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The behaviour of some major and trace elements in feldspar phenocrysts from Zaker granitic rocks of Zanjan area, northwest Iran

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ABSTRACT

Broadly speaking, the irregularity of K content in the investigated alkali feldspars and plagioclases is mainly due to the kaolinization and sericitization processes. The alkali feldspars examined have lost most of their Na content while Ca is not expelled from its host. The myrmekitic intergrowths around the alkali feldspars have resulted mainly from the interaction between the recrystallized albite and perthitic albite from the free Na with the excess silicons which are expelled from the alkali feldspars during exsolution. The Ga content in the feldspars varies to a large extent. It is interesting to note that the disordered alkali feldspars incorporate less Ga than the ordered albite crystals during the post-magmatic recrystallization.

It is suggested that most of the Rb and K content is extracted from the sodic plagioclases during the sericitization process. The rate of this process decreases with the increase of bridge numbers of SiO_2, which do not break down easily towards the end of the felsic member.

Great similarity has been observed between the examined feldspars and Grimstad feldspars (Christie *et al.* 1970), in which the weight distribution coefficient of Sr is rather similar. It varies from 0·3 to 1·0 in the Zaker and Grimstad feldspars. The ratios of Sr in the coexisting feldspars indicate the temperature of crystallization at which these ratios increase as the temperature becomes high. According to Barth (1961), the ratio equals 1 at 450°C. The Sr ratios of the feldspars examined vary from 0·33 to 1·04, showing that these feldspars began to crystallize at 450°C, falling gradually towards the felsic end member. It is concluded also that the weight distribution coefficient of Ba in these feldspars ($D = 7$ to 20) decreases with the An content.

The pink and red feldspars have high contents of iron oxides (haematite) which resulted mainly from the effects of late hydrothermal solutions. The strong alteration of biotite in the host rocks gave rise to ferric oxides which were redeposited along the fractures and cleavage planes of the studied feldspars.

INTRODUCTION

Zaker pluton forms one of the numerous post-Miocene granitic intrusions (Hirayama *et al.* 1966) in the western part of Tarom District nearest to Zanjan area (Fig. 1). The granitic rocks of the Zaker batholith consist essentially of grey, white, pink and red granites in addition to adamellites, granodiorites and quartz-diorites. These granitic

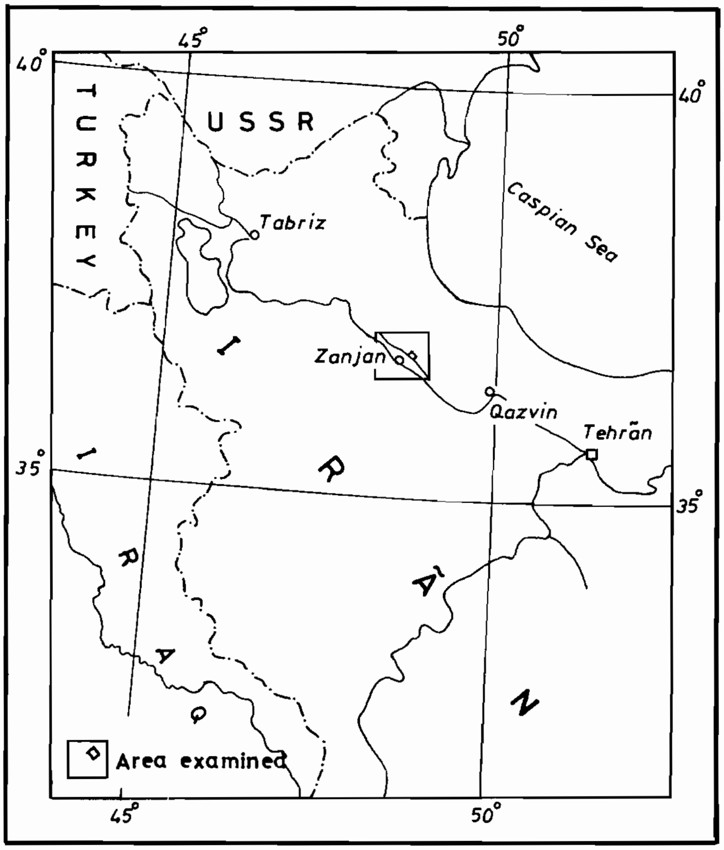

Fig. 1. Location Map.

series include 37 petrographic types comprising 12 porphyritic varieties (Refaat 1975). The phenocrysts in the porphyritic rock units are mainly represented by alkali feldspars and sodic plagioclases in which the former vary from 5 to 17 mm in length and from 4 to 15 mm in breadth, while the latter feldspars range from 7 to 23 mm in length and from 3 to 13 mm in breadth. Refaat (1975) indicated that the feldspars in the red granites are characterised by high contents of iron oxide resulting from the effect of late hydrothermal solutions. These iron minerals reflect partially the red coloration in both feldspars.

The purpose of this study is to examine the distribution and behaviour of major and trace elements in the coexisting feldspar phenocrysts from the porphyritic granitic rocks of Zaker batholith. In addition, to elucidate the relation between the composition of coexisting feldspars and their temperature of crystallisation (Barth 1961, 1962; Winkler 1961).

