SVERIGES GEOLOGISKA UNDERSÖKNING

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ÅRSBOK 19 (1925) N:o 3

ON THE DIFFERENTIATION OF THE ALKALIES IN APLITES AND APLITIC GRANITES

BY

N. SUNDIUS

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STOCKHOLM 1926
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The differentiation of rock magmas must still be considered as an unsolved problem. At least no theory has as yet been generally accepted, nor is a survey of the various processes involved at present possible. As regards the main process of the differentiation — the separation of the silicates — there are two different views hold by petrographers, one being the principle of the mutually limited solubility of the molten silicates. This is the »liquation» theory of Bäckström.[1] The other theory is based on the thesis of Brögger, that the crystallisation in the magmas develops conformably with their differentiation. By dating the differentiation to the actual time of the growing of the crystals, the theory of the fractional crystallisation, worked out by Bowen and others, resulted. The necessary postulate for this hypothesis is that the experience of Brögger from the Christiania field has general validity, but this is not sufficiently proved.

In this paper one detail of the differentiation of the magmas will be considered, viz. the splitting up of the alkalies of aplitic magmas and the generation from a common aplite of two rocks containing different kinds of alkalies. The ordinary course of the differentiation of the magmas is that determined by the diminution of the anorthitic plagioclase and of olivine and pyroxene — when emerging from the basic pole — and by a corresponding increase of alkali feldspars, ordinarily also of quartz, the dark minerals hornblende and biotite simultaneously replacing the more basic and Ca-rich femic minerals. By this process salic, and generally Or-rich, granites are generated, and as the last products aplites and pegmatites result. In most cases the differentiation will end in the aplitic and pegmatitic phase, no further separation of the minerals being reported by the investigators, apart from the pneumatolytic agents. This, however, is not always the case,

[1] Journ. Geol. 1893, p. 773.

but a splitting up of the alkalies in the last named rocks also occurs, producing rocks of different alkali characters, extremely plagioclase-rich rocks on the one hand and Or-rich members on the other. Some phenomena of this kind are known from the pegmatites.[1] Other instances have been adduced in the last few years from the boundary phases of urgranites in Sweden. On a much greater scale the same phenomenon appears in the ore-bearing leptites and hälleflintas of Sweden. In this formation the phenomenon has long been known, first through the papers of H. E. Johansson[2] and later through the more detailed researches in the westernmost part of the ore-bearing district,[3] and through different works on other parts of it.

In this paper the separation of the alkalies will be discussed principally on the basis of observations on aplitic dykes and the boundary areas of an archean granite, the Loftahammar granite in South-Eastern Sweden, all the rocks described belonging to the older of the two archean granite groups of Sweden — the urgranites. In these rocks the relations of the two different alkali rocks to each other and to the parent granitic magma can be better understood than in the volcanic leptite-hälleflinta formation. Further, some remarks will be made on the analogous differentiation in other urgranites, and lastly the corresponding phenomena in the leptites and hälleflintas will be briefly summarized.

Differentiated aplitic dykes.

The aplites that will be considered here all occur in a large area of urgranitic rocks that underlies the greater part of the geological sheets 1 : 50,000 Skrikerum and Valdemarsvik, situated at the boundary of the Provinces of Östergötland and Småland. These rocks form a well-developed series of various differentiates, from hornblenditic or periotitic varieties to granites and aplites, though amphibolites and plagioclase granites are the quantitatively predominant members. Most of the rocks contain aplites and pegmatites, richly developed and occurring partly as segregations or Schlieren, partly as cutting dikes, or as somewhat greater masses brecciating the older rocks. As to distribution, these salic differentiates show a certain relation to the chief rocks, occuring sparingly or even being quite absent in the more alcaline and salic granites, but increasing in amount in the intermediate and basic members. They are most richly developed in the amphibolites, though they are also well represented in the plagioclase granites and are not absent from granites with a more intermediate position as regards the alkalies. The often diffuse relation of the aplites to the enclosing

[1] Comp. H. E. Johansson G. F. F. Bd. 36, p. 116 and E. Mäkinen Bull. Géol. Comm. Finlande No. 35.
[2] G. F. F. Bd. 29, p. 143, Bd. 32, p. 376, Bd. 36, p. 441.
[3] S. G. U. Ser. C. No. 312, p. 155. Kungl. Kommerskollegium, Beskr. över mineralfyndigheter No 2, p. 46.

rocks has — in neighbouring districts similarly composed — led the workers to suggest some re-melting processes as the explanation of the appearance of the salic differentiates. For this assumption, however, little support is to be found from the distribution of the salic material in the different rocks. The conclusion of the writer is that the great variety of the rocks and the occurrence of the richly developed aplitic and pegmatitic material are both due to the same process, viz. to a magmatic differentiation.[1]

When commencing his work in the north-western and western parts of the Skrikerum sheet, the writer was struck by the appearance not only of ordinary red aplites, but also of white aplite almost exclusively composed of plagioclase and quartz. Both aplitic and pegmatitic forms of this material were found, no essential difference seemingly being exhibited by the same, excepting the coarseness of the grain. Where they met each other, the red aplite always behaved as the younger of the two and cut through the white aplite. Moreover, in some instances both kinds of aplites were found in the same dyke, the white aplite in this case occurring as a border along the boundaries of the aplite body. During the progress of the field work, more instances of this latter kind were met with, and such differentiation was found to be a rather common phenomenon of the aplites of the whole district examined. In all the instances of differentiated dykes seen by the writer, too, the same distribution of the two aplite varieties prevails, the white rock being concentrated along the boundaries of the dykes. There are instances also of small patches of the white component being seen in the red rock, irregularly distributed in it, but when any concentration of the former has occurred it has regularly been found at the contact against the wall rock. Boundary rims of this kind have also been seen in cases where the aplites brecciate the wall rock. An instance of this is reproduced in fig. 1. As is shown there, the white borders are generally continuous along the contacts, though this is not necessarily always the case. When smaller apophyses from a differentiated aplite dyke intrude the side rock, the material filling it is made up entirely of the white border phase, or of red and white aplite, the former occurring near to the dyke in the central part of the apophyse and rapidly thinning, the plagioclase aplite alone continuing its course. As to quantity, the white aplite is always subordinate to the red, in most cases the former is only made up of a thin border at the most 10—20 cm. in width, even where the breadth of the whole dyke runs to 2—3 m. The boundary between the two aplites is distinct, though not sharp, the transition between both occurring suddenly. No dykes of the one aplite in the other has been seen by the writer anywhere.

The petrographical properties of both kinds of aplite, when occurring in the manner described in one and the same body, have been examined

[1] Cf. also the relations described by the writer in Fennia, 45, No. 12.

by the writer in specimens from two dykes, one occurring in an amphibole-bearing plagioclase granite (outcrop about 1,500 m. to the north of Hannäs Church), the other cutting through a massive amphibolite immediately to the south of Sund Farm, in the parish of Gärdserum. Both localities are situated on the Skrikerum sheet.

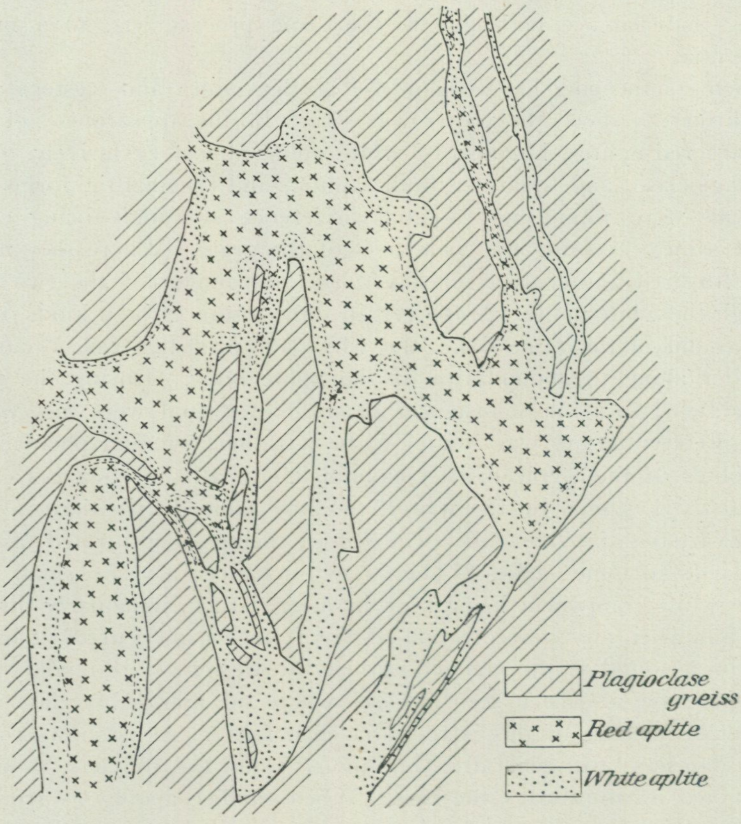

Fig. 1. Dyke of red and white aplite brecciating the wall rock.

Dyke to the north of Hannäs. As usual, the white border aplite is developed as a fine-grained, homogeneous rock. Its width amounts to 2 dm. at the most, the breadth of the whole dyke being about 2—3 m. Under the microscope the white rock is made up of an equigranular mixture of quartz and oligoclase (An_{22}), the latter more abundant than the former. There also occur isolated flakes of biotite. As accessories there are to be seen small needles of apatite and small isolated grains of magnetite. Microcline is almost quite absent, being represented only by insignificant grains filling out the spaces between the plagioclase individuals. The structure of the rock is real aplitic, neither of the two main minerals showing more idiomorphic forms than the other. Small rounded, or seldom dihexaedral, inclusions of quartz occur sparingly in the plagioclase and suggest a possibly somewhat earlier commencement of the separation of this mineral. Also the biotite is more truly idiomorphic than the quartz and the plagioclase.

A graphical analysis of the aplite under the microscope gave the following result:

Table 1.

	% by weight	SiO_2	Al_2O_3	(FeMg) O	CaO	Na_2O	K_2O
Quartz	37.3	37.3	—	—	—	—	—
$Ab_{78}An_{22}$	58.6	36.9	13.7	—	2.7	5.3	—
Microcline	3.3	2.1	0.6	—	—	—	0.6
Biotite	0.8	0.3	0.2[1]	0.2	—	—	0.1
	100.0	**76.6**	**14.5**	**0.2**	**2.7**	**5.3**	**0.7**

For the calculation the oligoclase was assumed to hold 5 % by weight of Or. The figure originally found for the plagioclase was thus 61.7. The measured content of microcline was 0.2 %.[2]

In the red main mass of the dike the following table resulted:

Table 2.

