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TRACE ELEMENTS IN ALKALI FELDSPARS, QUADRILÁTERO FERRÍFERO, MINAS GERAIS, BRAZIL[1]

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ABSTRACT

Twelve samples of alkali feldspar from post-tectonic granite and metamorphosed gneiss, granite, and granodiorite from the Quadrilátero Ferriífero, Minas Gerais, Brazil, were analyzed for Fe, Ca, Na, and K, by rapid chemical analysis and for Ba, Sr, Li, Cs and Rb, by spectrochemical analysis.

In the alkali feldspars, Na_2O varied from 1.0 per cent in gneiss to 3.8 per cent in post-tectonic granite, and K_2O reciprocally from 14.8 per cent to 10.8 per cent. Temperatures calculated from the distribution of albite in these feldspars and their associated plagioclase range from 380° C in gneiss to 610° C in the postmetamorphic granite.

Cs is low in all samples, from 0.7 to 2.5 ppm; Fe_2O_3, 0.08 to 0.22 per cent; and Li, 2.3 to 38 ppm; none show any systematic variation. Rb is highest in the post-tectonic sample, 720 ppm, and lowest in granodiorite, 85 ppm. Ba and Ca vary inversely to Rb: Ba from 90 to 5,500 ppm, and Ca from 430 to 1,790 ppm. Sr is lowest in the post-tectonic granite, 30 ppm, and highest in the granodiorite, 665 ppm. Nearly all the Ba of the rocks and generally less than half of the Sr is in the alkali feldspars.

The Ba/Rb ratio alone or Ba/Rb used together with K/Rb were found to be valid criteria for differentiating the samples genetically. A plot of the two ratios shows a curvilinear relationship, with the post-tectonic sample nearest the origin and the granodiorite farthest away.

INTRODUCTION

Pre- and postmetamorphic gneiss and granite underlie a large part of the Quadrilátero Ferrífero of Minas Gerais, Brazil, generally as domelike bodies. Some are within the area of metamorphosed sedimentary rocks, as the Bação granitic complex, but most bound the area, as the Moeda complex and others (Fig. 1). Some granites and gneisses have been described, as in the Itabira (Dorr and Barbosa, 1963), and Congonhas districts (Guild, 1957), and regional correlations have been attempted (Herz and Dutra, 1958; Herz, *in* Dorr *et al.*, 1960).

One of the last metamorphic events in the area was widespread low-grade regional metamorphism at the greenschist level which destroyed original textures in places, and caused a retrogression of higher grade minerals, such as biotite to chlorite, and calcico ligoclase to albite plus clinozoisite. Such changes have made it difficult to correlate granites and gneisses across the area and also to reach a consensus as to their origin.

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The present study is an attempt to decipher the origin and history of these rocks by analysis of their alkali feldspars.

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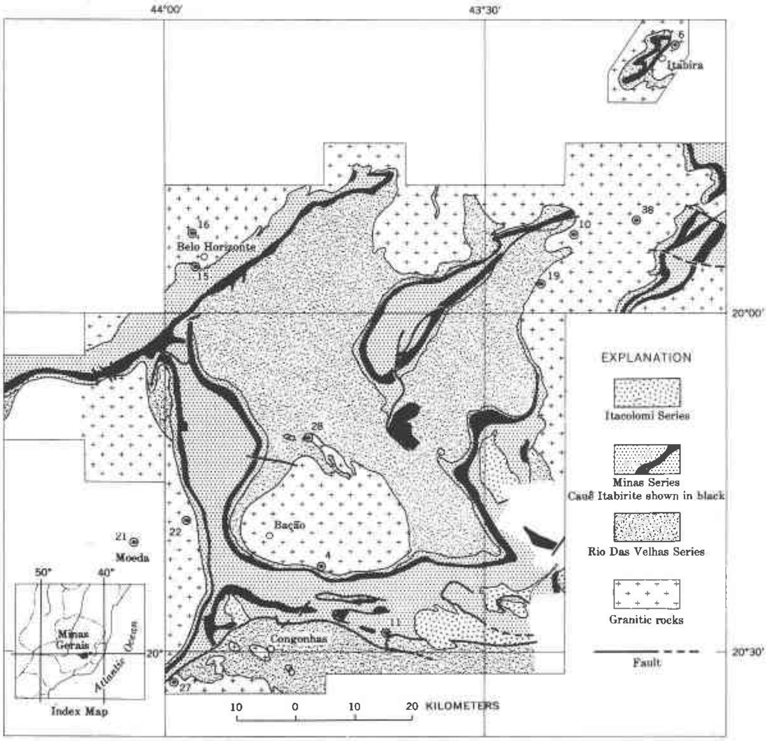

FIG. 1. Sample locations of Quadrilátero Ferrífero alkali feldspars.