Table 1. Major and trace elements of alkali feldspars from Zaker granites

	1	2	3	4	5	6	7
SiO_2%	64·50	65·10	64·27	64·81	64·73	63·89	64·09
Al_2O_3%	19·32	19·82	18·00	19·08	19·43	20·54	18·99
CaO%	00·18	00·16	00·17	00·20	00·19	00·18	00·18
K_2O%	14·81	14·21	16·32	14·69	15·41	14·55	15·54
Na_2O%	00·56	00·66	00·64	00·49	00·52	00·69	00·50
H_2O%	00·05	00·06	00·05	00·08	00·04	00·08	00·10
Total	99·43	99·92	99·45	99·15	99·92	99·93	99·40
Ga (ppm)	12	15	10	10	8	12	13
Rb (ppm)	350	600	400	400	350	300	450
Sr (ppm)	220	230	250	150	200	150	230
Ba (ppm)	1500	2800	3000	3500	2500	200	3300
Fe (ppm)	25	20	15	15	20	130	165
SiO_2% of the host rock	70·72	74·00	73·13	73·92	72·61	72·20	73·98

1, Orthoclase from porphyritic biotite grey granite.
2, Orthoclase from porphyritic leuco grey granite.
3, Orthoclase from porphyritic biotite white granite.
4, Orthoclase from porphyritic muscovite white granite.
5, Orthoclase from porphyritic leuco white granite.
6, Perthite and orthoclase from porphyritic biotite pink granite.
7, Orthoclase from porphyritic leuco red granite.

ANALYTICAL METHODS

Twenty-four samples of the alkali feldspars and plagioclases representing the phenocrysts of the main rock units in the granitic batholith were analysed. The major elements of the feldspars were determined by using volumetric and the gravimetric methods of Bennett & Reed (1971) (Tables 1–4). The trace elements (Ga, Rb, Sr, Ba and Fe) of the feldspars were determined by spectrographic methods (Tables 1–4). Tables 1–4 comprise also the silica contents of the porphyritic granitic rocks of the Zaker batholith, from which the feldspars were separated.

The alkali feldspars studied were separated from the host rocks by magnetic and heavy liquid methods. The plagioclase varies in composition from albite to oligoclase (An_5–An_{18}). As it is difficult to separate quartz from sodic plagioclase, most of the plagioclase was selected from the big phenocrysts which were separated easily from the host rock by drilling with an electric nail bit. The powder of plagioclase was purified by repeated treatment with bromoform and acetone mixtures, gradually made to approximate to the specific gravity of plagioclase. Final purification of the plagioclase powder was carried out using the maximum current setting on the isodynamic separator.

Three samples of plagioclase–quartz mixtures were analysed and the analyses were recalculated to exclude the silica of quartz on the assumption that quartz comprised negligible amounts of the studied elements (Table 3). The amount of silica in the three examined plagioclases were calculated from the analyses of plagioclase+quartz mixtures, depending on the calcium and alkali contents. The remaining silica was assumed to be present as quartz.

Table 2. Major and trace elements of alkali feldspars from adamellites and granodiorites of Zakar batholith

	8	9	10	11	12
SiO_2%	64·61	64·54	63·41	63·43	65·83
Al_2O_3%	20·13	19·40	20·21	19·87	20·56
CaO%	00·36	0·29	00·28	00·39	00·40
Na_2O%	3·20	4·01	2·98	3·89	1·03
K_2O%	11·41	10·63	12·66	11·45	10·82
H_2O%	00·20	00·21	00·35	00·41	00·32
Total	99·91	99·08	99·89	99·44	98·96
Ga (ppm)	9	8	11	5	7
Rb (ppm)	180	250	200	150	200
Sr (ppm)	380	450	300	550	550
Ba (ppm)	1000	800	900	1000	800
Fe (ppm)	112	27	8	20	40
SiO_2% of the host rock	68·65	67·62	69·40	65·39	64·01

8, Perthite and orthoclase from porphyritic biotite adamellite.
9, Perthite and orthoclase from porphyritic hornblende biotite adamellite.
10, Perthite and orthoclase from porphyritic leuco adamellite.
11, Perthite and orthoclase from porphyritic hornblende biotite granodiorite.
12, Perthite and orthoclase from porphyritic diopside hornblende granodiorite.

PETROCHEMICAL CHARACTERS OF FELDSPARS

Discussion of the character of the major constituents in both feldspars was carried out in this study as follows.

The relationship between K_2O, Na_2O and CaO of the alkali feldspars and plagioclases versus SiO_2 of the rocks are shown in Figs. 2 and 3 respectively. The potassium content of alkali feldspars and plagioclases increases irregularly as the Si content of the rocks increases. The irregularity of the potassium content in both feldspars is due to the strong alteration of alkali feldspars and plagioclases which is represented mainly by the kaolinization and sericitization processes respectively. The alkali feldspars are represented by orthoclase and perthite. Most alkali feldspar phenocrysts are bounded by rims of quartz, perthitic albite and albite intergrowths showing that these albite grains and myrmekite were derived mainly from the alkali feldspars through exsolution and recrystallization processes (Ashworth 1972; Phillips & Carr 1973). Figs. 2 and 3 show that Na_2O in alkali feldspars decreases with the increase of SiO_2 of the host rocks, while the opposite relation is observed in plagioclases in which Na_2O increases as the host rocks become richer in SiO_2. The alkali feldspars have lost most of their sodic constituents which were recrystallized as albite and perthitic albite grains around the alkali feldspars. Some of these sodic plagioclases were recrystallized with excess SiO_2 which could have been expelled from the alkali feldspars during exsolution to give a myrmekitic intergrowth. These evidences explain the reason for decreasing