	% by weight	SiO_2	Al_2O_3	CaO	Na_2O	K_2O
Quartz	28.1	28.1	—	—	—	—
Microcline	42.3	27.4	7.8	—	—	7.2
Albite	4.6	3.2	0.9	—	0.5	—
$Ab_{95}An_5$	3.0	2.0	0.6	—	0.3	—
$Ab_{85}An_{15}$	20.7	13.4	4.6	0.7	2.1	—
Muscovite	1.1	0.5	0.4	—	—	0.1
	99.8	**74.6**	**14.3**	**0.7**	**2.9**	**7.3**

To the minerals of the table are to be added 0.2 % of biotite, which was neglected in the calculation. As a sparingly represented accessory small grains of apatite are present.

The dominating feldspar of the red aplite is a microcline, with a rather small amount of perthitic intergrowths, estimated at 6 %. The quantity of this microcline was found to be 48.8 %. The plagioclase of the pertitic

[1] Incl. the small amount of Fe_2O_3.
[2] All figures for quantities calculated here and subsequently indicate weight per centages, unless otherwise stated.

intergrowths was calculated as Ab_{95}. Further, the microcline was assumed to hold in solution 10 % of albite. The free plagioclase amounts to 21.8 %. Of this a great part is developed as myrmekite, the quartz contained being deducted from the figure in the table. The compositions of the myrmekitic and non-myrmekitic plagioclase are similar. The composition was determined as An_{17} in the main part of the grains, and An_{10} in a narrow discontinuous outer rim. An_{15} was assumed as an average. Further, in the calculation the Or-content of the plagioclase was as before estimated at 5 %. Unless otherwise stated, this value is generally assumed for the plagioclase in the following pages.

In this aplite, too, a fine-grained, equigranular development of the components prevails, though the degree of idiomorphism is not quite the same for them all. Thus the non-myrmekitic plagioclase shows somewhat better idiomorphic forms than the microcline, as there can also be seen isolated inclusions of the former in the latter. In the same manner, small rounded or dihexaedral quartz grains are included in the microcline. The separation of these two minerals, therefore, may possibly have begun a little earlier than that of the microcline, though the difference is slight. The myrmekite is still later, being as usual formed at the expense of the microcline. Finally it is to be noted that the biotite present is distinctly of a darker brown colour than in the plagioclase-aplite, and may be richer in iron.

Dyke immediately to the south of Sund Farm. The wall rock here is an amphibolite of medium or somewhat finer grain. The border of plagioclase-aplite amounts to about 0.5 to 1 dm. As before, we find in the rock an aplitic aggregate of quartz and plagioclase, which latter is here somewhat more basic (An_{27}). Besides, there is present a little biotite and small amounts of microcline and epidote. Muscovite occurs as an accessory. The epidote contains some iron (about 14 % Fe_2O_3, according to the birefringence) but in the calculation was regarded as zoizite. The structural relations are identical with those already described. The results of the calculation are shown in the following table.

Table 3.

	% by weight	SiO_2	Al_2O_3	(FeMg) O	CaO	Na_2O	K_2O
Quartz	42.2	42.1	—	—	—	—	—
$Ab_{73}An_{27}$	52.6	32.4	12.8	—	3.0	4.5	—
Microcline	2.6	1.7	0.5	—	—	—	0.4
Biotite	2.2	0.9	0.5	0.5	—	—	0.2
Epidote	0.4	0.2	0.2	—	0.1	—	—
	100.0	77.3	14.0	0.5	3.1	4.5	0.6

The figure for the plagioclase found by the measurement was 54.8, from which is subtracted 2.7 for the Or dissolved. The figure originally found for the microcline was 0.4 per cent by weight.

The table obtained for the main red aplite was the following:

Table 4.

	% by weight	SiO_2	Al_2O_3	(FeMg) O	CaO	Na_2O	K_2O
Quartz	31.3	31.3	—	—	—	—	—
Microcline	31.3	20.2	5.7	—	—	—	5.3
Albite	4.0	2.7	0.8	—	—	0.5	—
$Ab_{79}An_{21}$	30.1	19.1	7.0	—	1.3	2.8	—
Biotite	2.8	1.0	0.7	0.8	—	—	0.2
Muscovite	0.5	0.3	0.2	—	—	—	0.1
	100.0	74.6	14.4	0.8	1.3	3.3	5.6

The figures found from measurement were, for the microcline 33.7, and for the plagioclase 31.7. The perthitic intergrowths of the former are very subordinate and were estimated at 2 % by vol. This small quantity was calculated as pure albite together with the Ab-content of the microcline (assumed to 10 % by weight).

The structure of the Or-rich aplite is rather obscured through the occurrence of fine granular rims around the feldspar grains. Strangely enough, this re-crystallisation is not to be seen in the bordering plagioclase aplite. From the parts of the minerals left intact by the re-crystallisation, however, it may be concluded that the structural relations are like those in the corresponding Hannäs aplite. Thus, here too, small inclusions of quartz and plagioclase are present in the microcline. Biotite also occurs in the plagioclase, as small accessory idiomorphic inclusions. The biotite again is deeper coloured in the Or-aplite than in the plagioclase-aplite.

When occurring as independent dykes or Schlieren, the white aplite has been found in amphibolites and plagioclase granites. Some instance are also found in granites containing somewhat more microcline. The separate white aplite is evidently generated in most cases from these microcline-poor rocks directly, no separation *in situ* of red and white aplite occurring. The white aplite in these rocks is often developed as thin stripes regularly arranged in parallel systems. These stripes or bands sometimes occur alone in the rocks, in other cases they form part of a differentiation series, running from amphibolite or plagioclase granite, through more salic members, to pure quartz-feldspar rocks, all tending to a schlieric or banded arrangement. When red aplites are combined with the system, as is often the case, it is the youngest member of the series. As the genesis of these white aplites may not be identical with that of the plagioclase components of the differentiated dikes, they will not be considered in the following discussion, only some date on their composition will be included.

When occurring as thin stripes in amphibolite or plagioclase-granite, the white aplite appears as an aplite of these rocks, in which the quartz-content of the rocks is more or less completely concentrated. The white stripes are made up of plagioclase and quartz, with which a little biotite, amphibole, and small amounts of microcline may be combined. Accessory apatite, ore grains, and in some cases, epidote are present. The plagioclase of the aplite is somewhat more albitic than in the surrounding amphibolite or granite, but the difference is not great as a rule, amounting in most cases to 1—2 per cent. On the other hand, the difference in the quartz-content is great, this being especially striking in the amphibolites. Even when the rock is free from quartz, the aplite is rich in this mineral, the quantity amounting to about what would correspond to the eutectic ratio. In a specimen of an amphibolite banded with white aplite stripes, a calculation of the minerals of the stripes gave the following result. The specimen was taken at the small farm of Karlshamn, NE. of Hannäs Church.

Table 5.

	% by weight	SiO_2	Al_2O_3	CaO	Na_2O	K_2O
Quartz	35.4	35.4	—	—	—	—
$Ab_{63}An_{37}$	59.8	35.3	15.6	4.6	4.3	—
Microcline	4.8	3.1	0.9	—	—	0.8
	100.0	**73.8**	**16.5**	**4.6**	**4.3**	**0.8**

To the minerals named, small, sparse grains of epidote are to be added. The amount of free microcline in the stripe was found to be 2.4 % by weight, the remainder of the figure in the table originating from the quantity being supposed as dissolved in the plagioclase (in this case estimated at 4 %). It is to be noted that the amphibolitic mother rock is quartzless and principally made up of pyroxene, amphibole, and labradore (An_{50}), of which the two former are predominant. The considerable difference between the plagioclase of the aplite and the amphibolite as to the An-content is in this case unique, as the latter rock also belongs to the most anorthite rich varieties found in the district. In other cases examined, the plagioclase of the amphibolite contains 33—35 % An, the amount of the anorthite of the aplite plagioclase at the same time being 32—33 %.

In a specimen of plagioclase granite, banded with white stripes of aplite some mm. to 1 cm. in width, the following table resulted from a measurement in a broad stripe. The specimen originates from an exposure about 500 m. to the south of the little lake of Långgöl, NE. of Falerum.

Table 6.

	% by weight	SiO_2	Al_2O_3[1]	(FeMg)O	CaO	Na_2O	K_2O
Quartz	39.4	39.4	—	—	—	—	—
$Ab_{73}An_{27}$	55.8	34.4	13.5	—	3.2	4.7	—
Microcline	2.3	1.5	0.4	—	—	—	0.4
Biotite	2.5	1.1	0.6[1]	0.6	—	—	0.2
	100.0	76.4	14.5	0.6	3.2	4.7	0.6

The measured quantity of the plagioclase was 58.1 %. It was assumed to contain 4 % Or. Free microcline is absent. Besides the minerals of the table some negligible amounts of epidote and magnetite are present. The plagioclase granite of the specimen is made up of plagioclase (An_{29}), biotite, amphibole and quartz, the quantity of the quartz, even when compared with the plagioclase alone, being considerably lower than in the aplite, possibly half of the value found there.

Occurrences of plagioclase aplite in the boundary zones of the Loftahammar massive.

The rocks occurring in the Loftahammar massive were studied by the writer at the north-western end of the massive, where it enters the Skrikerum sheet. From here the massive continues to the south-east, extending through the Gamleby, Loftahammar and Västervik sheets, the whole length amounting to some 40 km. with a breadth of 5—7 km. From the Loftahammar sheet the distribution of the rock varieties are described in detail by A. Gavelin,[2] who has also done the chief mapping work on the Skrikerum sheet. For the other parts of the massive corresponding data are lacking. Probably, however, the relations are very similar in the whole massive. The bounding rocks on the south-western side are leptite and quartzite; on the north-eastern side the same amphibolites as are described in the foregoing. On the Skrikerum sheet a large massive of younger granite forms the immediate side rock on the south-western side. This granite, in the most northwesterly parts of the contact, also intrudes the massive and contains inclusions of its boundary phases. Rich inclusions of leptite and quartzite in the younger granite just along the contact — when going more to the southeast — show, however, that here the present boundary between the two granites is not far from the old one between the Loftahammar granite and the supercrustal rocks mentioned. Immediately to the south of the boundary of the sheet, a coherent zone of quartzite and leptite also develop, separat-

[1] Incl. Fe_2O_3.
[2] S. G. U., Ser. Aa, No 127. See also Ser. C., No 224 and G. F. F., Bd. 32, p. 988.

ing the Loftahammar massive from the younger granite. This quartzite and leptite belong to the great area of these rocks occupying the surroundings of Västervik.

Very little can be said about the form and the geological site of the massive. Most probably it forms a lens or a sheet intrusive along the contact of the quartzite and the amphibolite. In that case the upper side would be to the south-west, the bottom on the north-eastern side. Yet it is also possible that the massive cuts the amphibolites along a slightly dipping plane. In this latter case both sides may belong to the roof of the massive.

