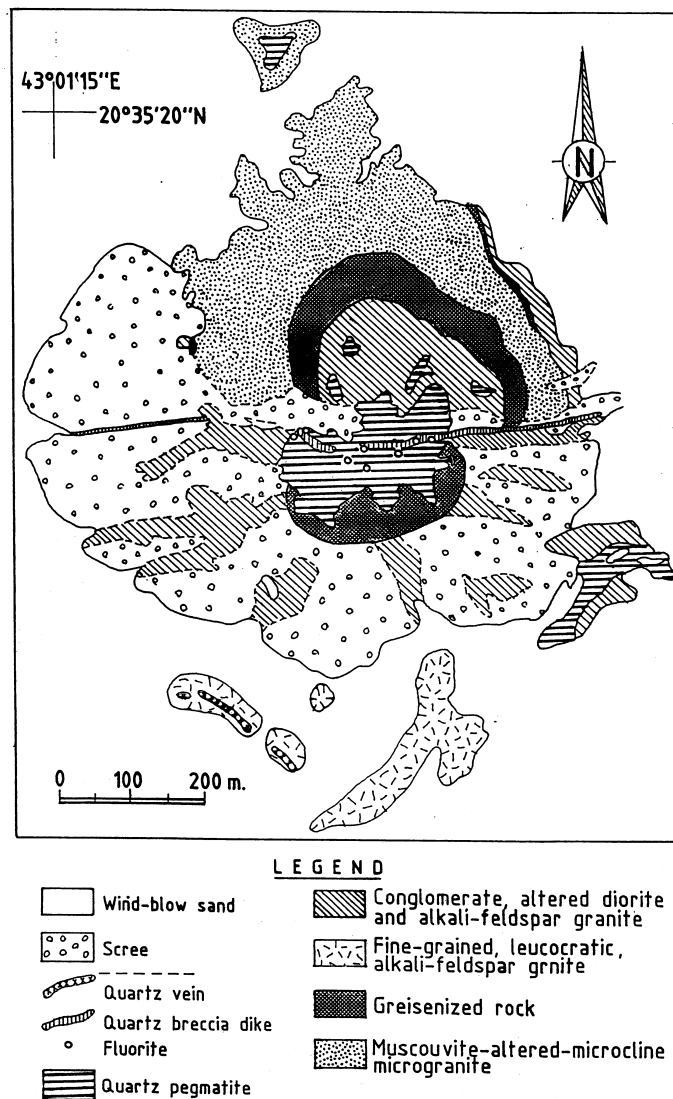

LEGEND

Wind-blow sand

Scree

Quartz vein

Quartz breccia dike

Fluorite

Quartz pegmatite

Conglomerate, altered diorite and alkali-feldspar granite

Fine-grained, leucocratic, alkali-feldspar grnite

Greisenized rock

Muscouvite-altered-microcline microgranite

Fig. 2. (a) Geologic map of Jabal Umm Al Suqian [8].

The quartz pegmatite caps the granite mass and forms a cliff about 20 m thick. It consists of meter-sized interfingering quartz crystals whose c-axis orientation varies from shallow dipping to vertical. The lower part of this unit also contains lenses of massive K-feldspar up to 3 x 10 m long. Small fluorite veins, veinlets and pods cut the pegmatite, particularly near the top. In addition, barren quartz-breccia dykes (1 x 2 m) cut the pegmatites and all other rock units comprising the Jabal Al Suqian granite mass. Towards the base of the quartz pegmatite, intermixed conglomerate and quartz-diorite xenoliths occur in a microgranite matrix. The conglomerate consists of rounded to sub-rounded granitic cobbles and volcanic fragments embedded in fine-grained greenish-grey matrix. This rock unit is considered as part of the base of the Halaban Group [10]. The greisen zone is about 20–30 m thick, it exhibits intercalations of several facies including muscovite-rich, microcline-rich and albite-rich facies. Mineralization is mainly encountered in this zone and is represented by the minerals ixiolite, monazite and bastanesite.

The base of the Umm Al Suqian granite mass consists of leucocratic fine-grained porphyritic albite-rich granite with an exposed vertical thickness of about 50 meters. The albite granite (the subject of this study) is massive and some outcrops exhibit irregular black patches of ferruginous material. Such features are commonly associated with albite granites elsewhere in the Arabian-Nubian Shield [12]. The upper few meters of the albite granite contain veinlets of quartz and k-feldspar-rick aplite. Such veinlets have a sharp horizontal upper surface from which the quartz crystals are projected downwards. [13] described similar features associated with mineralized granitic intrusions and attributed them to successive interfaces between crystallized rock and magma.

3. Petrography of the Albite Granite

The albite granite exhibits a fine-grained hypidiomorphic granular texture (average grain size < 2 mm), porphyritic texture is occasionally recorded at some outcrops. The mineral constituents of the albite granite are quartz (30 – 40%), albite (40 – 60%), K-feldspar (10 – 15%), muscovite (3 – 5%), and accessory apatite, fluorite and hydrated iron oxides. Based on the modal quartz-alkali feldspar-plagioclase (QAP) classification diagram of [14], the Umm Al Suqian albite granite is alkali feldspar granit.