Table 3. Major and trace elements of plagioclase from Zaker granites

	I	II	III	1	2	3	4	5	6	7
SiO_2%	82·04	81·17	82·09	68·30	67·48	68·27	65·91	68·09	67·58	67·42
Al_2O_3%	11·38	10·92	10·79	20·35	19·59	19·38	20·42	18·20	19·32	20·14
CaO%	00·43	00·38	00·50	00·71	00·64	00·82	00·67	00·85	00·62	00·74
NaO_2%	5·79	6·72	6·20	10·34	11·87	11·01	11·73	11·03	10·49	9·99
K_2O%	0·18	0·25	0·31	0·30	0·42	0·52	0·44	0·35	0·46	0·55
H_2O%	—	—	—	—	—	—	0·52	0·74	0·60	0·87
Total	99·81	99·43	99·88	100·00	100·00	100·00	99·69	99·26	99·07	99·71
Ga(ppm)	28	40	20				25	30	22	35
Rb(ppm)	60	55	90				45	80	40	95
Sr(ppm)	450	220	430				300	320	450	250
Ba(ppm)	180	150	210				250	200	95	170
Fe(ppm)	200	120	50				30	20	300	350
SiO_2% of the host rock	70·72	74·00	73·13	70·72	74·00	73·13	73·92	72·61	72·20	73·98

I, Plagioclase plus quartz from porphyritic biotite grey granite.
II, Plagioclase plus quartz from porphyritic leuco grey granite.
III, Plagioclase plus quartz from porphyritic biotite white granite.
1, Plagioclase from I recalculated to 100% on a quartz-free basis.
2, Plagioclase from II recalculated to 100% on a quartz-free basis.
3, Plagioclase from III recalculated to 100% on a quartz-free basis.
4, Plagioclase from porphyritic muscovite white granite.
5, Plagioclase from porphyritic leuco white granite.
6, Plagioclase from porphyritic biotite pink granite.
7, Plagioclase from porphyritic leuco red granite.

Table 4. Major and trace elements of plagioclase from adamellites and granodiorites of Zaker batholith

	8	9	10	11	12
SiO_2%	63·41	63·34	65·81	63·09	61·62
Al_2O_3%	23·11	22·15	20·91	23·99	24·96
CaO%	3·87	2·22	2·00	4·32	5·08
Na_2O%	9·20	8·78	9·41	8·13	7·50
K_2O%	0·07	0·06	0·07	0·04	0·05
H_2O%	0·29	0·40	0·59	0·22	0·16
Total	99·95	98·99	98·79	99·79	99·37
Ga(ppm)	25	18	20	12	15
Rb(ppm)	20	15	25	15	16
Sr(ppm)	600	550	500	700	850
Fe(ppm)	200	130	180	150	170
Ba(ppm)	90	110	100	95	70
SiO_2% of the host rock	68·65	67·62	69·40	65·39	64·01

8, Plagioclase from porphyritic biotite adamellite.
9, Plagioclase from porphyritic hornblende biotite adamellite.
10, Plagioclase from porphyritic leuco adamellite.
11, Plagioclase from porphyritic hornblende biotite granodiorite.
12, Plagioclase from porphyritic diopside hornblende granodiorite.

