ON THE DISTRIBUTION OF STRONTIUM AND BARIUM IN THE ERUPTIVE ROCKS OF THE OSLO REGION

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A b s t r a c t. Determinations of the contents of Sr and Ba in a number of specimens of the principal eruptive rock types of the Oslo Region have been made by a semi-quantitative spectrochemical method. The general trends of the resulting figures are in support of the geologically observed age relations within the rock series, all the rocks of monzonitic and similar compositions being comparatively rich in Sr and Ba, and the younger rocks successively poorer. Very striking is the difference between the series biotite nordmarkite – biotite granite on the one hand, and aegirite nordmarkite -- ekerite on the other. In the former series Sr and Ba are still moderately abundant, while in the latter they tend to disappear completely.

The absolute concentrations of Sr and Ba in granites, as well as their coefficients of distribution between the feldspar phases of these rocks, seem to be rather insensitive to variations in the temperature of crystallisation.

It is known that many of the eruptive rocks of the Oslo Region are comparatively rich in Sr and Ba. On the other hand it has been shown recently (1) that a sample of ekerite was extremely poor in Sr. In the course of a survey of various Norwegian rocks as to their contents of Sr and Ba I have collected a considerable material of determinations on Oslo rocks.

Analytical procedure.

The determinations were made by means of a "Hilger Large" quartz spectrograph, using Kodak P-25 plates. The powdered samples were packed into cavities in carbon cathodes of standardized shape and dimensions; the cavity was 1.5 mm in diameter and 4 mm deep,

and was always filled completely with the pure substance. The arcing was done at 250 V and about 5 A. Exposure time $2\frac{1}{2}$ minutes. This was found to give fairly consistent results. The arc image was formed on the prism, and a rotating stepped sector employed. The spectral lines used were Sr 4607 and Ba 4554. The stepped lines were compared visually with corresponding ones in spectrograms of standard mixtures containing SrO and BaO in the following concentrations: 30000, 10000, 3000, 1000, 300, 100, 30, 10 parts per million. It was found necessary to prepare two sets of these mixtures, one for comparison with alkali feldspars and one for comparison with plagioclases; the base substances in these were microcline perthite (amazonite) and albite respectively, both of course carefully selected among specimens particularly poor in Sr and Ba. Actually the amazonite contains about 30 p.p.m. SrO and below 10 p.p.m. BaO, and the albite still lower percentages. The intensities of the Ba lines agree fairly well in the spectrograms of the two sets; however, those of the Sr lines differ considerably, especially at low concentrations. At 1% concentration the Sr line is about equally strong in both kinds of spectrograms, but at lower concentrations it grows successively weaker in the albite mixture spectrograms as compared with the amazonite mixture spectrograms. Obviously abundant K in the arc is able to enhance the intensity of the Sr line considerably at low Sr concentrations. In a number of cases, especially in many Oslo rocks, it has not been possible to obtain separate samples of alkali feldspar and plagioclase for arcing. However, in most such cases the concentrations of Sr and Ba are so high that the intensity differences between the spectrograms of the K-rich and the K-poor substances are negligible.

It is obvious that the procedure described will not give a very high degree of accuracy. But the accuracy obtained is sufficient to show characteristic differences between the various rock types.

Mr. JENS HYSINGJORD, cand.mag., has prepared all the samples and standard mixtures, and taken all the spectrograms.

Results of spectrochemical analysis, and discussion.

As far as possible the Sr and Ba determinations were carried out on pure feldspar samples. Thus the resulting figures apply to the feldspar components of the rocks. In a number of cases the rocks were so