Development of the United States Department of State. We also thank Michael Fleischer and Fred Barker for critically reviewing the manuscript.

Sample Description and Preparation

The geology of the Quadrilátero Ferrífero has been described in some detail elsewhere (Dorr *et al.*, 1960). In a general way, the metamorphic grade is low, with widespread development of the chlorite and biotite isograd. In the northwest, the staurolite isograd appears as the contact with granites and gneisses is approached; around the Bação granitic complex, in the southwest, and in the eastern parts of the area, the amphibolite facies has developed. Widespread presence of kyanite in certain phyllites and schists is considered to be largely a function of chemical composition and pressure, rather than a temperature increase above the greenschist level.

Representative granite gneisses and granites were selected from

TABLE 1. SAMPLE DESCRIPTIONS. ARRANGED IN ORDER OF DECREASING BA-MOLECULE IN ALKALI FELDSPAR (TABLE 6)

Sample	Rock type	Mode								
		Qz	Plag	(an%)	K-feld	Bio	Musc	Epid	Chlor	Acc.[1]
Ha−27	Unfoliated granodiorite	18.3	50.2	(22)	10.9	14.1	2.7			C, S, Z, Am 3.7
− 4	Poorly foliated granodiorite	30.4	44.0	(15)	14.8	5.3	3.3	1.0		M, A
−16	Banded gneissic granite	23.1	23.7	(17)	33.1	12.0	5.1		0.6	Am 2.0, S, M, A, C
−38	Granoblastic flaser gneiss	45	22	(15)	22	9	p			A, O, Z
−28	Banded granodiorite gneiss	22.8	32.5	(8)	21.6	9.3	6.8		p	C, P, S, T
− 6	Foliated granite gneiss	34	31	(2)	32	2	p	p	p	A, G, Z
−15	Unfoliated granite gneiss	27.4	28.5	(10)	32.2	3.7	5.0	2.1	1.1	O, A, Z
−11	Banded crushed gneiss	35.3	17.2	(0)	32.6	3.6	8.0	1.2	1.8	O
−19	Foliated granodiorite gneiss	41	25	(13)	17	4	8	5		C, A, O, Al, Z
−21	Porphyritic granite gneiss	27.3	29.1	(15)	35.7	3.7	2.7	1.2	0.2	C, O
−22	Porphyritic granite	37.2	27.5	(10)	20.8	7.3	2.8	2.8		A, S, Al
−10	Unfoliated granite	32.3	22.5	(0)	26.3	6.3	4.5	p	p	F, O

[1] Accessories: A = apatite, Al = allanite, Am = amphibole, C = carbonate, F = fluorite, G = garnet, M = magnetite, O = opaques, P = sulfides, S = sphene, T = tourmaline, Z = zircon.

throughout the area for this study (Fig. 1, Table 1). Samples Ha-15 and 16 are near Belo Horizonte, 21 and 22 from the Moeda complex, 27 from a granodiorite from Congonhas (Guild, 1957), 4 and 28 from the Bação granite complex, 11 from south of the complex, and 6, 10, 19, and 38 from the eastern part of the area. Samples 4, 16, 27, and 28 from the western part are considered to belong to older intrusive suites, that is older than about 2,500 my, and most of the others to be younger than about 1,400 my. (Aldrich *et al.*, 1964; Herz *et al.*, 1961). No determinations yet made, however, have been concordant, so these ages should be considered tentative. Correlation of different rock bodies has also proven difficult because some rocks have a partially anatectic origin, *i.e.*, the Bação complex, and nearly all were later metamorphosed.

Concentrates of alkali feldspar were prepared from rock samples ground to 100–200 mesh and floated in a mixture of bromoform and *N*-dimethylformamide (Hickling, *et al.*, 1961) of G = 2.60. The separation procedure was repeated and checked with immersion oils, until the samples were at least 98 per cent pure alkali feldspar. Splits were made for chemical, spectrographic, and isotopic-age analyses. Plagioclase composition was determined by four-axis universal stage using the technique of Slemmons (1962a) or by oil immersion for grains that did not show good twinning. Order-disorder relations, expressed as the intermediacy index, were also determined by optical methods (Slemmons, 1962b).