The distribution of the rock varieties in the part of the massive I have studied is shown on the map in fig. 2. As is seen from this map, the inner main part of the massive is occupied by a coarse granite, developed as an eye-granite, more or less shistose. Around this granite are developed salic rocks of an aplitic composition and of a medium or rather fine grain. These rocks seem to form a continuous border varying somewhat in width. There is, however, some uncertainty in the most north-westerly occurrences of the boundary rocks, resulting from the splitting up of the rocks by the younger granite. For this reason a direct transition of the north-eastern aplite zone in the south-western border cannot be followed. Structurally there is also a difference, the aplite of the north-eastern zone being very fine-grained and schistose, whereas the rocks along the south-western contact are coarser and but little deformed. This, however, may be due, to some extent at least, to the fact that the north-eastern boundary of the massive is coincident with a great fault-line, along which the rocks are strongly deformed. On the whole, the schistosity of the rocks in the massive diminishes in the direction towards the south-west. To judge from the slides studied, both aplite rocks are very similar chemically.

In the south-eastern part of the map, in the vicinity of Marieholm Manor, a smaller area of leptite and quartzite is seen in the massive. Also here, at the contact towards these rocks, an aplitic boundary zone analogous to that of the south-western side is developed.

The seeming concentricity of the boundary phases, however, does not reappear in the interior of the massive. The coarse granite predominant here shows, on the contrary, a regular change from the north-eastern side to the south-western, the amount of the dark minerals and of the plagioclase diminishing in the direction indicated. The most basic phases of the granite are thus found at the north-eastern boundary against the fine-grained aplite, the boundary here being distinct, though no contact is seen exposed. Owing to the diminution of the minerals named in the opposite direction, a more salic type of the eye granite develops, and this granite has no boundary towards the aplitic rocks in the south-west, but passes into it by means of a transition zone. This would speak for the supposition that the dense aplite along to the north-eastern side is not identical with rocks on the other side of the massive, though the relation between the two cannot be determined within the area examined.

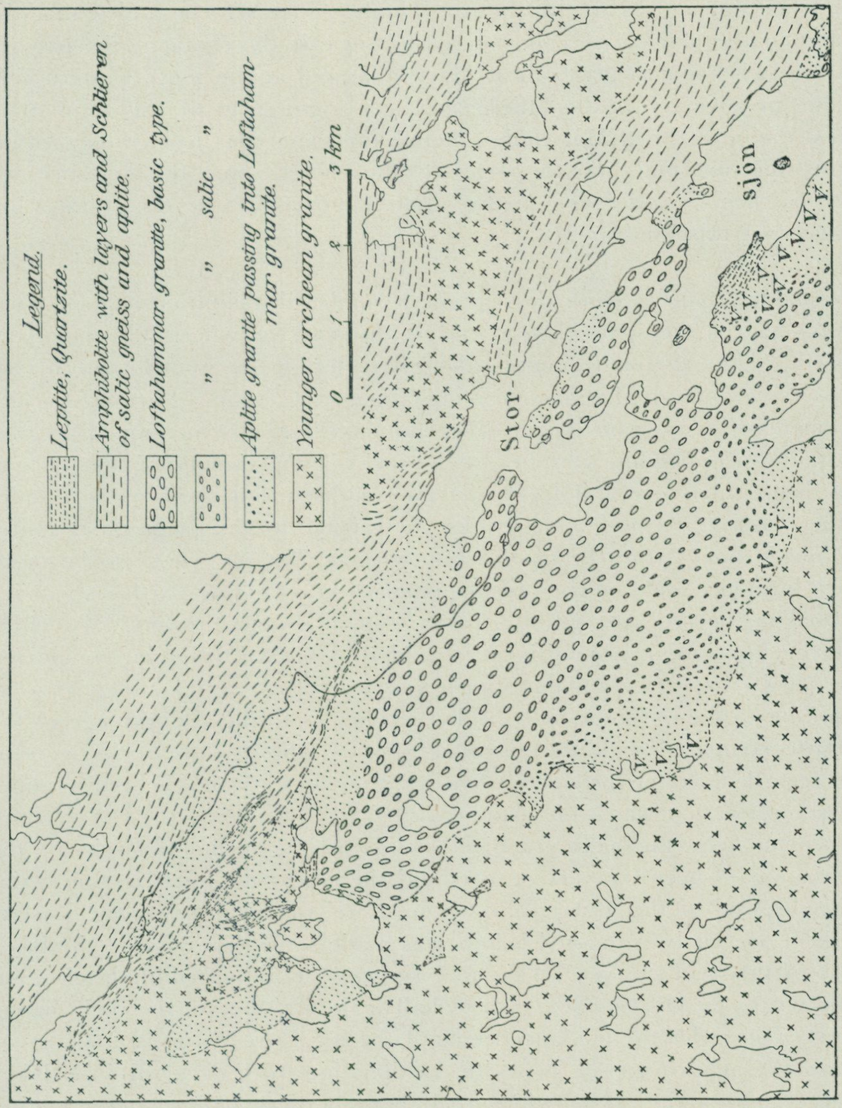

Fig. 2. Map of the north-western part of the Loftahammar massive. V = patches of plagioclase aplite.

In the red aplitic rock of the south-western boundary zone, as also along the contact towards the quartzite at Marieholm, lying in the massive, there appears a white, extremely salic, or gray, somewhat more richly biotite-bearing, plagioclase aplite, in irregular stripes or patches, diffusely bounded against the red rock. These patches vary in size from some feet to several meters. In the parts lying nearest to the quartzite at Marieholm, they comprise in some cases several neighbouring outcrops. At this locality intrusions of the white aplite in the quartzite have also been seen, the latter being brecciated by the aplite. The distribution of these white or grey patches is seen from fig. 2. As to this figure, it only remains to be added that the amount of the plagioclase-aplite increases towards the contacts, the patches growing richer and larger both at Marieholm and at the south-western side of the massive. Probably there is a continuous rim of the white rock against the quartzite at Marieholm, though this cannot be decided on account of the soil covering. To the west of Marieholm, some few instances of white patches are also seen in the adjacent coarser, salic eye-granite, but instances of this kind are rare.

To judge from Gavelin's description, a similar distribution of rock types prevails also at the south-eastern end of the massive, where it is wider developed. Thus the same, more salic, character of the south-western part of the eye-granite of the massive is described by Gavelin. Further, the development of even-grained and salic boundary zones is mentioned, as also the appearence of white varieties of the rocks in the vicinity of the contacts towards the quartzite and leptite on the southern and south-western sides of the massive. These white rocks correspond to the plagioclase aplites mentioned above from the north-western end. But they seem to be more amply developed, only on the Loftahammar sheet occurring partly as patches enclosed in the red salic granite, partly as real contact borders. To judge from the description, a breadth of 25 m. does not seem to be uncommon for these white aplites, but the dimensions may be several times greater. According to the old view held by Törnebohm as to the younger age of the quartzite compared with the gneissous granite, these white rocks were at first regarded as the products of weathering effects on the red granite, an assumption that was soon abandoned.

Unfortunately the petrographical notes on the boundary rocks of the Loftahammar sheet are very scanty, and there was not sufficient material at the disposal of the writer. From the island of Ödhällan on the Västervik sheet one analysis, quoted below, was made some years ago at the laboratory of the Geol. Survey. This analysis was kindly placed at the disposal of the writer by Dr. Gavelin. On Ödhällan the writer saw the rock during a short visit under the guidance of Dr. Gavelin. Here it forms a border of the massive at least 100 m. in width. In the white rock occur diffuse dykes of red Or-rich aplite. The white rock here borders against a grey leptite, split up by intrusions of the plagioclase-aplite.

The petrography of the rocks of the Loftahammar massive.

The Loftahammar massive exhibits an excellent opportunity for the study of the relations of the plagioclase aplite to the main red boundary aplite, as also of the progress of the evolution of the aplites from the granites, all the phases being connected with one another. The petrography of the various rocks, therefore, has been worked out by the writer in some detail on the basis of the material collected by him from the north-western part of the massive reproduced in fig. 2. To this end analyses were made of the principal rock types, the north-eastern aplite zone only being excluded. Of the analysed specimens, four were selected to illustrate a section through the massive from the north-east to the south-west. Moreover, one analysis of the red aplite at Marieholm from the immediate vicinity of a patch of plagioclase aplite was analysed, the composition of the white aplite and of a greyish variety of this rock type being reached by graphical measurements in the slides. The results obtained are shown briefly below.

The composition of the basic eye-granite predominating in the northern half of the area occupied by the coarse granites is shown by analysis I. The specimen analysed cannot be said to be representative of the whole northern part of the coarse granite, as there is a diminution of the dark minerals and of plagioclase from the north-east to the south-west. Thus, nearest to the northern boundary, the prevailing rock is considerably richer in the minerals named, but to the south of this boundary zone, the change is slow. The analysis, therefore, gives an approximate idea of the composition of the predominant part of the basic granite. Under A an older analysis of the corresponding northern part of the massive on the Loftahammar sheet is reproduced. The specimen corresponding to this analysis is a little richer in femic silicates and somewhat more basic, but on the whole the difference is not great, thus proving that the rock in the whole northern part of the massive must be fairly homogeneous.

	I		A
SiO_2	68.63	114.38	66.03
TiO_2	0.53	0.66	0.72
Al_2O_3	13.89	13.62	14.41
Fe_2O_3	1.43	0.89	2.17
FeO	3.32	4.61	3.70
MnO	0.06	0.08	0.07
MgO	0.67	1.67	0.98
CaO	2.65	4.73	2.28
Na_2O	3.60	5.81	3.15
K_2O	4.56	4.85	4.99
H_2O	0.55	3.06	0.77
P_2O_5	0.14	0.10	0.21
	100.03		99.48 [1]
	Sp. gr. 2.696		

I. *Loftahammar granite*, basic type, specimen from an outcrop 100 m. to the south of the manor of Kasinge. Anal. by *A. Bygdén* and *N. Sundius.*

A. *Loftahammar granite*, Loftahammar sheet, anal. by *R. Mauzelius.*

An approximate calculation of the minerals contained in the rock corresponding to I gives the following result. The amphibole and biotite were

[1] Hereto 0.09 BaO and 0.05 S.

calculated after analysed specimens of these minerals exhibiting similar proportions between the oxides FeO and MgO as in I[1]

Quartz	25 %
Microcline	24 %
Albite	29 %
Anorthite	8 %
Amphibole, biotite	13 %
Titanite, magnetite, apatite	1 %
	100 %

This calculation is only a rough approximation, but will give an idea of the real quartz-content within the limits of about 1 per cent. From the calculation it is also possible to get a fair idea of the actual relations of the feldspars. This corresponds to the formula $Or_{38}Ab_{50}An_{12}$, which implies a not inconsiderable divergence from the figures of the normative formula (Or_{40} Ab_{48} An_{12}).