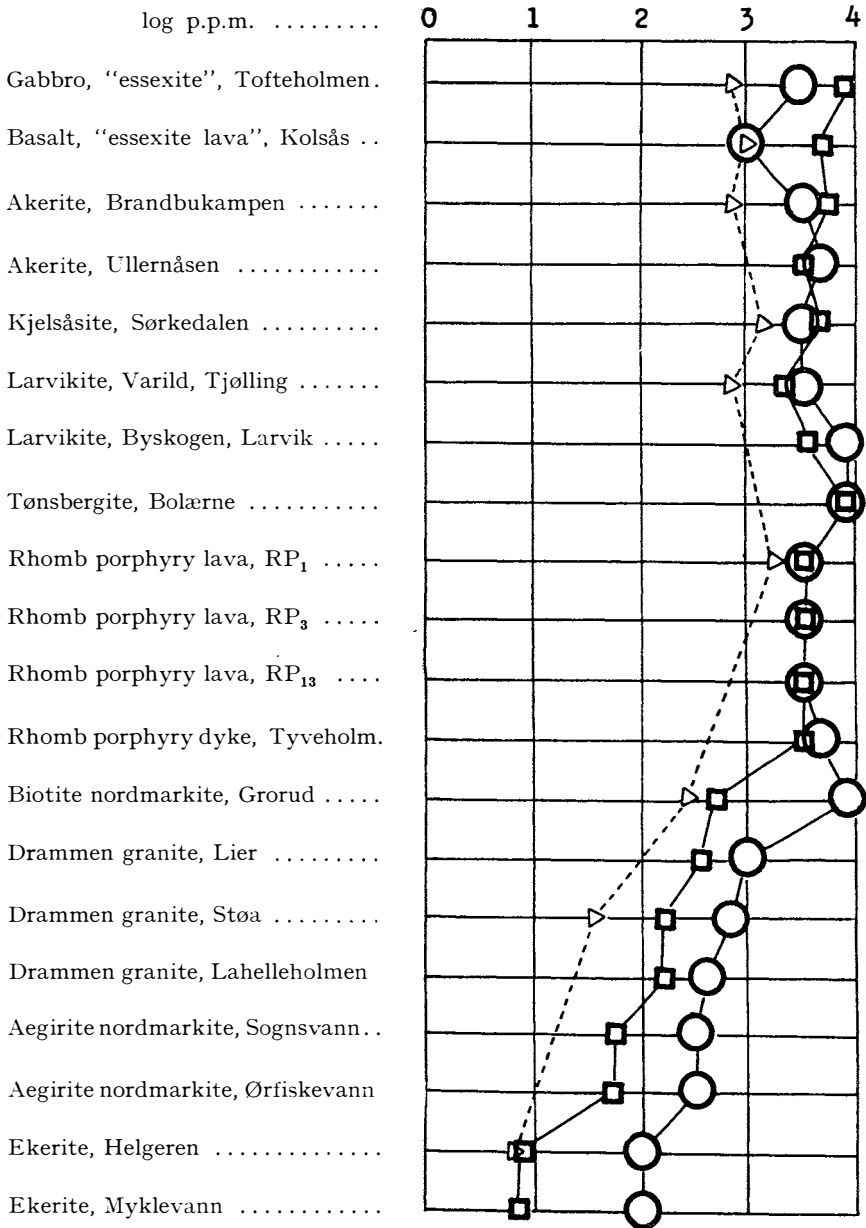| log p.p.m.	0	1	2	3	4
Gabbro, ''essexite'', Tofteholmen.					
Basalt, ''essexite lava'', Kolsås ..					
Akerite, Brandbukampen					
Akerite, Ullernåsen					
Kjelsåsite, Sørkedalen					
Larvikite, Varild, Tjølling					
Larvikite, Byskogen, Larvik					
Tønsbergite, Bolærne					
Rhomb porphyry lava, RP_1					
Rhomb porphyry lava, RP_3					
Rhomb porphyry lava, RP_{13}					
Rhomb porphyry dyke, Tyveholm.					
Biotite nordmarkite, Grorud					
Drammen granite, Lier					
Drammen granite, Støa					
Drammen granite, Lahelleholmen					
Aegirite nordmarkite, Sognsvann..					
Aegirite nordmarkite, Ørfiskevann					
Ekerite, Helgeren					
Ekerite, Myklevann					

Fig. 1.

