

REMARKS ON THE VARIABLE CONTENTS OF Ba AND Sr IN MICROCLINE FROM A SINGLE PEGMATITE BODY

By

IVAR OFTEDAL

Abstract. Based on spectrochemical determinations of Ba and Sr in about 70 microcline samples collected from roughly 75 m² of the surface of a pegmatite body, the distribution of these elements within the pegmatite and within single microcline crystals is discussed. This distribution is very far from uniform, and no sign of subsequent adjustment towards an even distribution is observed. The different crystal chemical characters of Ba and Sr are strikingly apparent. The accuracy of spectrochemical Ba- and Sr-determinations is briefly considered.

Data on the distribution of Ba and Sr within a relatively broad pegmatite band in plagioclase gneiss on the Norwegian Skagerrack coast have been published and discussed earlier (1, 2). A number of new determinations have been added later, and the total number of microcline samples examined is now more than 70. These were collected more or less at random within a selected area of about 75 square meters of the pegmatite surface. The pegmatite proper, apart from enclosed gneiss remnants, consists of smaller and larger crystals of microcline perthite with very subordinate oligoclase. Locally it is rich in quartz, which generally appears to be younger than the microcline.

The results of the spectrochemical determinations of Ba and Sr in the microcline samples are shown in the diagram Fig. 1. The samples have been arranged (from left to right) according to decreasing contents of Ba. The vertical lines connecting the curves for Ba and Sr represent individual samples. The samples poorer in Ba than about 500 p.p.m. nearly always represent very large and light coloured

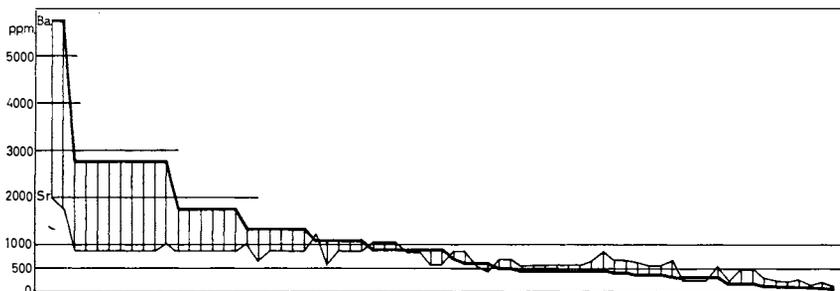


Fig. 1.

crystals, while the others were in general taken from more reddish crystals a few centimeters or less in size. As the large crystals have developed in the interior of the pegmatite, evidently in complete absence of tectonic movements — which have otherwise conspicuously affected the rocks of the area —, they apparently belong to late stages in the development of the pegmatite. Thus it may be supposed that the abscissa axis in the diagram corresponds roughly to a time axis. This is also supported by the fact that the highest concentrations of Ba and Sr plotted in the diagram approach those found in microcline crystallized in actual contact with the plagioclase of the gneiss, as observed in all examined cases of small pegmatite veinlets in the same area. It is obvious that also the crystallization of the larger pegmatite bodies in the area must have started along the contacts towards the country rock. As pointed out earlier (1, p. 236), the distribution of Ba and Sr between the microcline and the adjacent plagioclase in such cases most probably approaches equilibrium, since it is similar to the distribution of Ba and Sr between the feldspar phases of Archaean granites. According to observations on several granites, this distribution is as follows. If the Ba-concentration is x in the plagioclase, it is about $10x$ in the microcline; then the Sr-concentration is not far from $10x$ in the plagioclase and x in the microcline. The value of x is about 200 p.p.m. for the Østfold granite and the Birkeland granite. In the present case (contact gneiss-pegmatite) x is about 500 p.p.m., giving a Ba-concentration in the microcline of about 5000 p.p.m., which is in good agreement with the observations. It is seen that the highest Ba-concentrations shown in the diagram are also of this magnitude, though the corresponding Sr-concentrations differ

considerably from 500 p.p.m. These microclines evidently approach rather closely the supposed equilibrium with the plagioclase of the gneiss.