Under the microscope, the microcline of the eyes is seen to be perthitic with a moderate content of albitic intergrowths. The perthite forms coarse granular aggregates of tabular or more irregularly formed individuals, between them occur some interstitial quartz and some grains of plagioclase, amphibole and biotite. The eyes are thus not homogeneous, but mixed with all the other minerals occurring in the rock. In the microcline individuals there are further distributed small inclusions of plagioclase and quartz, the former as rounded or idiomorphic grains, the latter more irregular and sometimes ramifying. Very seldom small isolated quartz grains are developed as idiomorphic dihexaedrons. The amount of the plagioclase is greater than that of the quartz. It is a peculiar phenomenon that the grains of each kind of the two included minerals are grouped into a sub-parallel arrangement, several grains forming a group, the extinction within it being simultaneous. We find one or more such groups of plagioclase, which may or may not be combined with quartz groups within one and the same microcline individual. The orientation of the groups, further, varies in the different microcline individuals. The composition of this plagioclase is An_{18}—An_{19} in the majority of the grains and An_5 in an outer narrow zone. The amount of the grains is not great as compared with the microcline.

The free plagioclase of the rocks is of two kinds. The bulk has the composition An_{20}—An_{21}, sometimes with inconsiderable outer zones of An_{19}. This plagioclase forms granular aggregates of markedly greater dimensions than the inclusions in the perthite. The other plagioclase has an inner

[1] Biotite from Port Henry, New York (Sneider and Clarke U. S. G. S. Bull. 419) average of FeO-riche amphiboles (S. G. U. Ser. C. No. 312, p. 242). The amount of the amphibole was found from the excess of CaO over that requisite for apatite, titanite (estimated in the slide) and anorthite. It was assumed that the CaO of the amphibole amounts to 11 %. The relation of the biotite to the amphibole was found in the slide to be 2: 1.5. In the calculation there occurs a remainder of 1.01 % FeO, which, in the form of olivine-silicate, was added to the dark minerals.

part of the composition An_{30}. It is somewhat speckled with small spots of the same kind as the outer plagioclase that surrounds the kernels. These outer, and sometimes rather extensive, zones have the same composition as the more albitic-free grains (An_{20} An_{21}). In its outermost parts the more albitic plagioclase can be seen grown simultaneously with perthite and intergrown with it. This latter feldspar also occurs as extensive envelopes around the whole plagioclase individuals. From this it appears that the separation of the perthite began about simultaneously with the last part of the plagioclase mixture An_{20}—An_{22} and then grew simultaneously with the somewhat more albitic inclusions in the eye perthite. The quartz began to separate about simultaneously with the perthite, though its crystallization continued longer than that of the latter.

Of the dark minerals the amphibole is a deeply coloured variety of the common hornblende group rich in FeO, $2V\,\alpha$ being very small. Correspondingly the biotite is of a deep brown colour. Both are seen as idiomorphic grains included in the feldspars, even in the earliest andesine. For the most part, however, they are aggregated as xenomorphic individuals in clusters between the eyes. Thus there is a general tendency in the rock for the minerals to collect into more homogeneous aggregates, which is also true of the quartz.

Myrmekite is rather abundantly developed. The composition of the plagioclase of this compound was found to be An_{17}, thus about a similar formula to those of the inclusions in the perthite and of the outermost zones of the plagioclase.

Of the southern more salic type of the coarse granite one analysis (No. II) was carried out. Further, one analysis was made of material from the transition between the eye granite and the aplitic rocks to the south (No. III). The specimen used for the former analysis is typical of the main mass of the southern coarse granite, the eye structure being distinctly developed. At some isolated places rims of plagioclase around the granular perthite bodies have been seen, and a rim of this kind was also present in the analysed specimen. To the south the eye structure, however, becomes more indistinct, the femic minerals and the plagioclase diminishing in amount, and the rock thereby altering to an even-grained granite of coarse or medium texture. Under B is quoted an older analysis published by Gavelin. The slight difference between it and II makes it evident how uniformly this type also is developed in the massive, the two analysed specimens originating from opposite ends of the massive.

	II		B	III	
SiO_2	72.89	119.90	72.94	74.98	124.97
TiO_2	0.40	0.50	0.43	n. d.	—
Al_2O_3	12.28	12.08	12.67	13.65	13.30
Fe_2O_3	1.49	0.93	1.44	0.49	0.31
FeO	2.42	3.36	1.48	1.05	1.46
MnO	0.03	0.04	0.02	0.02	0.03

	II		B	III	
MgO	0.47	1.17	0.46	0.26	0.65
CaO	1.71	3.05	1.89	1.06	1.89
Na_2O	3.02	4.87	3.04	2.89	4.66
K_2O	5.08	5.40	5.18	5.29	5.63
loss of ign.	0.47	—	0.27	0.51	—
P_2O_5	0.10	0.07	0.11	n. d.	—
	100.36		100.02	100.20	
Sp. grav	2.652			2.643	

II. *Loftahammar granite*, salic type, specimen from an outcrop 100 m. S. of Kasinge, parish of Ukna. Anal. by N. Sundius and A. Bygdén.

III. *Loftahammar granite*, transition form to aplitic granite. Specimen 375 m. to the north-east of Kulla, parish of Ukna. Anal. by A. Bygdén and N. Sundius.

In the rock corresponding to III a little fluorite is present, the amount of which was found graphically to be 0.04. For the apatite the amount 0.12 was found in the same way.

From II the mineral composition was reached in a similar way as in I. In III the small amount of hornblende present was estimated in the analysed powder at about 10 % of the dark minerals. Their approximate amount was reached when first calculating them as biotite from the excess of Al_2O_3.

	II	III
Quartz	33.1	35.4
Microcline	26.1	27.5
Albite	24.4	24.0
Anorthite	4.6	4.3
Amphibole, Biotite	11.1	8.5
Apatite, magnetite, titanite, fluorite .	1.1	0.4
	100.4	100.1

From the calculation, the actual feldspar in II becomes Or_{46} Ab_{46} An_8, the normative formula being Or_{48} Ab_{44} An_8. In III the corresponding formulae are Or_{48} Ab_{44} An_8 and Or_{50} Ab_{42} An_8.

The structural relations of the salic eye granite are similar to those described from the basic type. Thus the perthite is collected into the same eye like bodies of similar size and form, and as in the basic rock they are of a coarse granular texture. The plagioclase and the quartz, like the dark minerals, tend to aggregate to more homogeneous aggregates between the eyes. In the case examined of a rim of plagioclase around an eye, the plagioclase is homogeneous, but like the eye itself it has a granular development. There are seen in some instances projections from the plagioclase grains into the adjacent perthite individuals, the plagioclase continuing in the latter in the form of wholly or partly isolated grains. This makes it

[1] Also 0.08 BaO and 0.01 S.

probable that no great interval existed between the later part of the plagioclase and the perthite.

Mineralogically the salic eye granite differs from the basic in being richer in quartz and perthite and to a corresponding degree poorer in plagioclase and femic minerals. Furthermore, the albite-content in the perthite is greater in the salic type. The plagioclase present is fairly uniform. For the free grains between the eyes and in the rim around them the value An_{22}—An_{23} was found, with a little more albitic variation, An_{20}—An_{21}, in the outer parts in some cases. As before, small inclusions of plagioclase, as of quartz, are found in the perthite, arranged in the same graphic manner. The plagioclase here may have nearly the same composition as in the free grains, the value obtained being An_{20}—An_{22}. As before, myrmekite is rather abundant. The plagioclase has a similar composition to the predominant plagioclase (An_{21}—An_{22}).

The two granite species I and II exhibit great similarities as to the course of the crystallization, the chief difference being the appearence in the basic type of a more anorthitic plagioclase. In I an oligoclase of the mixture An_{21}—An_{18} crystallizes about contemporaneously with the perthite, in II the anorthite-content is, at the same time, about An_{22}—An_{20}. The amount of the perthite in this latter granite is greater.

In the rock corresponding to III we find essentially different relations. This transition type to the aplitic rocks described below, consists predominantly of a fine striated microperthite and quartz, with a minor quantity of oligoclase and biotite, to which are to be added a small quantity of a hastingsitic hornblende seen in one of the two slides examined. No real eye-structure is seen in this rock, the two chief minerals being mixed with each other as individuals of considerable size, the quartz only being granulated to some lesser degree. The quantity of the albite intergrowths in the perthite, again, is somewhat greater than before and amounts, according to a graphical estimation, to 20—25 %. The plagioclase present has the composition of An_{18}—An_{19}, with narrow outer zones of An_{9}—An_{12}. It is distributed as small grains or minor aggregates between the perthite individuals. The plagioclase shows idiomorphic relations against the perthite. Besides, there are inclusions of oligoclase and of quartz in the perthite, though the quantity is smaller than in the foregoing cases. These inclusions seldom exhibit the graphical arrangement exhibited by the eye granites, but are as a rule distributed irregularly and independently of each other. In any case, the difference in the time of separation between the two minerals is not considerable, though the oligoclase must to some extent have been of a somewhat earlier date, which is also true of the quartz.

As usual, myrmekite is plentiful; its plagioclase, being the same as in the dominant oligoclase. Here, too, the biotite is seen as small tables included in the feldspars, but the bulk of the dark minerals form clusters, the grains of which are irregularly bounded by the quartz and the perthite and show corroded contours against them.

The analyses obtained for the aplites surrounding the coarse granite are quoted as Nos. IV and V, the former representing the type where no plagioclase aplite is separated. The specimen for the analysis was selected from a locality near to the one for analysis III and from the inner part of the aplite zone. The specimen of V originates from the immediate vicinity of a patch of white aplite to the west of Marieholm. It belongs to the outer part of the aplite zone. Besides, under 7 are quoted the figures obtained graphically for the white rock in question. Under C. the analysis of the plagioclase aplite from Ödhällan is given.

			V		7[2]		C	
SiO_2	77.02	128.37	77.14	128.57	77.8	129.67	75.08	125.13
TiO_2	0.10	0.12	0.10	0.12	0.2	0.20	0.13	0.16
Al_2O_3	11.99	11.75	11.79	11.56	13.6	13.33	15.32	15.02
Fe_2O_3	0.45	0.28	0.57	0.36	(0.03)	—	tr.	—
FeO	1.00	1.39	0.81	1.12	0.1	0.14	0.25	0.35
MnO	tr.	—	0.01	0.01	—	—	tr.	—
MgO	0.11	0.27	0.18	0.45	0.1	0.25	0.29	0.72
CaO	0.68	1.21	0.72	1.29	1.9	3.39	2.12	3.79
Na_2O	3.07	4.95	2.90	4.68	5.2	8.39	5.62	9.06
K_2O	5.09	5.41	5.24	5.57	1.1	1.17	0.88	0.94
loss of ign.	0.55	—	0.61	—	0.1	—	0.29	—
P_2O_5	n. d.	—	0.01	0.01	—	—	—	—
	100.06		100.08[1]		100.1		99.98	
Sp. gr.	2.633		2.624				2.627	

IV. *Red aplite granite*, 50 m. to the north-east of Kulla, parish of Ukna, Skrikerum sheet. Anal. by A. Bygdén and N. Sundius.