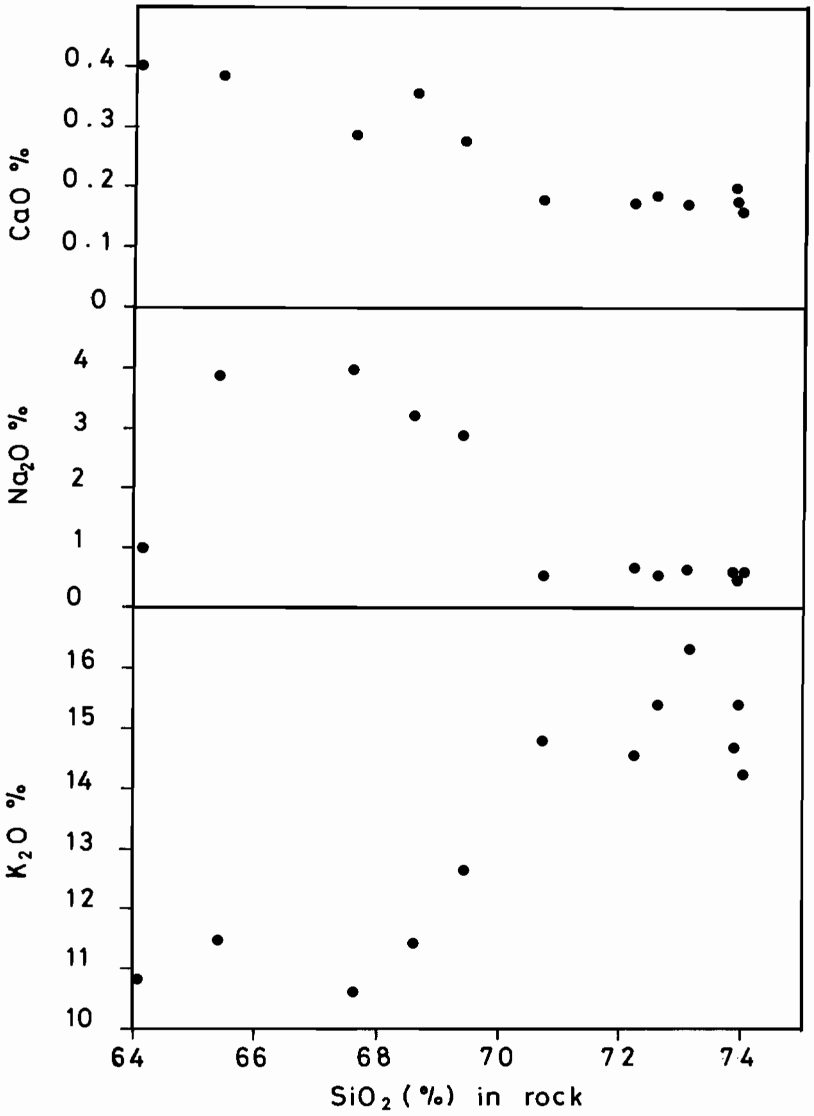

Fig. 2. The relation between K, Na and Ca content of the alkali feldspars and the composition of the rocks.

Na content in alkali feldspars as the rocks become richer in quartz. They also indicate a higher content of Na in plagioclase with increasing SiO_2 in their host rocks.

Figs. 2 and 3 show also that CaO in feldspars decreases with increase of SiO_2 in the rocks. Therefore, it is clear that the alkali feldspars do not lose their Ca content as easily as their Na content, i.e. the migration of Ca is more difficult than that of Na, because Na and K are both univalent. In addition, Na can easily change its position with K without changing the balance of charges in the crystal structure (Hall 1967). The exchange between Na and K in the alkali feldspars shows the reason for the presence of high content of K as the host rocks become more acidic.

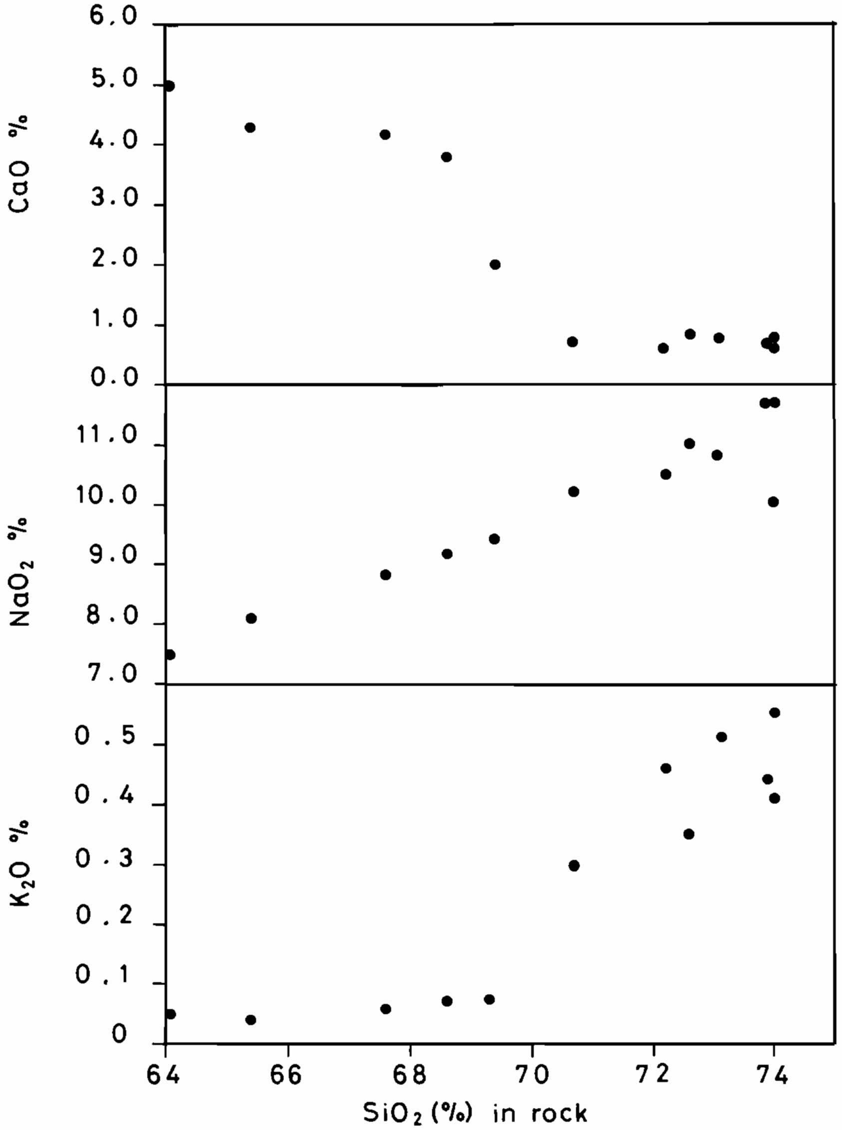

Fig. 3. The relation between K, Na and Ca content of the plagioclases and the composition of the rocks.

GEOCHEMISTRY OF FELDSPARS

The distribution and behaviour of Ga, Rb, Sr and Ba in both feldspars are discussed as follows.

Fig. 4 shows the relationship between Ga, Rb, Sr and Ba of alkali feldspars to SiO_2 of the host rocks. It is evident that Ga, Rb and Ba increase gradually toward the felsic end member, while Sr decreases rapidly in the same direction.