Total Fe expressed as Fe_2O_3, CaO, Na_2O, and K_2O were determined in the laboratories of the U. S. Geological Survey, Washington, D. C., by methods of rapid chemical analysis. Ba, Sr, Li, Cs and Rb were determined by Dutra spectrographically in the laboratories of the Instituto de Tecnologia Industrial, Belo Horizonte, M. G., Brazil (Table 2). The techniques and precision of these analyses except for Rb have been described elsewhere (Herz and Dutra, 1960).

Rb was determined using samples G-1 and W-1 as standards, mixed in different proportions in a base of "synthetic granite" (SiO_2 72.3 per cent, Al_2O_3 15.5 per cent, Fe_2O_3 1.5 per cent, $CaCO_3$ 1.2 per cent, $MgCO_3$ 0.5 per cent, Na_2CO_3 3.5 per cent, and K_2CO_3 5.5 per cent, sintered at 900° C) that was spectrographically pure. Rb concentrations of 220 and 22 respectively were assumed, as recommended by Ahrens and Fleischer (1960, p. 97). The samples were then mixed in the granite base with those highest in Rb diluted four times. An idea of the accuracy of the spectrographic analyses can be obtained by comparing Rb/Sr ratios obtained by *x*-ray fluorescence analysis to ratios calculated from the spectrographic determinations (Table 4).

Temperatures of Formation

All the rocks studied, except Ha-27, have more than 80 per cent of normative albite+orthoclase+quartz, and so can be classified by the system of Tuttle and Bowen (1958). They fall within the low-temperature trough of the system albite-orthoclase-quartz, and are subsolvus, or rocks characterized by both potassium and plagioclase feldspars. Except for samples 10 and 27, the alkali feldspars are type II C of Tuttle and Bowen (1958), that is with less than 15 per cent albite molecule. They are assumed to have completed crystallization, or recrystallization at low temperatures, probably under metamorphic conditions. Sample 10, with 34.7 per cent albite in the alkali feldspar, is a type II A, or one that

TABLE 2. RESULTS OF ANALYSIS OF ALKALI FELDSPARS

[Fe_2O_3, CaO, Na_2O, and K_2O analyzed by Paul Elmore, Samuel Botts, and Gillison Chloe, U. S. Geological Survey Ba, Sr, Li, Cs, and Rb analyzed by C. V. Dutra]

Sample No.	Fe_2O_3[1] (per cent)	CaO (per cent)	Na_2O (per cent)	K_2O (per cent)	Ba (ppm)	Sr (ppm)	Ca[2] (ppm)	Li (ppm)	Cs (ppm)	Rb (ppm)	An (per cent)	Ab (per cent)	Or (per cent)	Plag-An[3] (per cent)	Intermediacy[4] index	Temperature[5] (°C)
Ha-27	0.12	0.24	2.4	12.1	5480	665	1720	2.9	1.5	85	1.3	22.7	75.7	22	100	570
4	0.08	0.25	1.6	13.7	5500	618	1790	28	1.0	240[6]	1.3	14.9	83.8	15	90	460
16	0.12	0.11	1.3	14.3	4530	540	790	1.0	2.0	276	0.6	12.1	87.4	17	80	420
38	0.16	0.12	1.0	14.8	4340	182	860	3.2	0.8	330	0.6	9.3	90.1	15	80	380
28	0.22	0.22	1.4	14.0	3050	48	1570	5.0	0.7	190[7]	1.1	13.1	85.8	8	100	420
6	0.10	0.10	1.4	14.3	2320	127	715	2.3	1.5	450[8]	0.5	12.7	86.6	2	96	400
15	0.18	0.12	1.1	14.6	2170	120	860	7.0	2.5	650	0.6	10.2	89.2	10	93	380
11	0.12	0.04	1.6	14.2	1560	30	290	2	1.0	250	0.2	14.6	85.2	0	96	420
19	0.08	0.10	1.4	14.4	1690	40	715	38	0.8	300	0.5	12.8	86.7	13	?	420
21	0.10	0.08	1.4	14.3	1330	82	570	5.5	0.8	540	0.4	12.9	86.7	15	100	430
22	0.12	0.08	1.3	14.4	1120	46	570	4.0	0.8	400[9]	0.4	12.0	87.6	10	90	400
10	0.12	0.06	3.8	10.8	90	30	430	13	0.8	720	0.3	34.7	65.0	0	100	610

[1] Total Fe reported as Fe_2O_3.
[2] Calculated from chemical analysis.
[3] Anorthite content of associated plagioclase.
[4] Slemmons, 1962b.
[5] Temperature calculated from distribution of albite in plagioclase vs. alkali feldspar.
[6] By spectroscopy 240 ppm, by *x*-ray fluorescence 245 ppm.
[7] By spectroscopy 198 ppm, by *x*-ray fluorescence 180 ppm.
[8] By spectroscopy 435 ppm, by *x*-ray fluorescence 465 ppm.
[9] By spectroscopy 360 ppm, by *x*-ray fluorescence 445 ppm.

formed at high, magmatic temperatures, and sample 27 with 22.7 per cent albite may be intermediate, that is an original magmatic alkali feldspar slightly modified under metamorphic conditions. The orthoclase-albite-anorthite diagram (Fig. 2) shows clearly the enrichment in Or of the gneissic samples compared to samples 10 and 27 which fall nearer to the Ab corner; all alkali feldspars, however, fall close to the Or-Ab join.