V. *Red aplite granite*, 250 m. to the west of Marieholm, parish of Ukna, Skrikerum sheet. Anal. by A. Bygdén.

7. Graphical analysis of *plagioclase aplite*, locality = V.

C. White plagioclase aplite, Ödhällan, parish of Loftahammar, Västervik sheet. Anal. by R. Mauzelius.

To analyses IV and V the information is to be added that fluorite is present in both rocks. Its content was determined in the slides as 0.49 and 0.55 per cent by weight. This mineral is invariably met with in the slides from the aplite zone of the massive, both in the aplites on the north-eastern side as well as on the south-western side. The rock of Nr. 7 shows an irregular schlieric distribution of the quartz. The measurements were therefore controlled by a determination of SiO_2 made by A. Bygdén. The result was 77.2, thus nearly the same as that found graphically (77.8).

As is seen from the table, the composition of the two red aplites IV and V is very similar. This holds good for all specimens from the aplite zone

[1] Also 0.02 = BaO. On S was proved with a negative result.
[2] Compare also table 7, p. 22.

examined under the microscope. Noteworthy, however, is the difference of the alkalies, the »undifferentiated» aplite of IV being somewhat richer in Na_2O and poorer in K_2O than the »differentiated» one of No. V. This may be due to the separation of the plagioclase aplite from the latter. The difference is not great, as the total mass of the white rock is small when compared with the red one.

From the two analyses the following mineral composition results, the quantity of the micas being reached from the excess of Al_2O_3:

	IV	V
Quartz	38.5	39.0
Microcline	27.5	28.8
Albite	25.5	24.3
Anorthite	1.8	2.0
Biotite and Muscovite	5.9	5.3
Fluorite, apatite	0.6	0.5
	99.8	99.9

The actual formulae of the feldspars become, in IV Or_{49} Ab_{48} An_3, and in V Or_{50} Ab_{46} An_4, the normative formulae at the same time being Or_{51}, Ab_{46} An_3 and $Or_{52.5}$ Ab_{44} $An_{3.5}$.

The two aplite granites, though chemically similar, mineralogically exhibit remarkable differences. The rock corresponding to IV is made up of a fine-grained mixture of quartz, microperthite, and some small amounts of free plagioclase. Also there is biotite and, as accessories, fluorite and some grains of zircon. The behaviour of the minerals does not show anything indicating a difference as to the time of crystallization, the only exception being the presence of small inclusions of quartz in the perthite. These, however, are rare. Also some isolated tables of biotite can be seen included in the same manner in the perthite. Some corrosion of the feldspars as of the biotite from the quartz may also have occurred, to judge from the irregular and — at the side of the feldspars — convex forms of the boundaries between them. Otherwise the mineral assemblage represents what would be expected from an eutectic mixture of the minerals present. In the rock some myrmekite is developed, but considerably less than in the foregoing granites. The plagioclase of the myrmekite is an oligoclase of the same mixture as in the free plagioclase. This was determined to be An_{12}—An_{14} with a somewhat more albitic outer part of An_8—An_9. For the perthite the amount of the albitic component was graphically estimated at about 30 %, thus a higher figure than in the foregoing cases.

In the aplitic rock corresponding to No. V there is no microperthite of the type just described. The minerals in this rock have been subjected to some granulation, which has occurred chiefly in the microcline and in the quartz, but the alteration is only of a restricted degree, the greater part of the minerals being unaffected by it. In the unaltered parts, the rock is made up of a microcline poor in perthitic intergrowths, the quantity amounting at the most to some 6—10 %. Free plagioclase is separated to a corresponding degree. Its composition is An_{10}, with some outermost parts of An_6—An_7. For the rest the relations of the minerals to each other are as before, no distinction as to the time of the crystallization of the different components being traceable, with the exception of the biotite and possibly of some small part of the quartz that occurs in the same manner as in the foregoing aplite. With the biotite in this rock there is combined some muscovite, developed as idiomorphic tables. Some myrmekite is also seen here.

From the analysis of the plagioclase aplite from Ödhällan (C) we find the following mineral assemblages:

	C.
Quartz	34.2
Microcline	2.2
Albite	47.2
Anorthite	10.5
Biotite, muscovite	5.7
Rutile	0.1
	99.9

The table from which the composition of the white aplite from Marieholm was reached is quoted in table 7.

Table 7.

	% by weight	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O
Quartz	39.00	39.00	—	—	—	—	—	—	—	—	—
Microcline	5.65	3.66	—	1.04	—	—	—	—	—	0.96	—
$Ab_{83}An_{17}$	53.24	34.21	—	11.97	—	—	—	1.91	5.16	—	—
Albite	0.32	0.21	—	0.07	—	—	—	—	0.04	—	—
Biotite	0.81	0.32	0.02	0.16	0.03	0.12	0.08	—	—	0.06	0.02
Muscovite	0.82	0.37	—	0.32	—	—	—	—	—	0.09	0.04
Rutile	0.15	—	0.15	—	—	—	—	—	—	—	—
	100.01	**77**.77	**0**.17	**13**.56	**0**.03	**0**.12	**0**.08	**1**.91	**5**.20	**1**.11	**0**.06

The amount of the plagioclase and microcline originally found from the measurements was 56.04 and 3.17. As in the foregoing, it was assumed that the former feldspar contains 5 % Or and the latter 10 % Ab.

The actual average composition of the feldspars in the two aplites is, in the Ödhällan rock, $Or_{3.4}\,Ab_{79.8}\,An_{16.8}$, and in Nr. 7, $Or_{9.2}\,Ab_{75.5}\,An_{15.3}$. The corresponding normative formulae are $Or_{7.9}\,Ab_{76.2}\,An_{16}$ and $Or_{10.4}\,Ab_{74.4}\,An_{15.2}$.

In the slides both rocks are quite similar. They consist of a fine-grained assemblage of quartz and plagioclase. Besides, there are small, scanty flakes of a pale phlogopite, as of muscovite. The accessories of both are isolated crystals of zirkon and rutile. In 7 fluorite is also traceable. In the plagioclase aplites the rutile is sometimes present in more considerable amounts and visible to the naked eye. It then tends to congregate in narrow Schlieren. Its crystals sometimes attain a size of 1—2 mm. in length. Microcline in the Ödhällan rocks is very subordinate (0.7 % by weight in the slide). It forms small grains, which fill out the spaces between the plagioclase individuals. For the rest no difference as to the habitual development of the minerals can be shown. As a rarity, small rounded inclusions of quartz can be seen in the plagioclase, suggesting a possibly slightly earlier beginning of the separation of the former, this difference, however, being insignificant. A more striking phenomenon, on the other hand, is the already mentioned tendency of the quartz and the plagioclase to separate from each other and to form more homogeneous stripes or patches. In homogeneous stripes of quartz of this kind this mineral shows a coarser grain. Furthermore, from the irregular and curved boundaries between the two minerals, especially developed at the boundaries of the stripes, it becomes evident that the feldspar is somewhat corroded by the quartz. This latter may thus to some extent have been retained in solution longer than the plagioclase.

The composition of the plagioclase in the Marieholm rock (7) was found to be An_{17}—An_{18}. It is in parts somewhat clouded by inclusions of muscovite, suggesting some alteration. In grains altered in this way the formula found was An_{15}. In the Ödhällan aplite (C) we find a somewhat more basic feldspar (An_{19}), which is more generally altered in the same way.

In a slide of the grey, more biotite-rich, aplite variety from Marieholm the following table of the minerals present was obtained:

Table 8.

	% by weight	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O
Quartz	37.0	37.0	—	—	—	—	—	—	—
Microcline	13.8	9.0	2.5	—	—	—	—	—	2.3
$Ab_{86}An_{14}$	35.9	23.4	7.9	—	—	—	1.1	3.6	—
Albite	1.3	0.9	0.3	—	—	—	—	0.2	—
Biotite	12.0	5.0	2.4	0.4	1.8	1.1	—	—	0.9
	99.8	75.3	13.1	0.4	1.8	1.1	1.1	3.8	3.2

The original figures for the microcline and the plagioclase were 13.3 and 37.8 per cent by weight. For the sake of simplicity the supposed plagioclase-content in the microcline was calculated as pure albite, the error introduced thereby being small. The formula of the average feldspar from the table becomes $Or_{26}\,Ab_{64}\,An_{10}$.

Neither in this rock can any distinct difference as to the time of the separation of the salic minerals be traced. For the most part, the microcline present is free from perthitic intergrowths. In a few individuals of somewhat greater dimensions a quantity of small albitic spots occurs, but the proportion of these does not exceed 5 % at the most. The plagioclase was determined as An_{14}. The most striking mineral is the biotite, the quantity of which is greater than in any of the foregoing rocks. The biotite is a feebly coloured variety, optically similar to that of the white aplite. It shows idiomorphic relations against the other minerals, though it is somewhat corroded by the quartz and the microcline.

This grey plagioclase-rich rock in some cases predominates in the patches of the red aplite. In other cases it is mingled with white aplite in an irregular and schlieric manner. In rare instances there have been seen Schlieren composed of both rocks, with the grey one distributed at the sides and the white rock in the more central parts. In such a case there has also been seen a concentration of the quartz of the white aplite in the very central zone of the Schlieren, the adjacent white rock in this case being poor in quartz. This all suggests a somewhat later time of crystallization of the white rock than of the grey one, and a somewhat later separation still of the quartz. This latter may be the result of a crystal differentiation caused by the long retention of the quartz in the soluble form.

The grey rock calculated has in essential parts the character of an intermediate form standing half way between the red and the white aplites. This holds good for the feldspars, the quartz being of the same amount as in both the aplites. In one respect, however, the grey rock is of a singular type different from both, in being rich in biotite. Whether any forms analogous to these grey varieties are present in the other parts of the massive lying outside the district here considered is not known to the writer.

The eye structure of the Loftahammar granite.

The coarse granites occupying the central and greater part of the Loftahammar massive exhibit an example of rocks possessing the structure generally designated as a double structure, the eyes and also the plagioclase rims, when occurring predominantly, being composed of granular aggregates. When mapping the rocks and before having studied them microscopically, the writer was of the opinion that the granular consistence was a work of metamorphism, and thus a secondary property. This opinion on the double eye structure may be the one generally held by geologists. As to the Loftahammar granite, a similar opinion was previously expressed by Gavelin.[1] In the case of some parts of the rocks described by him this writer seems to hold that the eyes were grown contemporaneously with the secondary granulation of the minerals, thus being formed under and through the metamorphism.[2] Lastly, in many cases, where the rock is cut by fissures, and in the neighbourhood of the same, an obviously cataclastic crushing of the minerals, and also of the eyes, is described by him. On studying the relations of the minerals microscopically, the present writer soon became aware that the granulation theory would not explain the facts encountered. Undoubtedly cataclastic features are developed, especially in the northern part of the massive adjacent to the fissure valley of Ukna. Also in many slides a re-crystallization has apparently occurred. The mineral mostly liable to this is the quartz, though in many cases the microcline perthite is also converted into granular aggregates. Instances of this kind have already been given in the foregoing. But even in such cases where the rock is quite massive and traces of re-crystallization are not at all to be seen, as in the analysed specimens Nos. I and II, the eyes — as well as the plagioclase rims when present — are not single crystals but granular aggregates, though many times coarser than in the case of the secondary granulation. From the description given of these rocks it will be clear that the eye bodies are not secondary aggregates, but have been primarily developed in the same form as they still possess. The most important facts proving this are the following:

1. The eye bodies are not homogeneous but, except the microperthite, contain some amount of the other minerals of the rock. The individuals of the perthite have a predominatingly tabular form and behave like idiomorphic crystals towards the quartz occurring in the interstitial parts of the aggregates.