Quartz occurs both as subhedral to anhedral phenocrysts (1 - 2 mm in diameter) with undulose extinction and as anhedral interstitial grains in the groundmass. Some quartz phenocrysts also contain many minute euhedral albite laths, which indicate early crystallization of albite [15]. K-feldspar crystals (mostly microcline) occur both as tabular phenocrysts of microcline perthites and as fine-grained interstitial microcline grains in the groundmass. The phenocrysts are generally clouded by sericite, locally replaced along their margins by albite and contain abundant albite laths. The amount of the altered K-feldspar crystals increases upward towards the greisen-rich part. Albite is the most abundant mineral in the albite granite and occurs in three forms according to the grain size and mineral relations. The first is minute laths in the quartz and K-feldspar phenocrysts, the second as larger phenocrystals in the groundmass whereas the third

form is very minor and occurs as late albite rims along the outer boundaries of the K-feldspar grains. White mica occurs as: minute laths, colorless to pale green inclusions in quartz (i.e. primary), fine-grained flakes of clearly secondary origin in K-feldspar grains, and medium-grained sub-hedral crystals with inclusions of zircon and iron oxides, which are believed to be pseudomorphs after biotite. The accessory minerals are mainly fluorite, which occur as discrete anhedral crystals or as clustered aggregates. The amount of fluorite increases towards the top of the albite granite where it may reach up to 6% of the rock mode in parts of the metasomatized facies. Few apatite crystals and iron oxides represent other accessory phases.

4. Analytical Techniques

A total of 14 representative samples from the albite granite were chemically analyzed for major and trace elements. Major oxides were determined on fused discs by a Philips PW 1410/20 X-ray fluorescence spectrometery at the laboratories of the Faculty of Earth Sciences, Jeddah. Calibration was done with international rock standards of which some were also used as unknowns. All trace elements including the REE were measured by ICP-MS analyses, using solutions prepared by $HF/HClO_4$ dissolution followed by separation with cation exchange procedure, at the Department of Geology, Royal Hollaway and Bedford, New College, England. Calibration was done with international rock standards and analytical precision is found to be better than ±3% for the major elements and ±5 to ±10 % for trace elements. Loss on ignition (LOI) was determined by heating powdered samples for about one hour at 1000ºC. Fluorine was determined in some samples by selective electrode method at the laboratories of the Faculty of Earth Sciences, Jeddah.

5. Geochemistry

5.1 Major and trace element variations

The investigated albite granite can be referred to as high-Si-F (SiO_2 = 74.4 - 79.4%, F = 297-796 ppm), and low-Ca, Mg and Ti granites. They have low CaO (0.08 – 1.04 wt%), MgO (0.01 – 0.18 wt%), TiO_2 (0.01 – 0.03 wt%), Sr (19 – 38 ppm), Ba (9 – 51 ppm), Zr (21 – 58 ppm) and high Na_2O (4.13 – 6.40 wt%), Rb (452 – 1224 ppm), Nb (24 – 85 ppm), Ta (65 – 330 ppm), and Th (10 – 52 ppm) (Table 1). Their K/Rb ratios are uniformly low (16 - 49), whereas the Rb/Sr ratios are high (8 – 76). The high Na_2O contents in the albite granite reflect the common predominance of albite as indicated microscopically. The variations of some major and trace elements versus silica (Fig. 4) show a gradual decrease in Al_2O_3, CaO, MgO, (Na_2O+K_2O), Ba, and Nb with increasing SiO_2 while Rb, and Sr show scattering with no correlation with increasing SiO_2.

Chondrite-normalized REE patterns [16] in the four analyzed samples of the Umm Al Suqian albite granite are presented in Fig. 5. Negative slopes of REE patterns characterize the albite granite with LREE enrichment relative to HREE (Cen/Ybn ratios

= 5 - 3), nearly flat HREE and deep negative Eu anomaly (Eu/Eu*= 0.3 - 0.5).

Table 1. Chemical data of representative samples from the Umm Al Suqian albite granite