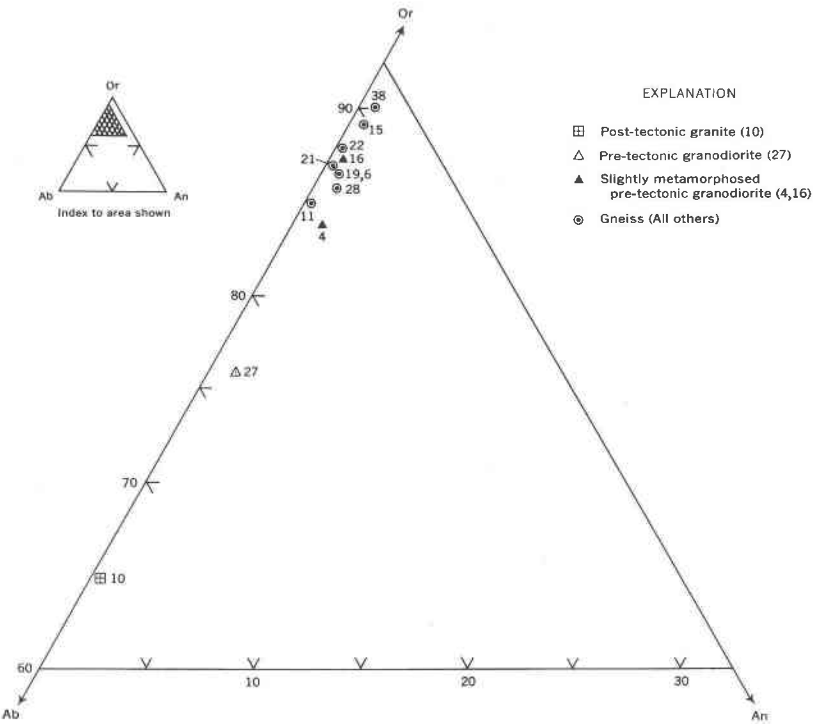

FIG. 2. Quadrilátero Ferrífero alkali feldspars in ternary albite-orthoclase-anorthite diagram.

Plagioclase associated with these alkali feldspars has uniformly high intermediacy indices (Table 2, and Slemmons, 1962b). This index is a means of evaluating order-disorder in feldspar and has been found to be very high in metamorphic rocks (Slemmons, 1962b). The high degree of ordering shown by the intermediacy indices of the Quadrilátero Ferrífero is a probable effect of the thoroughgoing low-grade regional metamorphism.

Temperature of formation was derived from the curve of Barth (1956) relating the albite content of K-feldspar and plagioclase. Barth suggested that the relationship of mole fraction of albite in K-feldspar to that of plagioclase should vary with temperature and pressure. These temperatures, however, may reflect only the most recent lowest temperature at which equilibrium existed between the feldspar phases, and not an original temperature of formation (Dietrich, 1961). The temperatures shown (Table 2) for 9 of the 10 subsolvus II C feldspars vary only from 380° C. to 430° C; the other sample, 4, is 460° C. These are expected temperatures for the regional greenschist metamorphic facies. Sample 27, a II B subsolvus is 570° C., and 10, a II A, is 610° C.

The Sc content of biotite has also been used to indicate geological temperatures (Oftedal, 1943). Results on biotite from three of these Quadrilátero Ferrífero rocks (Herz and Dutra, 1964) agree in a qualitative way with the temperatures obtained by the feldspar geothermometer. According to Oftedal, higher Sc content is associated with lower temper-