The relationship between Ga, Rb, Sr and Ba of plagioclases to SiO_2 of the host rocks is shown in Fig. 5. The behaviour of these four trace elements in plagioclases follows the same trend as in the alkali feldspars. The Ga content in both feldspars increases gradually as the host rocks become more acidic. The distribution of Ga in the alkali feldspars shows little change, varying from 5 to 15 ppm while the Ga content in the plagioclases ranges from 12 to 40 ppm.

Fig. 6 shows the distribution of Ga in the two feldspars indicating that the plagioclases contain more than twice the Ga present in the alkali feldspars. The great variability of Ga content in the examined feldspars is mainly attributed to the post-

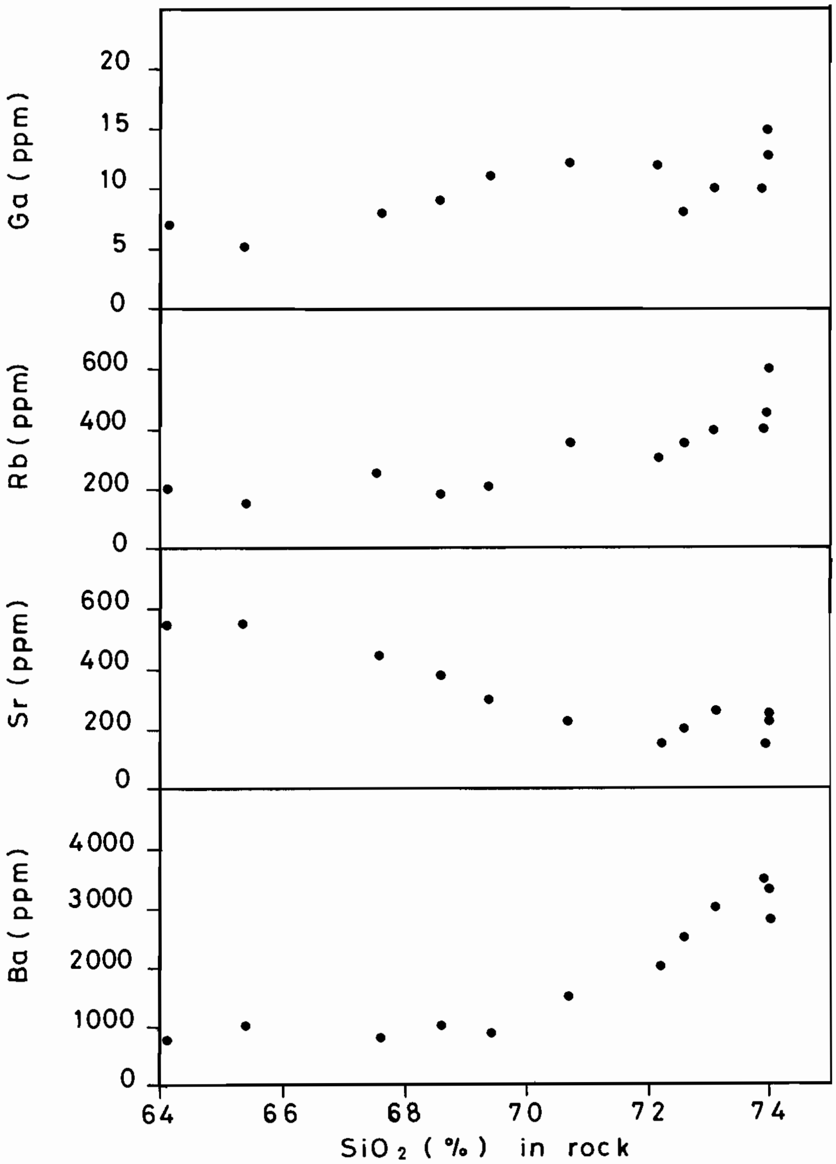

Fig. 4. The relation between Ga, Rb, Sr and Ba content of the alkali feldspars and the composition of the rocks.