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Major elements (wt%)														
SiO_2	74.90	74.40	76.00	76.90	75.27	76.30	77.25	77.25	77.56	78.80	79.44	76.30	75.69	76.13
TiO_2	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02
Al_2O_3	14.32	13.62	14.14	13.49	14.20	14.13	13.10	12.83	13.30	12.30	11.80	13.70	12.30	13.17
Fe_2O_3	0.23	0.27	0.35	0.39	0.21	0.21	0.34	0.34	0.22	0.54	0.24	0.32	0.21	0.11
FeO	0.11	0.11	0.07	0.19	0.07	0.04	0.18	0.18	0.14	0.11	0.06	0.07	0.09	0.14
MnO	0.12	0.05	0.17	0.18	0.05	0.05	0.05	0.24	0.05	0.05	0.05	0.03	0.03	0.04
MgO	0.04	0.02	0.02	0.18	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.03
CaO	0.38	0.40	0.19	0.08	0.34	0.16	0.34	0.19	0.40	0.21	0.46	0.25	1.04	0.54
Na_2O	5.42	5.06	5.85	4.73	5.98	5.90	4.58	5.05	5.00	4.13	4.39	6.40	5.85	6.37
K_2O	3.53	4.36	3.01	2.92	2.69	2.22	3.05	2.67	2.73	2.40	2.46	2.56	2.88	2.46
P_2O_5	0.03	0.02	0.03	0.03	0.04	0.01	0.04	0.03	0.03	0.01	0.05	0.03	0.06	0.02
LOI	0.73	1.02	0.53	0.73	0.60	0.58	0.84	0.83	0.62	0.75	0.52	0.60	0.90	0.84
Sum	99.82	99.34	100.37	99.83	99.48	99.64	99.80	99.65	100.09	99.34	99.50	100.29	99.08	99.87
CIPW norm														
Q	28.8	27.5	29.8	36.9	29.3	32.6	37.6	36.7	36.7	44.1	43.2	28.8	30.6	29.0
Or	20.7	25.8	17.6	16.9	15.7	12.9	17.7	15.6	15.9	13.8	14.4	15.1	17.0	14.5
Ab	45.5	42.8	49.1	39.2	50.1	49.1	38.2	42.3	41.7	34.1	36.7	54.1	47.2	53.9
An	1.7	1.6	0.7	0.2	1.4	0.7	1.4	0.7	1.8	1.0	1.9	1.0	0.1	0.1
C	1.9		2.0	4.9	1.8	3.5	3.4	2.7	2.9	5.0	2.4	0.1		
Trace elements (ppm)														
Cr	36	45	51	14	13	22	12	32	9	11	18	9	17	32
Ni	10	13	15	8	bd	6	bd	9	bd	bd	bd	bd	bd	9
Rb	1224	1200	663	1146	452	510	820	708	671	1224	462	510	719	566
Ba	36	45	51	14	13	22	12	32	9	11	18	9	17	32
Sr	31	23	31	15	53	22	36	22	33	33	38	30	33	19
Li	21	14	16	37	11	2	24	3	21	33	14	16	13	18
Ta	150	330	300	65	0	0	0	0	0	0	0	0	0	0
Nb	69	85	72	61	36	57	27	68	32	27	24	34	27	43
Zr	23	21	25	25	50	23	58	27	49	34	48	44	39	26
Y	2	4	3	2	33	3	63	2	53	41	33	35	51	2
Th	nd	nd	nd	nd	nd	nd	35.0	nd	11.4	nd	nd	10.0	52.0	nd
U	nd	nd	nd	nd	nd	nd	4.4	nd	3.1	nd	nd	4.8	6.3	nd
La	nd	nd	nd	nd	2.0	1.0	2.0	2.0	nd	nd	nd	nd	nd	nd
Ce	nd	nd	nd	nd	16.0	11.0	19.0	10.0	nd	nd	nd	nd	nd	nd
Nd	nd	nd	nd	nd	6.0	9.0	5.0	7.0	nd	nd	nd	nd	nd	nd
Sm	nd	nd	nd	nd	2.5	2.1	3.0	2.2	nd	nd	nd	nd	nd	nd
Eu	nd	nd	nd	nd	0.05	0.10	0.05	0.10	nd	nd	nd	nd	nd	nd
Dy	nd	nd	nd	nd	1.00	1.10	1.00	0.80	nd	nd	nd	nd	nd	nd
Yb	nd	nd	nd	nd	0.70	0.70	0.30	0.40	nd	nd	nd	nd	nd	nd
F	335	297	408	796	nd	nd	650	nd	nd	nd	nd	nd	nd	nd
K/Rb	23.9	30.2	37.7	21.2	49.4	36.1	30.9	31.3	33.8	16.3	44.2	41.7	33.3	36.1
Rb/Sr	39.5	52.2	21.4	76.4	8.5	23.2	22.8	32.2	20.3	37.1	12.2	17.0	21.8	29.8
Ba/Sr	1.2	2.0	1.6	0.9	0.2	1.0	0.3	1.5	0.3	0.3	0.5	0.3	0.5	1.7

Analyses 1-4 are from [8]; bd=below detection limit; nd=not determined
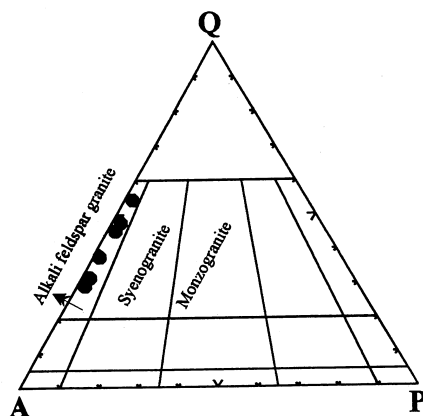
Fig. 3. Quartz-Alkali feldspar-Plagioclase (QAP) modal classification diagram [14] of the Umm Al Suqian albite granite.