TABLE 3. GEOCHEMICAL PROPERTIES OF THE ELEMENTS DETERMINED

	Li^+	Na^+	K^+	Rb^+	Cs^+	Ca^{2+}	Sr^{2+}	Ba^{2+}	Fe^{3+}
Ionic radius (Å)	.68	.97	1.42	1.57	1.82	0.99	1.16	1.43	0.64
Coordination	6	6	10	10	12	6	8	10	6
Ionization potential (volts)-	5.39	5.14	4.33	4.18	3.89	11.82	10.98	9.95	16.24

atures; in biotite from these rocks, sample 10 has 4.6 ppm Sc, sample 4 has 24 ppm, and sample 38 has 32 ppm. The feldspar geothermometer suggests the same order of falling temperature, with 610° C. for sample 10, 460° C. for 4, and 380° C. for 38. Considering only the possible order of differentiation, as was done in our biotite study, sample 10, a granite, should have more Sc than 4, a granodiorite. That the reverse is true suggests that the Sc content reflects metamorphic temperatures, as does the feldspar geothermometer, and that at least some of the biotite was recrystallized during metamorphism.

DISTRIBUTION OF CHEMICAL ELEMENTS

The feldspars studied are essentially (K, Na)$AlSi_3O_8$. Of the other elements analyzed, Rb, Cs, Li, Ca, Sr and Ba probably replace K and Na in the feldspar structure, and Fe is likely present as Fe^{3+} and replaces Al. Substitution of minor elements for K and Na is dependent on similarity of ionic size and charge, and also the character of the oxygen bond as measured by ionization potential (Table 3). Lower potentials indicate a greater tendency to form ionic bonds and be incorporated in the feldspar structure.

Iron and lithium. Fe and Li have much smaller ionic radii than the other elements, and higher ionization potentials, which indicates a greater tendency to form covalent bonds. Their distributions in these alkali feldspars do not appear to follow any discernible pattern and their abundance in any one sample may be due to fortuitous circumstances.

Sodium and potassium. The amount of sodium (as Na_2O) in most of the K-feldspars is low (Table 2), below 1.6 per cent except for sample 27 with 2.4 and sample 10 with 3.8 per cent. This agrees with Heier's study (1962) which found that K-feldspars from gneisses had generally low Na. This is also a reflection of lower metamorphic temperature compared with igneous. Potassium, as expected, varies inversely to sodium.

Sample 27 is mineralogically a granodiorite and occurs in an area of amphibolite-facies metamorphic rocks. Its indicated temperature of 570° C., judged by the distribution of albite in the feldspars (Table 2), is close to Barth's (1956) calculated 600° C. for a tonalite or 530° C. for granodiorite. Sample 10, with the highest Na of all, is a post-metamorphic granite as shown by its discordant field relations and textures; its indicated high temperature of 610° C. may represent original formation.

Rubidium. Rubidium should be the trace element most easily admitted to the K-feldspar structure because of the similar properties of the K^+ and

TABLE 4.—K/Rb, K/Ba, Ba/Rb, AND Rb/Sr RATIOS IN ALKALI FELDSPARS

	K/Rb	K/Ba	Ba/Rb	Rb/Sr	Rb/Sr[1]
Ha-27	1180	19.0	64.5	0.13	0.13
-4	474	20.7	22.9	0.33	0.39
-16	430	26.2	16.4	0.50	0.51
-38	372	28.3	13.2	2.5	1.3
-28	612	38.1	16.1	3	4.0
-6	264	51.2	5.2	4	3.5
-15	187	55.9	3.3	3	5.4
-11	472	75.6	6.2	8	8.3
-19	399	70.7	5.6	5	7.5
-21	220	89.2	2.5	5	6.6
-22	299	107	2.8	6	8.7
-10	124	997	0.1	20	24

[1] by *x*-ray fluorescence. Analysts C. V. Dutra, F. J. Flanagan, and H. J. Rose, U. S. Geological Survey laboratories, Washington, D. C.

Rb^+ ions. Rb ranges in abundance from 85 ppm in granodiorite to 720 ppm in granite. The variation of the K/Rb ratio with differentiation or with rock type is a debated question, but Heier has pointed out (1962) that some K-feldspars in pegmatites are enriched in Rb compared to feldspars in granulite facies mesoperthites and syenites. Ba on the other hand is most abundant in K-feldspars formed at higher temperatures.