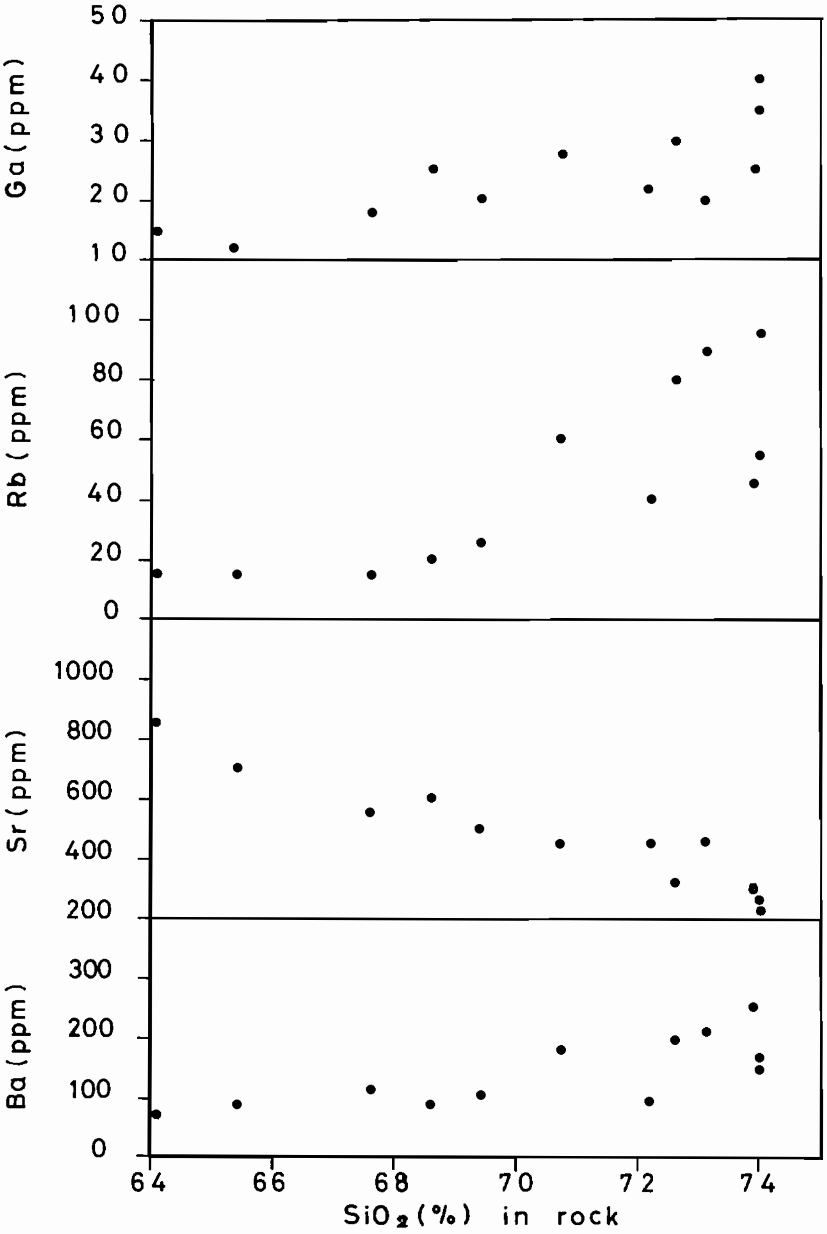

Fig. 5. The relation between Ga, Rb, Sr and Ba content of the plagioclases and the composition of the rocks.

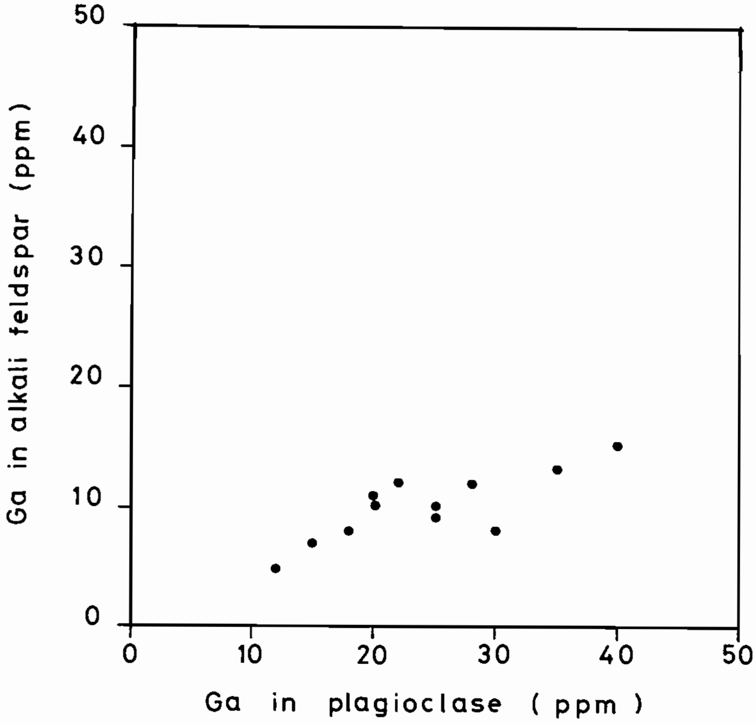

Fig. 6. The distribution of Ga between coexisting feldspars.

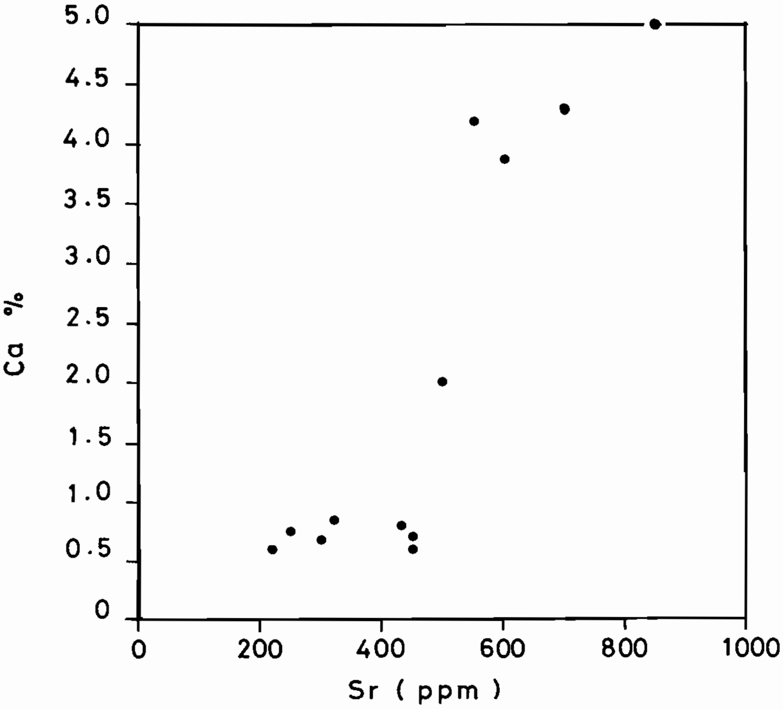

Fig. 7. The relation between Sr and Ca content of the plagioclases.