2. The inclusions of plagioclase and quartz in the perthite individuals are arranged in a graphic manner, the particular grains of the groups of the two minerals mentioned possessing the same orientation. This orientation, however, is not the same in the whole eye body, but different in the different perthite individuals. Also several groups of this kind can be found in one and the same perthite individual.

3. In the case studied of a plagioclase rim, parts of the plagioclase grains are seen intergrown with the adjacent parts of the perthite individuals. In this case also the individuals intergrown in this way possess different orientations in different parts of the eye body.

This eye structure differs from the ordinary one caused by the presence of large single crystals. In the latter case, as has previously been supposed by earlier authors, the cause of the structure may be the relatively small number of crystal nuclei formed by the microcline, the greater part of this feldspar being deposited upon these few centres during the crystallization. Also in the rocks here presented the same tendency of the micro-

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[1] S. G. U. Ser. C, No 224, p. 10.
[2] Ibidem p. 18.

perthite to form larger individuals when compared with the other minerals is exhibited, though not to the same degree.

For the structure described here two possibilities are open. According to one, it may be supposed that the eyes were already separated in the fluid state, thus forming globules in the crystallizing magma. This, as a consequence, would require a similar separation of all the other minerals, the same tendency to gather in homogeneous aggregates being exhibited by them also. This, however, in the opinion of the writer, is not reasonable. According to the other theory, the structure is developed during the crystallization itself, as a consequence of the simple aggregating of the growing crystals of the different mineral species. The chief difference from the ordinary eye type, then, lies in the greater number of crystal nuclei of perthite (sanidine) formed at the beginning of the separation of this feldspar.

When the above was already written, the interesting work of *W. Wahl* on the rapakivi granites of the Wiborg massive in Finland was published.[1] Of importance for the present discussion is the fact emphasized by this author, that the great feldspar balls of the Wiborg rapakivi are not always composed of single crystals, but are sometimes divided into several individuals. This also holds good of the plagioclase rims. The facts cited by *Wahl* exclude any metamorphic change after the final solidification of the rock.

The differentiation in the Loftahammar massive.

It is of importance for the following discussion of the aplites to know the differentiation of the whole rock series in the Loftahammar massive. For this reason the feldspar formulae and the molecular proportions of the feldspars to the quartz in the rocks analysed and calculated are reproduced in a graphical form in fig. 3. The corresponding formulae are compiled in table 9. All the figures refer to the actual content of the salic minerals. When using the normative figures, no important differences will be caused, the points only becoming somewhat displaced parallel to each other, to the left in the lower part of the diagram, and downwards in the upper part. The diagram is a combination of two triangular systems, the points of the lower part of the diagram referring to the feldspar diagram Or:Ab:An, those of the upper corner referring to the proportions of Or: plagioclase (Ab + An) : free quartz. The femic minerals are left out of consideration in the following discussion. Concerning them it may only be briefly recalled that their amount continuously diminishes from the femic north-eastern border towards south-west. The diminution is slow beyond the north-eastern border in the coarse granites, a more marked break appearing at the boundary towards the aplites, the biotite content of these rocks being small. Also in that respect a change occurs, the amphibole of

[1] Fennia, 45, No. 20.

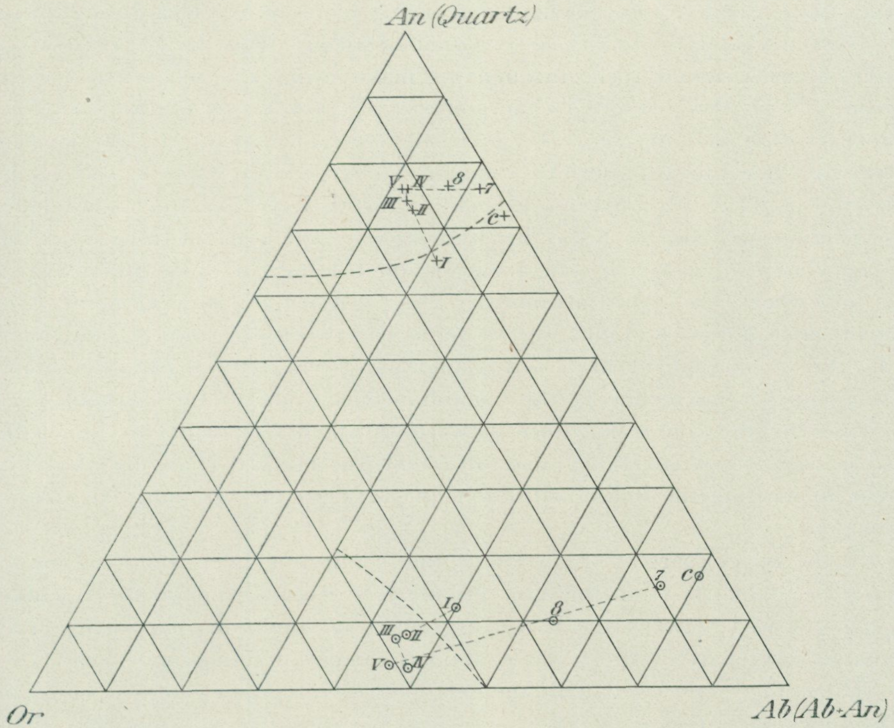

Fig. 3. Combined diagram of the systems Or: Ab: An and Or: (Ab + An): Quartz in the rocks of the Loftahammar massive. Circles refer to the former, crosses to the latter system.

the coarse granites disappearing when entering the aplites. Lastly a distinct enrichment of MgO occurs simultaneously with the increase of the total amount of the femic compounds. This is all clearly shown by the analyses.

Table 9.

	Quartz	Or	Ab	An	Or	Ab	An
I. Eye granite, basic type	65.0	13.2	17.5	4.3	37.8	50.0	12.2
II. » » , salic »	73.1	12.4	12.3	2.2	46.2	45.7	8.1
III. Medium grained granite, transition type	74.1	12.4	11.5	2.0	48.0	44.5	7.5
IV. Red aplite, not differentiated . . .	76.0	11.7	11.6	0.7	48.7	48.3	3.0
V. » » differentiated	76.1	12.1	10.9	0.9	50.8	45.6	3.6
7. White aplite	75.8	2.2	18.3	3.7	9.0	75.6	15.4
8. Grey biotite-rich plagioclase rock .	76.4	6.2	15.1	2.3	26.1	64.0	9.9
C. White aplite, Ödhällan	71.6	1.0	22.6	4.8	3.5	79.8	16.7

Turning to the salic minerals, points Nos. I—IV will be discussed here. The other points V, C and 7—8 illustrate the splitting up of the alkalies in the aplite border, this phenomenon being considered separately in the following chapter. As previously emphasized, analyses I—IV illustrate a continuous series of rocks through the massive into the red aplitic border zone. From the positions of the points in the lower part of the triangle it appears that the difference between the feldspar-content of the various rocks is caused by a diminishing amount of oligoclase-andesine when passing from I to III. The difference between the two eye granites I and II is seen from the diagram to be due to a higher content in the former of the plagioclase An_{30}. When comparing II and III the corresponding feldspar is somewhat more albitic, about An_{20}—An_{23}. When entering the aplite zone an abrupt change is found, the difference between III and IV not being due to an enrichment in III of plagioclase alone, but of plagioclase and microcline or microcline perthite simultaneously. The differentiation curve formed by the connecting lines between the points evidently becomes the same as the crystallization course of a feldspar mixture, changing its direction on meeting the individualisation line between the Or- and plagioclase components.

In the upper part of the triangle the connecting lines show a steady increase of quartz from the basic granite to the aplite, though the essential gap is located between the two eye granites, a condition reappearing also in the lower part of the triangle, though somewhat less pronounced.

These facts tally well with the relations found in the slides. Thus, in the rocks corresponding to I—III, plagioclase is earlier to crystallize than the microcline. In I the first generation of plagioclase is an andesine with 30 per cent of anorthite, this feldspar being absent in II. In II the free plagioclase present is distinctly more richly developed than in III, the composition in the former rock being An_{22}—An_{23} and An_{18}—An_{19} in the latter. Regarding the quartz, a simultaneous crystallization of this mineral and both the feldspars happens first in the aplite corresponding to point IV. A somewhat earlier beginning of the separation of the quartz, when compared with the perthite, is suggested by the appearance of small dihexaedral inclusions in the latter, in the coarse granites as in the transition rock but this amount of the early quartz must have been very small.

From these facts we may conclude that there is a close conformity between the crystallization process and the differentiation of the rocks of the massive. In view of this, some relations of the diagram are worthy of consideration. In the lower part of the diagram the individualisation line of the feldspar system is indicated as plotted by H. E. Johansson in his valuable paper on this mineral group.[1] The line was originally drawn for the relations in the quartz-free, effusive rocks, but it was supposed to hold with little change of its course also for the quartz-rich and deep-seated rocks. As is seen, this is not the case here. Evidently some complications enter into the salic granites and the aplites, changing the position of the line.

[1] G. F. F., Bd. 27, p. 342. Cf. also the figure 22, Bd. 32, p. 393.

The line drawn in the upper part of the diagram shows the position of the eutectic quartz-alkali-feldspar mixtures, as indicated by the relations of the graphic feldspars of the pegmatites (cf. fig. 5 of this paper). Evidently this line does not correspond to the one theoretically expected, the quartz-content of the eutectic ratio on the albitic side of the triangle being considerably higher than that of the Or-quartz system, the result theoretically expected being that the quartz content of both members would be about the same. Probably we have little chance of finding the real quartz-feldspar eutectic realized in the deep-seated rocks. Returning to the upper differentiation-line of the Loftahammar massive in the diagram, it clearly shows that the eutectic relation between the salic minerals does not enter at the same place as in the case of the graphic feldspars. On the contrary, the line crosses the line of these and continues about half-way towards the quartz corner, before a simultaneous crystallization of the salic minerals begins in the aplite (point IV). These departures of the salic granitic and aplitic rocks from what might be expected theoretically will be further illustrated by the following diagrams. Another illustration of this is the fact remarked in the petrographical description of the rocks that the quartz, though beginning to separate at a relatively early period, becomes continuously retained in the remaining solution, and to a greater or lesser extent separates later than all the other minerals. This fact has previously been emphasized by the writer when dealing with the granites and hälleflintas of the Grythyttefield.[1] A further manifestation of the same phenomenon is the partial separation of the quartz and the feldspar in the plagioclase aplites described in this paper, as well as in the Hälleflintas of the Grythyttefield, especially in the albite extreme members.