5.2. Magmatic affinity and tectonic setting

The Umm Al Suqian albite granites are peralumineous. The A/CNK ratios (molecular $Al_2O_3/CaO+Na_2O+K_2O$) [17] in all of the analyzed samples are >1 and the normative corundum values range between 0.05 and 5 % (Table 1). The peraluminous character is also shown on the A-B diagram of [18], where the albite granite samples have almost A values [Al - (K+Na+2Ca)] more than 0 and define a more or less positive linear array (Fig. 6a); a feature which is uncommon in granites other than peraluminous granites [19].

In the $Zr+Nb+Ce+Y$ versus $FeO*/MgO$ and (K_2O+Na_2O/CaO) diagrams (Figs. 6b,c) of [20], the albite granites are mainly classified as highly differentiated I- and S-types granites and A-type granite. However, the investigated albite granites share the enrichment of HFSE (Nb, Y, Ta) and depletion of Sr, P, Eu and Ti with the anorogenic alkaline granites. In the SiO_2 vs. Nb diagram (Fig. 6d) of [21] the leucogranites lie within the field of within-plate granite (i.e. A-type) [22] recognized the distinctive nature of A-type magmas, and subdivided them into two groups: post-orogenic and anorogenic. Also, [23, 24] subdivided the A-type magmas into two groups: A1, which represents differentiates of mantle-derived oceanic island basalts (anorogenic or rift zone magmas), and A2, which represents crustal derived magmas of a post-orogenic setting. Diagrams designed to discriminate between the A1 and A2 groups of anorogenic magmas indicate that most samples of the Umm Al Suqian albite granites plot in the A2 field on the Y/Nb-vs Rb/Nb diagram (Fig. 7) of [24]. However, the Y, Nb, and Rb contents in some samples are similar to those of the A1 sub-type granites (Fig. 7). This similarity suggests that high concentrations of these elements in the albite granites are related to unusual fractionation processes rather than to an enriched source rock of rift zone settings. It is
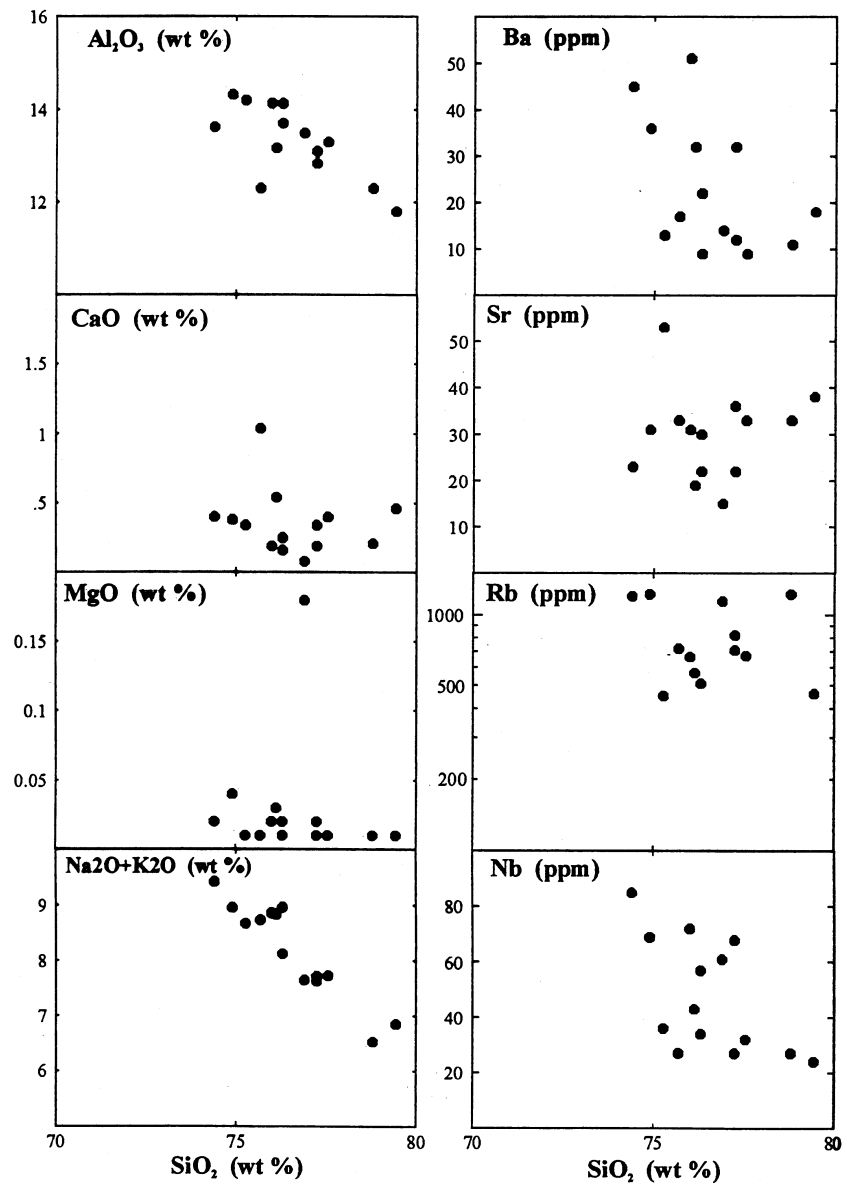
Fig. 4. Harker's variation diagrams of some major and trace elements of the Umm Al Suqian albite granite.
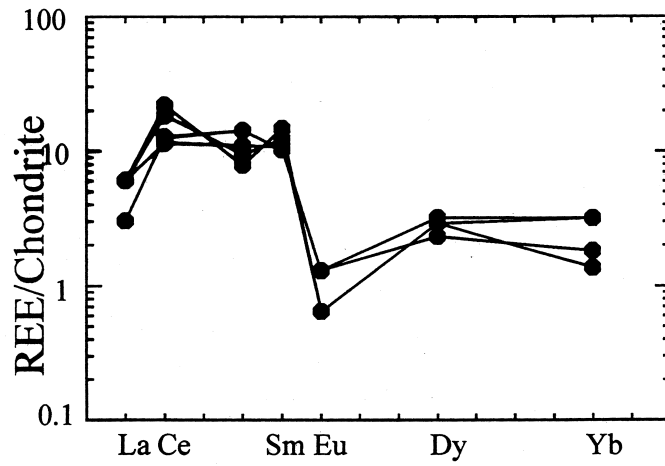
Fig. 5. Chondrite-normalized REE patterns of the Umm Al Suqian albite granite. Normalizing values are from [16].
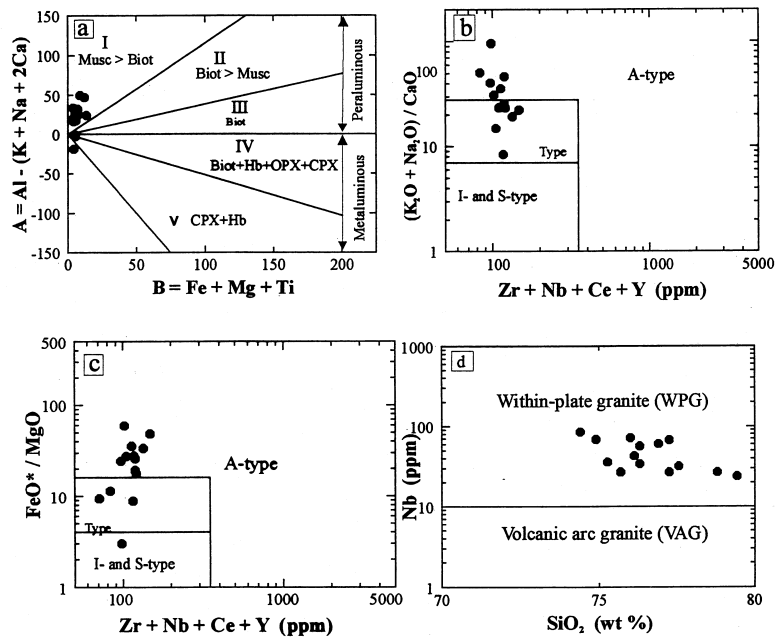