Very few K/Rb values (Table 4) fall near the 240 assumed by some to be a constant ratio for the major phases of differentiation. The ratios vary widely from a high of 1,180 in granodiorite, to a low of 124 in the late-stage granitic differentiate; the ratios in gneiss range between those

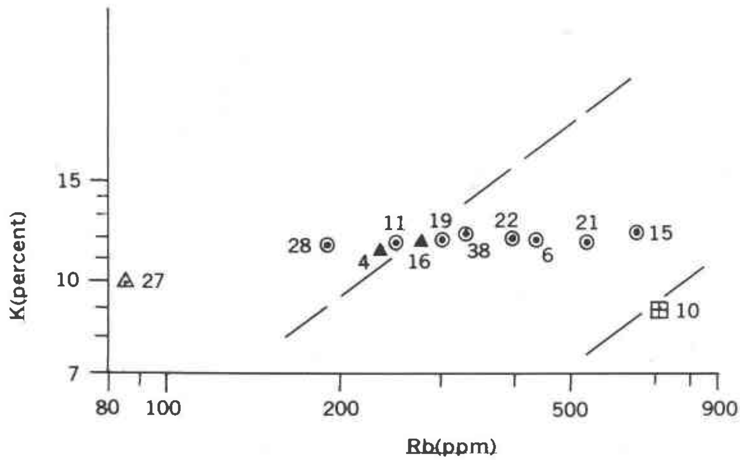

FIG. 3. K/Rb relationships. Dashed lines show "normal scatter" area (Heier and Taylor, 1959a).

values (Fig. 3). Thus, with differentiation, Rb is enriched in alkali feldspar, both in absolute abundance and as compared to K.

The Ba/Rb ratios (Table 4 and Fig. 4) for the gneisses cluster between the maximum in granodiorite of 64.5 and the minimum in granite of only 0.1. The diagram shows that as Rb decreases, Ba increases, which is similar to the results of Heier and Taylor (1959b) for feldspars from Norway. The K/Rb and Ba/Rb ratios appear to decrease in a systematic way from samples 27 to 10 (Fig. 5), whereas the K/Ba ratio increases (Table 4). Temperatures determined by the Barth geothermometer clearly are not related to the curve.

Cesium Cs^+ is the largest of the alkali ions and has 12-fold coordination. Because of this, it is relatively rare in the K-feldspars, having an erratic distribution and generally low abundance (Table 2).

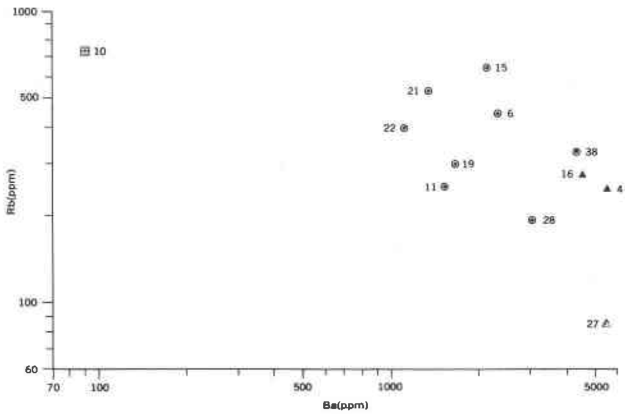

FIG. 4. Ba/Rb relationships.

Calcium, Strontium and Barium. Of Ca, Ba and Sr, Ba has properties that are most similar to those of K. The ionic radii of Ba and K are almost identical and their coordination numbers the same. Ba has a greater tendency to form ionic bonds than either Ca or Sr, shown by its low ionization potential (Table 3), and thus is preferentially incorporated in the feldspar structure. Ba has an inverse relationship to Rb (Fig. 4) which is also brought out by comparing the variation of each with respect to K (compare Figs. 3 and 6). One diagram is almost a mirror image of the other.

Ca is exceptionally low, ranging from 290 to 1790 ppm. Thus, although it is one of the three most important feldspar-forming elements, it is less

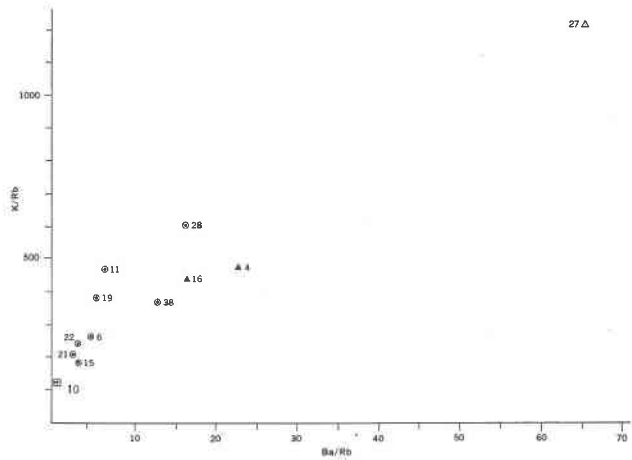

FIG. 5. K/Rb *vs.* Ba/Rb.