As to the causes of this departure from what would be theoretically expected in the case of pure quartz feldspar mixtures, several possibilities are conceivable. The dark minerals in the present case cannot play any essential rôle, as their amount is small. A greater rôle could be ascribed to alkalic compounds, when present in the magma and originating from the hydrolysis of feldspars. Assuming that these compounds are productive of the myrmekite, the real ratios of the different feldspar molecules of the magma are not shown by the points of the diagram, but would be found by replacing the myrmekite by microcline or microperthite. This would displace the points of the lower part of the diagram to the right. The displacement would be considerable, though the smallest change occurs in the aplite. Probably the presence of compounds of this kind in the magma contributes to the displacement of the individualisation line.

By some petrographers much stress is laid upon the under-cooling of the minerals, its strength being different for different minerals and different for effusive and deep-seated rocks. In this case it would imply that the mineral most liable to be under-cooled is the quartz, and in the second place the perthite (sanidine), the plagioclase being the one to

[1] S. G. U., Ser. C., No 312, pp. 89, 100—107, 248 and the summary pp. 336—337.

crystallize most easily. Against this theory of under-cooling, however, strong objections can be made. In the first place, the cooling of the deep-seated magmas is very slow, thus counteracting the under-cooling. Furthermore, the amount of the mineralizers in the salic and late-crystallizing magma must have been great, thus diminishing the viscosity of the magma and at the same time the probability of under-cooling. In the present rocks the percentage constant of fluorite in the aplites and in the transition zone directly proves the presence of mineralizers in the corresponding magmas.

From all this it seems to the writer more probable that the content of mineralizers is the chief factor causing the non-stability of the eutectic mineral relations in the salic rocks. Among the mineralizers the writer numbers also the alkalic compounds mentioned. The chief mineralizer in the magmas was no doubt the water. If any influence on the order of the separation of the minerals is to be attributed to this compound, it would be the retardation of the minerals most soluble in it at the temperatures prevailing during the crystallization of the rocks. To judge from experimental work, this would be the quartz. Evidently the behaviour of this mineral in the rocks may be well understood in this way.

The differentiation of the alkalies in the aplites described.

When first observing the differentiated aplite dykes, the writer was inclined to consider them to be the result of a fractional crystallization, the first separated minerals of the common magma being those of the contact borders. The phenomena exhibited by the dykes would thus be about of the same kind as the differentiation sometimes occurring in pegmatites.[1] In the progress of the investigation and after the establishment of the crystallization course of the rocks of the Loftahammar massive, objections to this view presented themselves. Combining all the facts collected, the most satisfactory theory of the separation may be that of separation already in the fluid state. This will be made clear by the following discussion.

First, summing up the geological facts, the following points will be made:

1. From the common aplite magma two rocks have been generated, both rich in quartz. Of the two aplites one, the white plagioclase aplite, regularly tends to collect at the contact with the side-rock. From this no exception is known to the writer. Even in the Loftahammar massive this holds good on a greater scale.

2. The white aplite has in several cases intruded the wall-rock in the form of narrow apophyses and dykes, sometimes forming breccias. This aplite must thus have behaved as a magma.

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[1] Cf. p. 4 this paper, op. cit.

3. No sharp contacts have been seen between the two aplites. The boundary is in many cases distinct, but a transition is always developed. In the Loftahammar massive slow transitions occur. No signs of different ages for the two rocks are traceable in most cases. When dykes of the one are developed in the other, they are not sharply bounded. In the boundary border at Ödhällan, the red rock is seen as dykes in the white one, this, however, probably being due to the situation of the white rock at the immediate contact against the cold side-rock and the broader development of the white boundary zone. When the white rock occurs as patches in the red one and the relations of the cooling have been the same for both, the white rock, on the contrary, is seen as dyke-like veins in the red, and may thus be somewhat younger. In any case the difference as in time of crystallisation can not be essential. When grey biotite-rich plagioclase rocks occur together with the white one, the succession of both rocks runs from the grey to the white, no great difference appearing even here, however.

4. The quantity of the white rock is always small as compared with that of the red aplite. In the analysed and calculated rocks from Marieholm this is apparent from the small displacement of point V in comparision with IV on fig. 3. Even if all the occurrences of the white rock with the red aplite were combined, the resulting feldspar mixture would not fall far from that of the undifferentiated aplite.

The molecular relations of the actual salic minerals of the analysed and calculated aplites are shown in tables 9 and 10. The figures are projected on the double diagram of fig. 4.

Table 10.

	Quartz	Or	Ab	An	Or	Ab	An
1. Red aplite, Ulriksdal	64.4	20.9	13.0	1.7	58.8	36.5	4.7
2. White » , »	72.9	1.4	20.0	5.7	5.1	74.1	20.8
3. Red » , Sund	68.4	14.8	13.7	3.1	46.7	43.4	9.9
4. White » , »	77.3	1.0	15.8	5.8	4.6	69.7	25.7

As before, the points of the lower part refer to the feldspar triangle, those of the upper part to the quartz-feldspar system. The aplites belonging together are connected by broken lines. Further, the same line as before, showing the relation of the quartz and the feldspar in the graphic feldspars, is reproduced. The small elliptical area shown in the lower part of the diagram is a reproduction of the discontinuity area of Johansson, to which reference is made in the latter part of this paper.

The differentiation of the aplites into two different rocks appears very well, the one tending to a mixture of nearly pure plagioclase and quartz, the other being of a more intermediate composition. The quartz-content

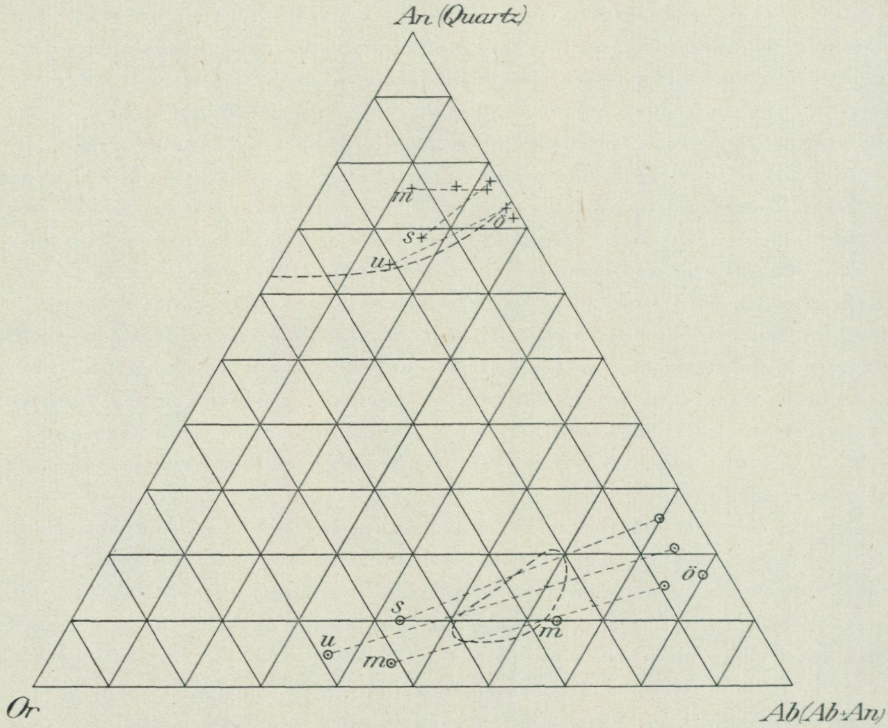

Fig. 4. Combined diagram of alkali differentiated aplites and aplitic granites on the Skrikerum and Loftahammar sheets. For the signification of the circles and points cf. fig. 3.

is high in both groups, though a tendency to an increase of the quartz in the plagioclase rocks is evident. A special variety of the aplite is represented by the rock corresponding to point 8, the grey plagioclase rock from Marieholm. With reference to the feldspars, this rock occupies an intermediate position. The most unique feature in the mineralogy of the rock, however, is the high biotite-content (12 % by weight). Possibly, the intermediate position of the rock is caused by this biotite-content, the solubility of the feldspars in each other, being modified by this mineral. Possibly, however, the rock is only a not fully differentiated part of the aplite.

A mineralogical fact of great interest is that nowhere in the differentiated aplites is the feldspar of the red rock a microperthite, but a microcline, poor in or free of albitic intergrowths, combined with free plagioclase. This proves that the temperature of the consolidation in the differentiated aplites was very low, lower than at the commencement of the splitting up of the homogeneous feldspars to form perthite. An interesting consequence of this is that *the temperature of the consolidation in these marginal parts of the massive was lower than in any of the other parts of the massive.*

The mere arrangement of the points in the diagram does not provide any information on the nature of the process that caused the differentiation.

The position of the points in the lower part of the triangle is the same as would have come about through an earlier crystallization of the feldspar of the white rock. Undeniably the relations in the diagram also show close similarities to the behaviour of the graphic feldspars in pegmatites. On fig. 5 a similar diagram for these is reproduced. In it all the analyses found by the writer in the literature are collected. Only the feldspars from Evje and Raade (Vogt), and the one from Beef Island, West India (A. Bygdén) have been excluded, the former because the analyses are not quite trustworthy, the latter as a consequence of the specimen used not being homogeneous and the feldspar being mixed with dark mica. The analyses reproduced are compiled from the following authors: A. Bygdén (Bull. Geol. Inst., Upsala, Sweden, Vol. VII p. 1), E. Mäkinen (Bull. Comm. Géol. Finlande, No. 35 p. 30), E. Bastin (Bull. U. S. G. S. No. 445, p. 124). One of the points, the one in the lower right-hand corner, refers to a dyke of albite granophyre from the Rödö district, Sweden (P. J. Holmquist, S. G. U., Ser. C, No. 181, p. 83). Besides, two new analyses, kindly placed at the disposal of the writer by Dr. A. Bygdén, are added. The figures are as follows:

	1		2	
SiO_2	74.93	124.88	76.01	126.88
Al_2O_3 . . .	13.24	12.98	13.14	12.88
Fe_2O_3 . . .	0.44	0.27	0.13	0.08
CaO	0.32	0.57	0.15	0.27
Na_2O	2.13	3 44	2.46	3.97
K_2O	8.52	9.06	7.68	8.17
H_2O	0.65	3.61	0.53	2.94
	100.23		100.10	

1. *Graphic feldspar*, Svinö. Åland. Analysed by E. Virgin.
2. » » Mursinka, Ural. » » A. Bygdén.