Fig. 6. Major and trace element characteristics and chemical classification diagrams for the Umm Al Suqian albite granite. (a) A - B diagram [18], (b) (K₂O+Na₂O)/CaO vs. Zr+Nb+Ce+Y diagram [20], (c) FeO*/MgO vs. Zr+Nb+Ce+Y diagram [20], (d) SiO₂ vs. Nb diagram [21].

thus the process of evolution, which controls the chemistry of the studied granites, and thus they represent A2 subtype granites characterizing post-collisional settings. This agrees with the previous studies where granites with A-type geochemical signatures in the Arabian Nubian Shield have been considered to be formed during post-orogenic transpression/extension period commencing at about 600 Ma [3], [25], [26], [27], [28].
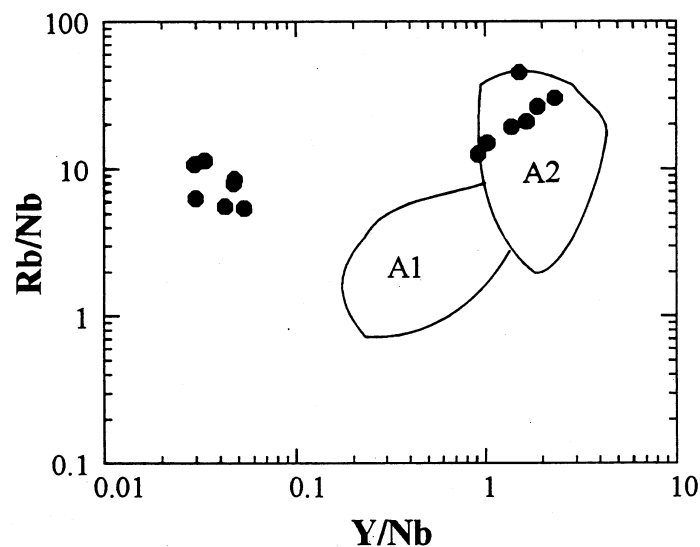

Fig. 7. Y/Nb vs. Rb/Nb diagram [23,] distinguishing between the A1 (rift-related) and A2 (post-collision) subtypes of the A-type granites.