fine grained that we did not succeed in getting satisfactory feldspar samples, and had to use bulk samples. As feldspar is by far the most abundant constituent of the majority of the examined rocks, this is generally of little consequence. But in the case of the very dark basalts the observed concentrations have been corrected so as to give approximately the concentrations in the feldspars; this could be done fairly safely, as it was shown that the dark minerals of basalts contain much less Ba and Sr than the feldspars. Fig. 1 shows the main results of the Sr and Ba determinations in the feldspars of Oslo rocks. The scale of concentrations is in units of *log parts per million*. Circles represent BaO and squares SrO. All fairly reliable determinations have been included. But a number of other determinations, which I consider less reliable, have been made. These include observations on "essexites" from Brandberget, Dignes, Trasop, Randviksholmen, the "essexite lavas" E_1, E 10 B, E 13 A, akerites from Midtstuen and Ullernåsen, larvikite from Tuft, lardalite from Farris, nearly the whole series of rhomb porphyry lavas RP_1 to RP_{13}, and several other rhomb porphyries, a number of nordmarkites from Sognsvann, Årvoll, Grorud, and others. Although I have not quoted the results from these somewhat inferior spectograms I would add that they are all in support of the general picture shown in Fig. 1. The Sr and Ba contents of the examined specimen of lardalite are similar to those of the larvikites. For comparison we have taken spectograms of basalts from Table Mt, Colorado and from Spitsbergen. Their contents of Sr and Ba agree fairly well with those of the Oslo basalts. In the same way the "rhomb porphyry" from Moshi in Tanganyika exhibits Sr and Ba contents similar to those of the Oslo rhomb porphyries.

The triangles in Fig. 1 represent the Sr determinations in some Oslo rocks given in the paper by TUREKIAN and KULP (1). (The localities of the various specimens do not in general agree with those quoted in the figure.) In that paper the concentrations have been given in percentages of Sr; these have been recalculated to percentages of SrO, but really they should still be increased a little to be comparable with the present values, as they are percentages of the total rock substances. Even so the values given by TUREKIAN and KULP are on the average very considerably lower than the present ones. Since the determinations of TUREKIAN and KULP are said to be very accurate,

my values seem to be on the average much too high. I am not able to explain this discrepancy. Of course my standard mixtures are not exactly like the examined feldspars, as they consist of powdered felds- par and the oxides of Sr and Ba, but I think it is surprising that this should make such a large difference in the intensities of the Sr and Ba lines. I may have to admit that my values are too high. But to the present discussion this is of little consequence, since the general trend of the Sr contents in the rock series agrees very well in both sets of determinations, as is apparent in Fig. 1.

From the data presented it appears immediately that the Sr and Ba contents are high and fairly constant in all the rocks of monzonitic composition, including the lardalite. In these rocks SrO and BaO are about equally abundant, and the concentrations in the feldspars are, according to my determinations, several thousand p.p.m., in some cases even as high as 1%. That Sr and Ba are about equally important in these rocks is not surprising, since Sr replaces mainly Ca and Na, and Ba mainly K, in the feldspar structures. We have tried to prepare pure samples of alkali feldspar and plagioclase from some of the monzo- nitic rocks, with little success. Thus kryptoperthite crystals and what appeared to be "rhomb feldspars" from a specimen of coarse larvikite yielded practically identical spectrograms; the plagioclase crystals are here intergrown with large quantities of alkali feldspar. In rhomb porphyries, of course the phenocrysts and the ground mass could easily be examined separately, but even here the phenocrysts proved to contain large quantities of alkali feldspar in most cases. Only one of the samples from several examined phenocrysts – taken from the central part of a large phenocryst from RP_3 – proved to consist of fairly pure plagioclase (very weak K lines); it yielded SrO 3.7 and BaO 2.7 (log p.pm.). This demonstrates the coherence of Ca and Sr and of K and Ba in these rocks. The ground mass of the same rock, which contains much alkali feldspar, yielded SrO 3.5 and BaO 3.7 (log p.p.m.).

It is seen from Fig. 1 that in some monzonitic rocks SrO was found to be somewhat in excess of BaO, in others vice versa. Although I do not think this observation is of any great importance I would draw attention to the relation between larvikite and kjelsåsite. Here the SrO excess is in the more calcic rock, as would be expected. There seems to be a similar difference between the akerite from Brandbukampen

and that from Ullernåsen (the original akerite locality). In the gabbroic rocks SrO is, naturally, considerably more abundant than BaO, but the concentrations are more or less on the same level as in the monzonitic rocks. It may be surprising that Ba is so relatively abundant here, but the K content is very considerable in many of the Oslo "essexites".