magmatic recrystallization which has distorted the structure of the alkali feldspars. Therefore, this process permits redistribution of Ga between the two feldspars. The Ga content in the feldspars is mainly camouflaged by Al. The Al content of the alkali feldspars does not vary greatly due to the similarity of their composition. The Al content in the plagioclases decreases towards the end of the felsic member of the host rocks, i.e. as the An content decreases. Therefore, the high acidic rocks are characterized by high Ga/Al ratios. The rocks with high silica content are considered richest in low-melting-temperature constituents such as albite, orthoclase and quartz. Therefore, the decreasing of melting temperature for constituents allows a greater reception of Ga as compared to Al. It should be mentioned that Ga has a larger ionic radius than Al (Ga^{3+} 0·62Å, Al^{3+} 0·51Å). According to Mackenzie & Smith (1961), albite reaches its ordered state at low temperature more readily than alkali feldspars. It is evident that the ordered sodic plagioclases incorporate Ga more readily than the disordered alkali feldspars during post-magmatic recrystallization.

In the plagioclases, the Rb content may reach up to 95 ppm, while the maximum amount of Rb in alkali feldspars reaches 600 ppm. Figs. 4 and 5 show that both Rb and K increase as the rock becomes more acidic. The bulk of rubidium was extracted from the sodic plagioclases during the formation of sericitic muscovite as a result of the alteration process of plagioclases. It is evident that sericitic muscovite decreases with increase of SiO_2 content of the host rocks. Therefore, the rate of the alteration process decreases with the increase of the number of bridges in SiO_2 which are not broken down easily towards the felsic end members.

Strontium increases in the feldspars as the SiO_2 of the host rocks decreases (Figs. 4, 5). Fig. 7 shows a marked relationship between Sr and Ca of the investigated plagioclases in which the Sr content decreases as the Ca content decreases. It is evident that the more acidic rocks contain larger amounts of alkali feldspar. These alkali feldspars extracted from the magma some of the Sr which would otherwise have gone into the plagioclases. The behaviour of Sr in both feldspars can be seen in Fig. 8 which summarises the Sr data for the coexisting feldspars, referred to radiating lines of weight distribution coefficient (Smith 1974). This distribution coefficient varies from 0·2 to 2·0, with the feldspars from Grimstad granite mostly ranging from 0·4 to 1·0 (Christie *et al.* 1970). The distribution coefficient of the examined feldspars varies from 0·3 to 1·0 suggesting that the host rocks are similar to the Grimstad granite. The factors which control the Sr distribution are chiefly temperature, pressure, concentration of major elements in feldspars, order and disorder of the atoms, the extent of unmixing, the nature of the coexisting minerals and the bulk composition of the host rock (Smith 1974). Therefore, the distribution of Sr between feldspars is closer to its behaviour during the magmatic crystallization than is the distribution of Na and K, i.e. the Sr distribution in feldspars may be used as a geological thermometer for the temperature of crystallization. Barth (1961) argued that the ratio of Sr in alkali feldspars/Sr in plagioclases increases as the temperature increases. However, these ratios nearly equal 1 at 450°C. The Sr ratios of the feldspars vary from 0·33 to 1·04, indicating that crystallization of both feldspars began mostly at 450°C and then gradually fell off toward the end of the felsic member.

Fig. 9 shows the distribution of Ba between coexisting feldspars with the radiating lines giving weight distribution coefficient for alkali feldspar over plagioclase (Smith 1974). The examined feldspars are characterised by the distribution coefficient (D) varying from 7 to 20. It is concluded that the distribution coefficient of Ba in the co-

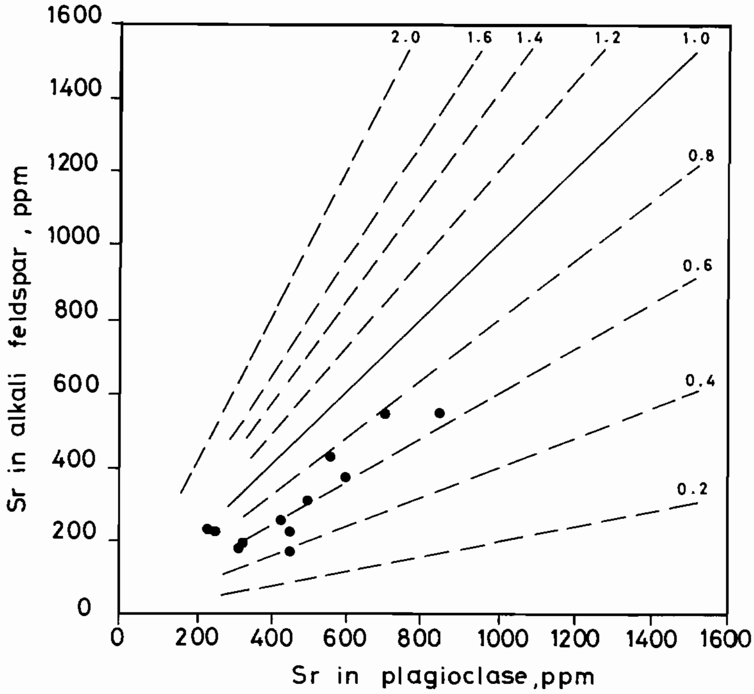

Fig. 8. Distribution of Sr between coexisting feldspars.