6. Petrogenesis

The Umm Al Suqian albite granite has remarkably high average concentrations of F and granitophile elements like Nb, Ta, Y, and Rb (Table 1), which is similar to plumasitic specialized granites in the Arabian Shield [7]. These high concentration levels of granitophile elements make it possible to consider the Umm Al Suqian albite granite as a mineralized granite. In this respect, the K/Rb ratio is considered as a good indicator for rare-metal potential [29] where it is very low in strongly differentiated or metasomatically altered granites. On a plot of Rb vs K/Rb (Fig. 8a) most of the Umm Al Suqian albite granite samples plot within the mineralized granite field, whose limits are proposed by [29]. Moreover, similar to rare-metal-bearing granites [30], [31], the analyses of Umm Al Suqian albite granite are strongly biased toward the Rb apex on the Rb-Ba-Sr diagram (Fig. 8b) of [32].

Some compositional variations observed in the Umm Al Suqian albite granite are compatible with partitioning of elements between a silicic melt and minerals
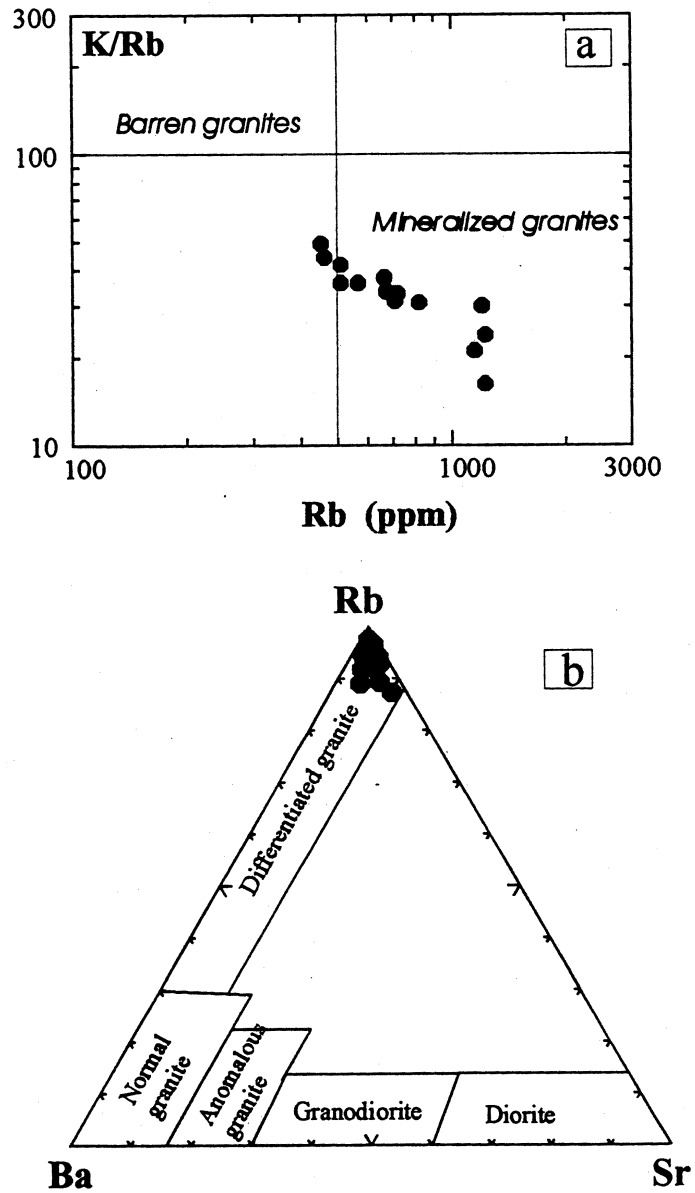
Omar A. Sherbini and Talal M. Qhadi

Fig. 8. (a) Rb vs. K/Rb variation diagram (Tichendorf, 1977), (b) Sr-Ba-Rb ternary diagram [32]for the Umm Al Suqian albite granite.

crystallizing from that melt (e.g. plagioclase, alkali feldspar, biotite). This is true for the elements Al, Ca, Mg, and Na+K, which show negative correlation with SiO_2 (Fig.4). The deep Eu anomaly (Fig. 5) also indicates extreme fractionation of plagioclase feldspar. Moreover, the very low contents of Ba and Sr and the high Rb/Sr ratios (Table 1) in the investigated granites are likely to result from Rayleigh fractionation [33]. However, the high concentrations seen among the elements Nb, Rb, Y and REE and their wide variations over a restricted range of SiO_2 in the albite granites cannot be explained by normal fractionation processes rather it is believed to be the result of combination of processes namely metasomatism, and fluorine complexing.