Passing from larvikites to nordmarkites, there is a very marked drop in the Sr content, a reduction by a factor of about 10 or more. On the other hand it is seen from Fig. 1 that there exist nordmarkites (mica nordmarkites) which are quite as rich in Ba as the monzonitic rocks. This is not surprising, since nordmarkites consist mainly of alkali feldspar. Such Ba-rich nordmarkites might be formed from monzonitic magmas by concentration of the alkali feldspar component of the monzonite. However, it has been necessary to distinguish between two kinds of nordmarkite on the ground of the Sr and Ba contents. The second kind is much poorer in Sr and Ba than the first one, in fact 10 or more times poorer, and the samples so far examined represent aegirite nordmarkites. Also here the Sr content is much lower than the Ba content. In the related ekerites the decrease in the Sr and Ba contents has proceeded still much further. As compared to the monzonites, the ekerites may be more than 1000 times poorer in Sr and 100 times poorer in Ba.

If we assume that a rock series ranging from nordmarkites of the first kind (biotite nordmarkites) to ekerites is formed by magmatic differentiation, this process brings about a gradual change in the composition of the alkali feldspar, here shown by the gradual disappearance of Sr and Ba. A similar change in the contents of Sr and Ba is observed when normal granites (outside the Oslo Region) are compared with their pegmatitic facies. Granite pegmatites will not be discussed in the present paper, but it may be recalled here that their feldspars are usually much poorer in Sr and Ba than those of normal granites. The Ba content of granite pegmatite is very often similar to that quoted for ekerite. The Sr content is usually considerably higher than that of ekerite, but in some cases it appears that the microcline of (Archaean) granite pegmatite was originally nearly devoid of Sr, as in these cases the microcline is very rich in Rb, so that the small amount of Sr observed must be mainly radiogenic. That the amount of radiogenic Sr in ekerite is negligible, is obvious, both because of the
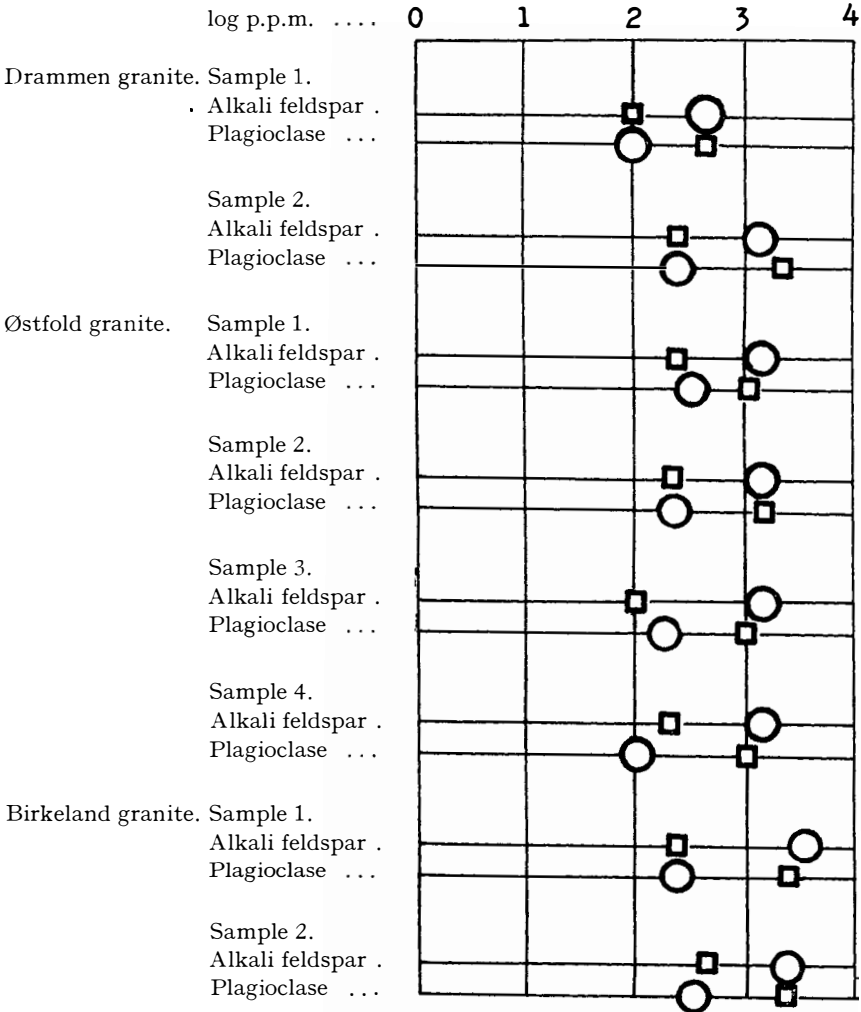
Fig 2.