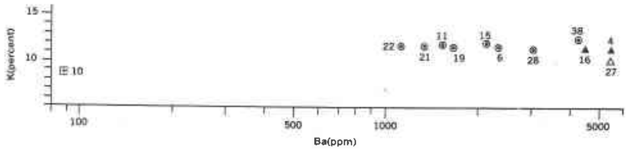

FIG. 6. Ba/K relationships.

abundant than Ba in these alkali feldspars. Ca is the least similar to K of the three elements: it has the smallest ionic radius, lowest coordination number, and greatest tendency to form covalent rather than ionic bonds.

Sr has properties intermediate between Ca and Ba. It has a much lower abundance in these alkali feldspars than either Ca or Ba. Comparing the alkali feldspar to the host rock, only sample 10 has more than half of its available Sr in the feldspar, yet in many samples, all the available Ba is in the alkali feldspars (Table 5). Sr is probably enriched in plagioclase of these rocks.

The Brazilian feldspars have higher Ba/Sr ratios than Norwegian Precambrian alkali feldspars (Heier and Taylor, 1959b). On a plot of Sr

TABLE 5. BARIUM/STRONTIUM/CALCIUM RELATIONSHIPS

Sample[1]	Ba in rock (ppm)	Ba % in K-feldspar	Sr in rock (ppm)	Sr % in K-feldspar	Ba/Sr in rock	Ba/Sr in K-feldspar	Ca/Sr in K-feldspar
27	1600	37	580	12	2.8	8.2	2.6
4	860	95	300	30	2.9	8.9	2.9
16	1600	94	380	47	4.2	8.4	1.5
38	1300	73	93	43	14.0	23.8	4.7
6	1000	74	130	32	7.7	18.3	5.6
15	1300	54	170	23	7.6	18.1	7.2
11	450	100	52	19	8.7	52.0	9.7
19	360	80	110	6	3.5	42.5	17.9
21	540	88	71	41	7.6	16.2	7.0
22	720	32	76	13	9.5	24.3	12.4
10	13	100	14	57	0.9	3.0	14.3

[1] No whole rock analysis for Sample 28.

vs Ba (Fig. 7), most feldspars from gneiss fall in the same general position as those from the Norwegian gneisses; sample 10 falls in a pegmatite feldspar area, and 27, 4 and 16, plot near feldspars of Norwegian granites or anatectic granites.

There appears to be almost a linear relationship between Ca- and Sr-enrichment in K-feldspar (Fig. 8). In the whole-rock analyses (Herz and Dutra, 1960), comparatively uniform average $Sr \times 1000/Ca$ ratios of 15.1 to 23.0 were found in the older rocks and 5.2 and 14.8 in the younger. Ca shows an inverse relationship to Rb; feldspars from granodiorite fall in the Rb-poor field (Fig. 3) and have exceptionally high Ca; whereas the late granite has the highest Rb, and one of the lowest Ca, as well as the lowest Ba. The samples from the gneisses have intermediate values of Rb and Ca. Heier and Taylor (1959a,) found the same striking correlation between Rb deficiency and Ca abundance in southern Norwegian alkali feldspars.

Summary and Conclusions

In this study, the alkali feldspars were divided into three groups: (1) occurring in post-tectonic intrusive granite, high-temperature subsolvus (sample 10); (2) occurring in pre- or syntectonic granodiorite, possibly medium temperature subsolvus, ranging to low temperature because of metamorphism (sample 27 and possibly 4 and 16); (3) occurring in gneiss, retrograded under greenschist metamorphic conditions, low-temperature subsolvus (all other samples). The most important differences between these groups is shown below:

Post-tectonic	*Pre- or syntectonic*	*Metamorphic*
highest Rb, Na	lowest Rb	
lowest Ba, K low Ca, Sr	highest Ba, Ca, Sr low K	highest K
lowest Ba/Rb, K/Rb, Ba/Sr highest K/Ba	highest Ba/Rb, K/Rb lowest K/Ba, Ca/Sr	
lowest rock Ba/Sr		highest rock Ba/Sr
	highest An-content in associated plagioclase	

Rb and Ba appear to enter alkali feldspars in a systematic manner, dependent on the temperature at time of formation or metamorphism, and both have geochemical properties (Table 3) that most closely approximate those of K. Ba is generally more abundant than Ca, and the $BaAl_2Si_2O_8$ molecule is invariably higher than anorthite in such feldspars (Table 6). In all alkali feldspars, except for the high-temperature sub-