6.1 Metasomatism

The metasomatic model for the origin of albite granite [34], [35] envisages subsolidus transformation of biotite leucogranite into Li-F granites by post-magmatic hydrothermal alterations. In the Umm Al Suqian albite granite, mineralization is in the form of disseminated Nb^-, Sn^-, Ta^-, and REE-bearing minerals is mainly confined to the zone containing greisens and microclinized rocks [8]. The origin of albite granite and mineralization are thus interpreted as a result of post-magmatic hydrothermal alterations. However, the following field and petrographic observations argue strongly for a comagmatic origin of the albite granite and the greisens: 1) intrusive sharp contact with the country rocks with no albitization in the country rocks, 2) gradational contact between the albite granite and greisens that means a comagmatic relationship, 3) the magmatic textures and mineralogy (euhedral albite laths aligned along growth planes of quartz and K-feldspar) indicate that albite in the albite granite was an early magmatic phase, and 4) replacement textures of albite after K-feldspar (evidence of metasomatism) in the albite granite are very minor and do not agree with the percolation of a large amount of fluid through the pluton required by a metasomatic process. The unusual high contents of some elements and their poor correlation cannot therefore be attributed to metasomatic processes.

In the Q-Ab-Or diagram, that shows minimum melts at different pressures [36], the albite granite plot at a position richer in Ab and poorer in Qz (Fig. 9). There are two explanations for the shift of the albite granite plots on this diagram as follows: it was generated under higher pressure [37] or it was formed from a melt enriched in F [38]. The high-pressure hypothesis is thought to be unlikely because these granites consist of a mineral assemblage that seems to be equilibrated under low pressure. The second hypothesis suggests that an increase in F concentration during fractionation caused the bulk composition of the residual melt to shift toward albite [42]. This explanation is supported by the high whole-rock F content, the presence of fluorite as interstitial grains and veins cutting the albite granite and the greisenized rocks.

6.2 Fluorine complexing and fluid fractionation

The effects of fluorine in granites is well known and it is suggested that the F-rich fluid could produce HREE and HFSE enrichment in the late stages of evolution of granitic melts due to F complexing [39], [40]. The addition of F into the melt promotes
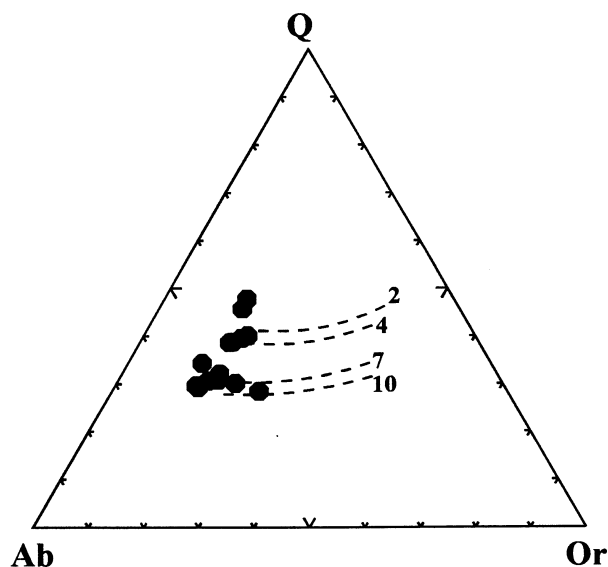
Fig. 9. Normative Q-Ab-Or composition of the Umm Al Suqian albite granite relative to experimental H₂O-saturated minimum melt composition [36].

the formation of SiO_3F complexes of HREE and HFSE, resulting in depolymerization and reduction in the availability of SiO_4 tetrahedra to form HREE- and HFSE-bearing phases [39]. The development of F-bearing fluids and their interaction with the silicic melt at late magmatic stage enhances element fractionation, since the addition of fluorine decreases silicate melt viscosity [41] and expands the primary phase field of quartz [38], [42], thus extending the duration of crystallization. In the studied A-type granites, there are abundant field and geochemical evidence of the presence of a late magmatic fluid phase. Field evidence includes the presence of greisen pockets and veins associated with rare metal mineralization as well as fluorite, which occur both as veins in the albite granite and greisens and as common interstitial phase.

6.3. Magma generation

Many aspects of the Umm Al Suqian albite granites make the identification of their source materials very difficult. First, the granites are geochemically highly evolved and the magma has clearly undergone extensive differentiation since its formation. Second, the granites were emplaced at shallow crustal levels and their root zones are not exposed. This is in addition to the absence of mafic rocks of the same age as the granites in the studied area. The aim of this section is thus to put broad constraints on possible sources of these granites, which can be inferred from the data presented in this paper and from previous studies.