It was concluded earlier (1, p. 238) that the pegmatite-forming medium must have been originally very poor in Ba and Sr, that it absorbed Ba and Sr from the plagioclase during its passage through the gneiss, and that the microcline crystals forming from it in direct contact with plagioclase crystals attained approximate equilibrium with these as to Ba- and Sr-contents. It may be of interest to reconsider the development of the large pegmatite in view of the data presented in the diagram. We have seen that the arrangement of the individual samples in the diagram probably corresponds roughly to the succession of crystallization. This being accepted, it is seen that Ba and Sr behave rather differently during the process of development. Apart from irregularities the Sr-concentration decreases much more slowly than the Ba-concentration. For Ba-concentrations lower than about 500 p.p.m. nearly all microclines are considerably richer in Sr than in Ba, and the opposite holds true for Ba-concentrations higher than about 1 000 p.p.m. This demonstrates well the characteristic crystal chemical difference between Ba^{2+} and Sr^{2+} in alkali feldspar crystals: Ba^{2+} is much more readily "captured" than Sr^{2+} (under the existing conditions, which, judging from the mineralogical composition of the surrounding gneiss complex, correspond to low amphibolite facies). This is a good example of preferred diadochy because of close similarity in ionic radii (K^+ 1.33, Ba^{2+} 1.34, Sr^{2+} 1.12). Part of the Sr is probably incorporated in the perthite lamellae (Na^+ 0.97, Ca^{2+} 0.99); individual plagioclase crystals within the pegmatite are much richer in Sr than most of the microcline crystals (usually 1 500 to 3 000 p.p.m.).

The whole succession of observed Ba- and Sr-concentrations in the microcline crystals might be explained on the simple assumption that the pegmatite-forming medium were an actual magma occupying the present site of the pegmatite. Such a magma might have accumulated through narrow veins like the ones now frequently observed as pegmatite veinlets in the gneiss, and subsequently intruded into place. The Ba- and Sr-concentrations in this magma must have been close to the average values calculated from all of the above determinations, which are 1 100 p.p.m. Ba and 700 p.p.m. Sr. If all of this Ba and Sr

has been extracted from the plagioclase of the country rock, it is evident that also the *liquid* K-rich medium must have had a much greater affinity for Ba than for Sr, being actually richer in Ba and much poorer in Sr than the adjacent plagioclase. If this magma really existed, it must have had a somewhat higher temperature than the country rock, so that crystallization started at the contacts. The alkali feldspar crystals first formed were highly enriched in Ba as compared with the liquid, showing that Ba had a stronger tendency to occupy the K-sites in the crystals than K itself. As a result the remaining liquid was impoverished in Ba. The next crystals to form must consequently be poorer in Ba, and the remaining liquid still more so. Continuing this process, eventually very Ba-poor crystals would form. The behaviour of Sr is similar, but the enrichment in the crystals relative to the liquid is much less pronounced. It is seen from the diagram that the lowest Ba-concentration observed is about 200 times less than the highest; for Sr (in the same samples) the corresponding figure is about 20. We may say that crystallizing alkali feldspar under these conditions is about ten times more efficient in capturing Ba than in capturing Sr; still Sr is very conspicuously captured. Since Ba and Sr are chemically very similar, it is natural to correlate this ratio of "efficiency" with the radius ratios Ba^{2+}/K^{+} and Sr^{2+}/K^{+} , which are practically unity and 0.84 respectively*. If this "crystallization differentiation" process could be continued further than in this particular instance, the Ba-contents and eventually the Sr-contents of the resulting alkali feldspars would approach zero asymptotically. Several examined amazonites (from other districts) all appear to represent very advanced stages in such a process (1, p. 243). Following this gradual crystallization of the pegmatite, there has been no observable adjustment of the Ba- and Sr-concentrations towards an even distribution within the pegmatite.

Although the hypothesis of a real pegmatite magma thus explains the observed facts very well, this does not of course prove that it is correct. At any rate it represents a simplified picture of the actual conditions, which appear rather complex in the field. If it is essentially correct, it is not necessary to assume that the K-rich pegmatite-for-

* Added in proof: According to later analyses by flame photometer, the composition of the microcline is close to $Or_{80}Ab_{20}$ irrespective of varying Ba- and Sr- contents.