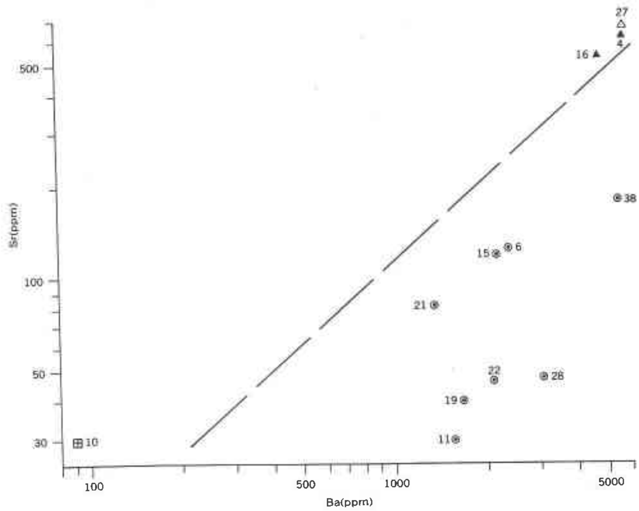

FIG. 7. Ba/Sr relationships. Broken line is trend of Norwegian alkali feldspars (Heier and Taylor, 1959b).

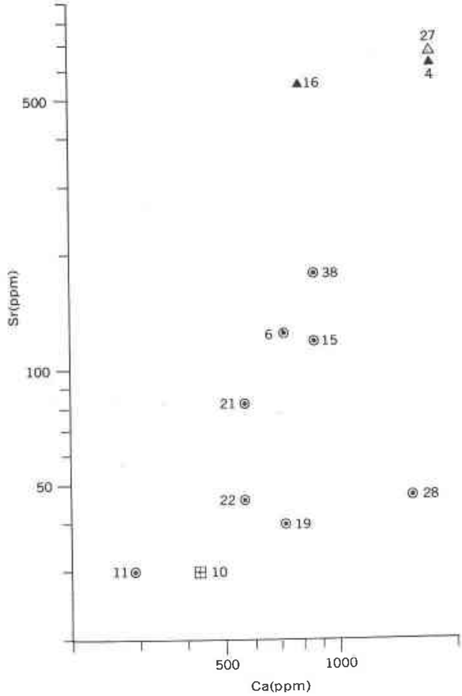

FIG. 8. Ca/Sr relationships.

TABLE 6. ALKALI ELEMENT MOLECULES IN FELDSPAR, IN PER CENT, IN ORDER OF DECREASING Ba-MOLECULE

	$RbAlSi_3O_8$	$BaAl_2Si_2O_8$	$SrAl_2Si_2O_8$	$CaAl_2Si_2O_8$	$NaAlSi_3O_8$	$KAlSi_3O_8$
27	0.02	1.73	0.33	1.24	22.39	74.29
4	0.07	1.69	0.30	1.26	14.57	82.10
16	0.09	1.40	0.26	0.55	11.86	85.84
38	0.11	1.34	0.09	0.60	9.11	88.75
28	0.06	0.95	0.03	1.12	12.91	84.93
6	0.15	0.72	0.06	0.51	12.77	85.80
15	0.22	0.68	0.06	0.61	10.11	88.32
11	0.08	0.56	0.02	0.20	14.50	84.65
19	0.10	0.52	0.02	0.50	12.73	86.13
21	0.18	9.41	0.04	0.41	12.82	86.14
22	0.14	0.35	0.02	0.41	11.95	87.13
10	0.24	0.03	0.02	0.30	34.63	64.78

solvus (sample 10), the sum of Ba-, Rb- and Sr-feldspar molecules is over 0.5 per cent, ranging to just over 2 per cent. Most, or all, of the Ba available in these rocks is present in the alkali feldspar (Table 5).

On a plot of Ba/Rb vs K/Rb (Fig. 5) distinctions between the samples are especially well shown. Sample 10, a product of a strongly differentiated residual magma, falls nearest the origin, showing Rb enrichment over both K and Ba, whereas sample 27, a granodiorite, is farthest from the origin, showing depletion of Rb. Of the other samples, 28, 16 and 4 fall closest to 27 and have been metamorphosed but preserved granodiorite affinities. Sample 28 may be related by anatexis to sample 4. Feldspars most depleted in Rb also have the highest Ca.

Sr is lowest in the post-tectonic sample, and highest in the granodiorites. There does not appear to be any systematic variation in the other minor elements Li, Cs, and Fe.

In Norwegian alkali feldspars, Heier and Taylor (1959b) found that as the absolute amounts of Ba, Sr, and Ca decreased, the relative decrease was Ba>Sr>Ca, so that Ca/Sr increased and Ba/Sr decreased. Comparing the Brazilian feldspars from the granodiorites to the post-metamorphic granite, this is so. When all the samples are considered, however, however, there is no discernible variation pattern (Table 5).

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