It has been shown that the Umm Al Suqian albite granites are peraluminous. Experimental data show that peraluminous granitic melts can be produced by fluid-absent melting of pelitic and tonalitic rocks [43]. In the Arabian Shield, the crust is juvenile (700 - 900 Ma) and composed of abundant granitic rocks of tonalitic composition. These rocks are attractive sources to produce peraluminous felsic melts at lower crustal pressures [44]. Crustal melting due to crustal thickening seems to be the most plausible model for the origin of post-orogenic granites [45-46]. Thus, a plausible explanation for the origin of the investigated albite granite is their origin by partial melting of tonalitic rocks in the lower crust. The partial melting can be attributed to crustal thickening that associate continental collision at the end of Pan-African Orogeny.

7. Conclusions

The Umm Al Suqian albite granite is a post-collisional peraluminous granite that host greisens and disseminated rare metal-bearing minerals and can be termed as specialized felsic granites. The chemical specialization is clearly reflected through major and trace elements characteristics such as: 1) the extremely low average values of CaO, MgO and TiO_2, 2) the characteristically high concentrations of Nb, Ta, Sn, Y, F, and Rb, 3) the more extreme values for some indicator ratios such as low K/Rb, Ba/Rb and high Rb/Sr.

A multistage model was proposed to explain the origin of the Umm Al Suqian albite granite: (1) partial melting in the lower crust due to crustal thickening. The partial melting process occurred at the end of the Pan-African Orogeny (at about 600 Ma) after the collision with the African continent. Fluxing with mantle-derived volatiles enriched the melt in HFSE and F, (2) ascent of the enriched melt and intrusion of the specialized granitic magma into the upper crust. Subsequent fractionation of this magma tends to concentrate fluorine in the residual melt. In such melts, F enriches HFSE through complexing, (3) fractional crystallization of the evolving F-rich peraluminous granitic magma was accompanied, particularly at later stages by fluid fractionation which plays an important role in the genesis of the greisens and the associated mineralizations.

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أصل الجرانيت الألبيتي الفوق ألوميني الحامل للعناصر النادرة لمحقون أم السقيان
– منطقة عسير – المملكة العربية السعودية

عمر بن أسعد شريبيني وطلال بن مصطفى قاضي
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ملخص البحث. يقع محقون جرانيت أم السقيان الألبيتي في منطقة عسير من المملكة العربية السعودية وهو جرانيت فوق ألوميني ينتمي إلى فترة ما بعد التجبل للعصر البروتيروزوي المتأخر . ويحوي هذا الجرانيت جرايزن ومعادن حاملة للعناصر النادرة . ولقد تداخل هذا المحقون عند مستوى قشري ضحل في صخور الدايوريت والرسوبيات المتحولة .

واعتماداً على الدراسة الميكروسكوبية فقد أمكن تقسيم صخور هذا المحقون إلى أربع سحنات بتروجرافية كما يلي :١- كوارتز بجماتيت، ٢- طبقة خليط من الكنجولـوميرات والكوارتز دايوريت والجرانيت الألبيتي،   ٣- نطـاق متجرزن و٤- الجرانيـت الألبيتي .أما التمعدن فهو يتكون من عروق صغيرة وعدسات من الفلوريت ومعدن مرقط مثل الأكسيوليت ، المونازيت والباستنازيت ، وتقترض المشـاهدات الحقلية أصل مشترك لكل من الجرانيت، الجرايزن والتمعدن المصاحب لهما .

لقد أوضحت النتائج الجيوكيميائية أن الجرانيت الألبيتي يتميز بثراء نسبي في عناصر الزركونيـوم، الصـوديوم، الفلـورين، الروبيـديوم، السـماريوم والاثيـروم، وإنخفاظ ملحـوظ فـي الماغنسيوم، الكالسيوم والتيتانيوم ولذا يمكن تسميته الجرانيت الفلسي المتخصص . وهذا النوع من الجرانيت يتميز بقيم منخفضة في نسبة البوتاسيوم والروبيديوم (٤٩-١٦) وقيم مرتفعة في نسبة الروبيديوم والاسترونشيوم (٧٦-٨) وهيئـة لعناصر الأرض النـادرة تشير إلـى تفارق منخفض .

هذا، وأشارت التغيرات الجيوكيميائية في صخور الجرانيت الألبيتي إلى تكوينها بواسطة التبلور التجزيئي لمعادن أساسية مثل الفلسبار والبيوتيت وقد تلى ذلك افتراض تكوين معقدات الفلورين والتي قامت بنقل العناصر ذات جهد التأين العالي على هيئة مكونات ذائبة . وقد كان التبلور التجزيئي لماجما جرانيتية فوق ألومينية غنية في الفلورين مصحوباً، خاصة في المراحل الأخيرة، بـالتجزء السـائل والـذي لعب دوراً مهماً في تكوين الصخور المتجرزنـه والتمعدنات

المصاحبة لها . أما بالنسبة للماجما الأم لهذا المحقون الجرانيتي فقد تكونت بالانصهار الجزئي (في عدم وجود ماء) لصخور القشرة الأرضية السفلية ، وهذا الانصهار يرتبط بزيادة سمك القشرة المصاحبة للتصادم القاري في نهاية الحركة التجبلية البان إفريقية .