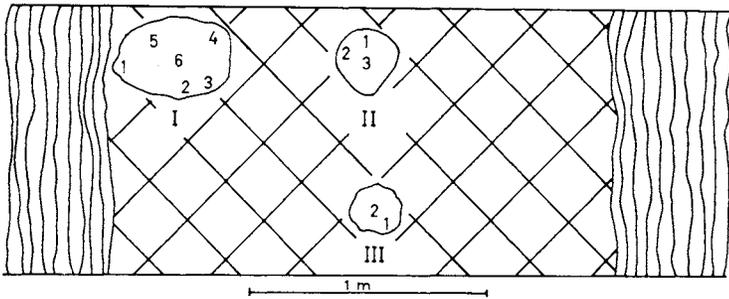


Fig. 2.

ming medium was originally extremely poor in Ba and Sr; it may very well, prior to the intrusion, have contained Ba and Sr in concentrations corresponding to the present averages for the pegmatite as given above.

If the hypothesis of a magma — or a medium behaving more or less like a crystallizing magma — is not accepted, it is difficult to conceive an explanation other than the one offered earlier, viz. that essentially Ba- and Sr-free K-rich fluids were continuously or intermittently introduced from below into the interior of the originally narrow pegmatite band, forming new alkali feldspar crystals which had to be successively poorer in Ba and Sr because the limited supply of these elements available there was gradually used up by the growing crystals. This explanation seems to be more in accordance with the appearance of the pegmatite in the field, but considering the high Ba- and Sr-contents of every examined pegmatite veinlet in the area, it is difficult to imagine a K-rich pegmatitic medium moving for a presumably long time through Sr- and Ba-rich gneiss without acquiring itself a considerable content of these elements. A differentiation process, not necessarily in a magma proper, as outlined above may be more probable after all.

Some observations on 3 large and evidently late microcline crystals in the same pegmatite may be specially mentioned. Fig. 2 shows schematically how these crystals appear on the rock surface. They are embedded in somewhat less coarse pegmatite. The crystals are numbered I, II, III, and the individual samples are indicated by 1, 2, — — — within each crystal. The results of the spectrochemical examination of these samples are shown in Table 1.

Table 1.

Sample no.	Sr, p.p.m	Ba, p.p.m
I, 1	700	500
2	600	450
3	700	500
4	650	250
5	650	300
6	700	400
II, 1	300	150
2	300	150
3	300	150
III, 1	700	350
2	700	600

Before commenting on these results some words on the accuracy of the determinations may be added. Sr and Ba are more difficult to determine quantitatively by spectrochemical analysis than many other elements; parallel exposures may give rather different results. In the present case utmost care was taken to keep the conditions of arcing and development identical throughout, and most of the samples were examined by 2 or more parallel exposures. In addition one of the K-lines was used as an internal intensity standard; only spectrograms showing a certain specified intensity of this K-line were used for the determinations. (It is true that K is not a suitable element for intensity comparison with Ba and Sr, but at any rate the K-line affords a check on the general intensity level of the spectrograms.) A few examples of individual results are shown in Table 2.

Table 2.

Sample no.	Sr, p.p.m.	Ba, p.p.m.
I, 1	650, 650, 800, 650	400, 400, 600, 600
I, 3	650, 800, 650	400, 500, 600
I, 4	650, 650, 650	250, 250, 250

The maximum deviation from the mean is here about 20 %. On the other hand it is seen that the observed deviations may be much smaller than this. More parallel exposures would doubtless narrow the probable limits of error considerably.

In view of these considerations the Sr-concentrations are evidently fairly constant within each of the crystals. The Ba-concentrations, on the other hand, are certainly variable within crystals I and III. Crystal II shows very consistent values, which are much lower than the corresponding ones for crystals I and III. According to the above discussion on the development of the pegmatite, crystal II ought to be "later" than crystals I and III. The distribution of Ba within crystals I and III indicates non-equilibrium, which evidently reflects a variable supply of Ba during the growth of the crystals. Even these very local variations have not been removed by subsequent diffusion. Of course this is not really unexpected in view of the frequent occurrence of e.g. zoned crystals in eruptive rocks. The series K-feldspar-celsian is in fact crystal chemically strictly analogous to the albite-anorthite series. It appears that Ba-ions (Ca-ions) once captured in K-feldspar (albite) are so strongly bound to their sites that they will not migrate in ordinary conditions.

REFERENCES

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