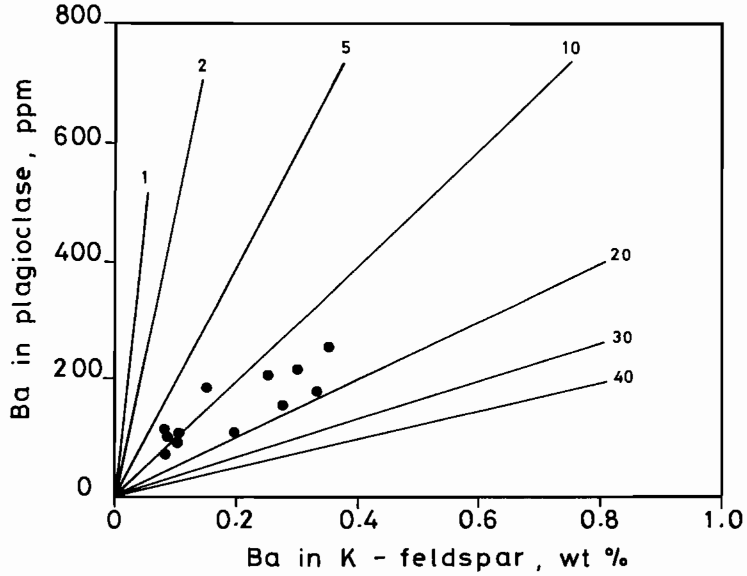

Fig. 9. Distribution of Ba between coexisting feldspars.

existing feldspars decreases with the decrease of SiO_2 in the host rocks, i.e. D increases as the An content of plagioclases decreases.

The colours of the examined feldspars vary from white to red, showing that there is a strong relationship between the colours of these feldspars and their iron content. The iron content of the white alkali feldspars varies from 15 to 20 ppm, while the iron content of the pink and red alkali feldspars may reach 165 ppm (Table 1). The iron content of the examined white plagioclases varies from 20 to 50 ppm, while the pink and red plagioclases range from 300 to 350 ppm (Table 3). The iron in the pink and red feldspars occurs mainly as haematite inclusions along the cleavage and fracture planes of the feldspars.

It is evident that the high content of iron in the pink and red feldspars is attributed to the effect of late hydrothermal solutions, in addition to the ferrous iron resulting from alteration of biotite and its redeposition as ferric oxide along the fractures and cleavage planes of the feldspars (Refaat 1975).

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سلوك بعض العناصر الشائعة والنادرة في بلورات الفلدسبارات الكبيرة فى الصخور الجرانيتية لزاكير بمنطقة زانجان ـ شمال غرب ايران

عادل محمد رفعت
معهد التربية للمعلمين ـ العديلية ـ الكويت

خلاصـــــة

لقد اتضح أن عدم انتظام المحتوى البوتاسى فى الفلدسبارات تكون نتيجة عملية الكولنة والسرستة . إن المحتوى الصودى للفلدسبارات القلوية قد نقص بينما المحتوى الكالسى لنفس البلورات ظل ثابتا تقريبا .

إن ظهور النسج الميرميكيتى حول الفلدسبارات القلوية قد نتج غالبا من عملية امتـزاج المحاليل الغنية بالصوديوم والسليكون . ومن الضرورى ذكر أن الفلدسبارات القلوية اشتملت على عنصر الجاليوم بنسبة أقل من بلورات الالبيت وذلك أثناء إعادة بلورتها . ان عنصر الروبيديوم قد استخلص من البلاجيوكليزات الصودية أثناء عملية السرستة ، وإن معـدل عملية السرستة يقل بزيادة عدد الروابط الموجودة فى ثانى اكسيد السيليكون والتى يقـل تكسيرهـا كلما زادت حامضية الصخر .

إن نسبة عنصر الاسترونشيوم الموجودة فى الفلدسبارات القلوية والصودية توضح درجة حرارة تبلورها ، حيث أن زيادة النسبة تعكس زيادة درجة حرارة التبلور ، ومن المعروف أنه إذا كانت هذه النسبة = ١ فان درجة حرارة التبلور = ٤٥٠ م° ، وحيث أن نسبة الاسترونشيوم فى الفلدسبارات تتراوح بين ٠,٣٣ و ١,٠٤ فان هذه النسبة تدل على أن درجة حرارة تبلور الفلدسبارات قد بدأت من حوالى ٤٥٠ م° ، ثم انخفضت مع تبلور فلدسبارات الصخور الأكثر حامضية . وقد اتضح أيضا أن اللون الأحمر المميز لبلورات الفلدسبارات فى صخور الجرانيت الحمراء راجع إلى كثرة وجود معدن الهيماتيت المتكون من المحاليل الساخنة ، بالاضافة إلى عملية تحلل معدن البايوتيت ، مما يؤدى إلى إعادة ترسيب الهيماتيت فى شقوق وتشققات معادن الفلدسبارات .