low Rb content of the rock and because of its relatively low age. It is a well known experience that most of the Sr and Ba in a magma will be consumed by relatively "early" feldspar crystals, so that very "late" feldspar crystals will be relatively poor in these elements.

Therefore it appears that ekerite is younger than nordmarkite in a similar sense that granite pegmatite is younger than a parent granite.

In Fig. 1 the Drammen granite has been placed in between the two types of nordmarkite, for the obvious reason that it is intermediate between these rocks as to the contents of Sr and Ba. Of course I do not suggest that there is a development of aegirite nordmarkite and ekerite from Drammen granite. The trend of the Sr and Ba concentrations is rather in support of the view that the granite as well as the ekerite series branch off from the biotite nordmarkite (2). As far as removal of Sr and Ba is concerned, the ekerite is much more advanced than the granite; in this respect ekerite would probably correspond to Drammen granite pegmatite (which, by the way, does not seem to exist, according to CHR. C. GLEDITSCH, who has studied the boundary relations of the Drammen granite in great detail). It is not improbable that the ekerite is really younger than the Drammen granite. As is well known, W. C. BRØGGER was not able to establish the age relation between these two rock types (3), and the matter is still undecided according to present experts on the geology of the Oslo rocks, e.g. Dr. CHR. OFTEDAHL.

Comparison of the Drammen granite with two well known Archaean granites*) as to Sr and Ba contents reveals the rather surprising fact that no real difference can be established, at least not by the analytical procedure employed here. See Fig. 2, which has been constructed in the same way as Fig. 1. In each rock specimen the alkali feldspar and the plagioclase have been examined separately. The purity of the samples for arcing was satisfactory, although it was sometimes difficult to obtain the plagioclase quite free from alkali feldspar. The alkali feldspars, of course, include perthite lamellae. It appears that in each granite the SrO content of the plagioclase is about equal to the BaO content of the alkali feldspar, and the BaO content of the plagioclase is about equal to the SrO content of the alkali feldspar. At the same time the first pair of concentrations is 5 to 10 times higher than the second pair. One should think that the absolute concentrations of Sr and Ba, and especially the equilibrium distribution of Sr and Ba between the two feldspar phases in a granite, would be sensitive to differences in the temperature of crystallization.

*) Specimens of the Birkeland granite were kindly supplied by Mrs. B. NILSSEN.

If this is the case, it must be concluded that all the granites entered into Fig. 2 have crystallized at approximately the same temperature. This seems to be at variance with a number of other observations, which are commonly considered to indicate that the Drammen granite has crystallized at a considerably higher temperature than the Archaean granites: the alkali feldspar is orthoclase, it is devoid of Pb (4), the biotite is very poor in Sc (5), the contact aureoles are in pyroxene hornfelds facies, etc. It seems to me that these observations are so strongly in favour of a higher temperature of crystallization of the Drammen granite as compared with granites in gneiss areas, that I am inclined to conclude that the coefficients of distribution of Sr and Ba between the feldspar phases are approximately constant within the temperature interval in which granites may crystallize. Thus these coefficients can probably not be used as geologic thermometers in this interval, except perhaps if they could be determined very accurately.

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