The specimen of No. 2 contains about 2.2 % of muscovite.

The graphic feldspars are generally thought to represent eutectic mixtures of quartz and feldspar. A simultaneous separation of both minerals may also have occurred in them. Notwithstanding, as has been found by previous authors,[1] the relations between the quartz and the feldspar vary, as appears from the diagram. As the cause of this variation the presence in the pegmatitic magma of other minerals and of mineralizers has been supposed. As is seen from the diagram, however, the variation is restricted, and the line drawn shows approximately the relation of the feldspars and the quartz in the graphic mixtures of these minerals. It is an interesting fact that the plagioclase members of this rock group, as also of the aplites, tend to contain a considerably greater amount of quartz than the intermediate or Or-rich members. This generally holds

[1] A. Bygdén, E. Mäkinen, E. Bastin op. cit.

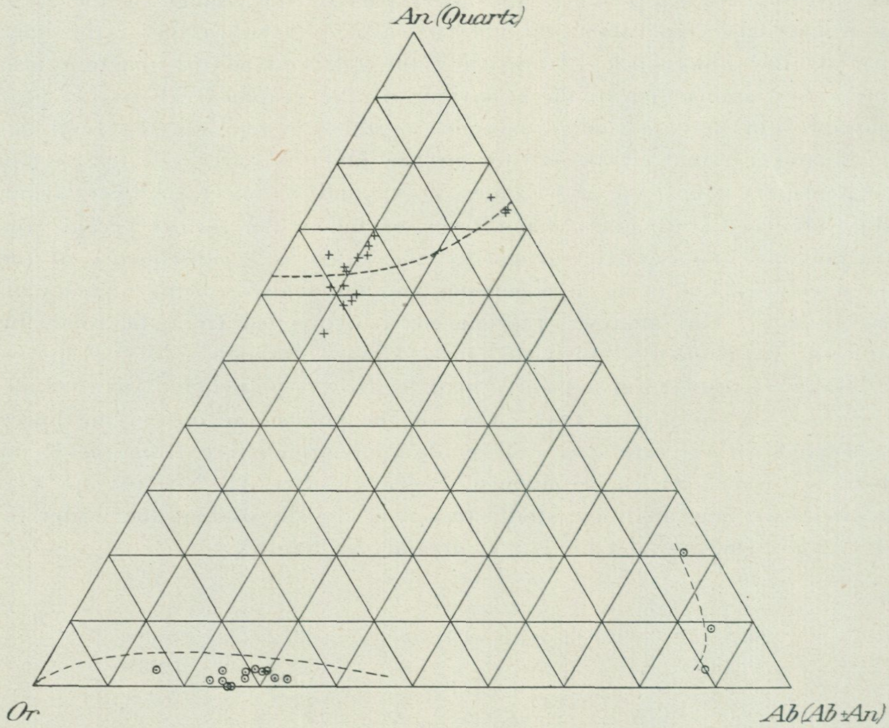

Fig. 5. Combined diagram of the graphic feldspars. For the signification of the circles and the crosses cf. fig. 3.

good when the total amount of the quartz of the common magma is not considerably in excess of that indicated by the line.

The relations of the graphic feldspars as shown in the lower part of the diagram does not present any great difficulty to the application of the crystal differentiation. Both feldspar components may have crystallized about simultaneously with each other and with the quartz. That the two feldspars crystallized as separate crystals does not require any special explanation, as this generally happens in the rocks. An acceptable explanation of the higher quartz-content in the plagioclase component, however, is still wanting.

In the differentiated aplites this view of the separation is not possible. Here the red rocks are built up, not of homogeneous perthite and quartz, but of two feldspars and quartz. When originating from a separation through crystallization, the red aplite must have crystallized at one time, the plagioclase aplite at another and earlier period. Thus, when applying the crystallization theory to these rocks, it follows that the first material separated out from the magma was the white aplite, this already being a solid mineral mixture when the red aplite crystalized. This is not in accordance with the geological relations showing that it is rather the white aplite that is the later of the two, when any actual difference as to the age can be shown. Furthermore, this order of separation does not agree with the relations found in the Loftahammar series, a simultaneous separation of plagioclase and perthite beginning in the aplite border. And there is no reason why the order of the crystallization should be reversed in the parts of the aplite zone where the differentiation of the aplites has occurred. These facts, combined with the fact that the white rock has behaved as a magma intruding the side rock, in the opinion of the writer, make it impossible to conceive the differentiation as a consequence of fractional crystallization.

Some attention, lastly, may also be paid to the minerals of minor importance. These, in the two groups of the aplites, show a distinct difference. Thus the biotite of the red aplites is rich in iron, the corresponding mineral in the white aplite being paler and partly a real phlogopite. From the analyses we quote the figures for (FeMn)O : MgO. In the red Marieholm aplite they are 0.82 : 0.18, in the Ödhällan white aplite 0.25 : 0.29. In the white aplites rutile is frequently present, sometimes in considerable amount. This mineral is really a characteristic accessory of the plagioclase aplites. In the red aplites the corresponding mineral is titanite. In the Loftahammar aplites the red rock constantly contains fluorite, this mineral being very rare and scanty in the white aplites.

Summing up the facts quoted, the geological as well as the petrographical, the most acceptable explanation of the differentiation in the aplites is that it occurred in the fluid state of the magma. In considering this process, the aplite magma can be regarded as a ternary system composed of plagioclase, microcline and quartz, the miscibility of the feldspars at sinking temperature becoming restricted. As a consequence of this, the quartz will also be dissolved in the two feldspar fractions in proportion to their dissolving power, thus producing a complete splitting up of the magma into two separate phases.

Other instances of the differentiation of the alkalies in the granites of Sweden.

In 1902 it was already suggested by P. J. Holmquist that no continuity of transition exists between the soda granites and the ordinary granites.[1] Some years later H. E. Johansson, in a larger work on granites chiefly from Swedish and American localities, found this rule to hold good. A restricted area shown in fig. 4 was found by him to be free from representatives when calculating the normative formulae of the feldspars and projecting them in the feldspar triangle.[2] This fact was apprehended by the author as being due to an instability of the granitic magmas falling within

[1] Förh. vid Nord. Naturf. mötet i Helsingfors 1902, p. 36.
[2] G. F. F., Bd. 28, p. 147.

this area, when cooling under deep-seated conditions. The same discontinuity, according to Johansson, also holds good for the leptites of the ore-bearing formation in Middle Sweden. The discontinuity area of H. E. Johansson is of a restricted extension, and in no case does the common magma of the aplites fall within it. If a corresponding area were constructed from the points of fig. 4, it would be considerable greater. This, however, would tally with the low temperature prevailing in the aplites during the crystallization, when compared with ordinary granites.

Referring to later works, more instances of rocks that may be similar to those described here are found to be known. No analogies to the differentiated dykes, however, are known to the writer. Possibly the phenomenon is not so rare in reality, though, because of their small dimensions, the light borders have escaped the attention of the geologists. From the urgranites themselves more instances are described of extremely soda-rich border phases connected with Or-rich granites. An example of differentiation of the alkalies of a similar kind to that occurring in the Loftahammar massive was found some years ago by the writer in the neighbourhood of Skönnarbo, on the Tjällmo geological sheet. While on a visit there he observed, immediately to the east and south-east of Lake Lyren, a red medium-grained salic gneiss, which was bounded on the northern side by a white plagioclase aplite. The boundary of the rocks was not sharp, and a schlieric mixture of both was also seen. A graphical analysis of both rocks under the microscope rendered the following result:

	Red rock	White rock
Quartz	36.8	2.9
Microcline	25.9	7.4
Plagioclase	An_{11} 25.1	An_{19} 86.2
Albite	2.7	0.3
Amphibole	4.5	—
Biotite	0.5	2.0
Muscovite	—	0.6
Rutile	—	0.6
Magnetite	3.2	—
Titanite	1.3	—
	100.0	100.0

The original figures for the feldspars were, in the red rock, 27.3 % of microline and 26.4 % of plagioclase; in the white rock, 90.7 % of plagioclase and 3.13 % of microcline. As in the differentiated aplites described above, the microline is nearly free from albitic intergrowths. Noteworthy, again, is the rutile-content in the white rock. From the figures the following molecular proportions of the salic minerals actually present result:

	Or	Ab	An	Quartz	Or	Ab	An
Red gneis	47.0	47.7	5.3	75.6	11.5	11.6	1.3
White aplite	7.6	75.0	17.4	11.9	6.7	66.0	15.4

The loci of the corresponding points in the combined quartz-feldspar diagram are shown by fig. 6 (sk). The white rock here differs substantially from the previous one in having a very low quartz-content. However, it would be possible that this is due to a schlieric distribution of the quartz, the specimen being taken in a part of the rock poor in this mineral. Unfortunately no observations on this point were made by the writer on his visit.

Some years ago a zone of albite granophyre was described by I. Högbom, occurring at the boundary of a red urgranite at Nyberget in Central Sweden.[1] The author is inclined to explain the granophyre as the result of a melting up of the side rock, an extreme albite leptite. This would be a very extreme case of contact metamorphism, another possibility being that the granophyre is differentiated from the red granite. This latter result was reached by P. Geijer after a visit to the place.[2] According to Högbom the albite granophyre intrudes the bounding leptite. As no details from the transition of the granite to the granophyre are given we are referred only to the two analyses of both rocks that are projected in the diagram (n). Evidently, when the granophyre is differentiated directly from the granite, the course of the separation must be essentially different from the one found by me in all the aplitic rocks. However, it is possible that modifications of the granite occur towards the granophyre boundary zone, the specimen analysed originating from the inner part of the granite. From Högbom's paper it also appears that the microcline of the gneiss granite is abundantly perthitic.

A rock similar in composition to the Nyberg granophyre is the Silverknut granophyre described by the writer from the Grythyttedistrict.[3] This rock occurring as an intruded mass in the volcanic hälleflintas, the relations of the same to other urgranites are not obtainable. Possibly it represents an injected part of an albitic boundary zone. The position of this rock in the diagram is marked on fig. 6 (si). The rock is extremely poor in CaO. Quite subordinately in one small part of the massive there is found a variety containing microcline, in which occurs perthitic intergrown with the albite.

According to N. H. Magnusson,[4] a tendency to an enrichment of the albite feldspar towards the border of the massive is exhibited by the granite of Horrsjö, in the western part of Middle Sweden, though the dimensions

[1] G. F. F. 42, p. 164.
[2] Kungl. Kommerskoll. Beskrivningar över mineralfyndigheter 1. Riddarhytte malmfält, p. 32.
[3] S. G. U., Ser. C, No. 312, p. 222. See also the summary p. 344.
[4] Kungl. Kommerskoll. Beskrivn. över mineralfyndigheter 2. Persbergs malmtrakt, Stockholm 1925.

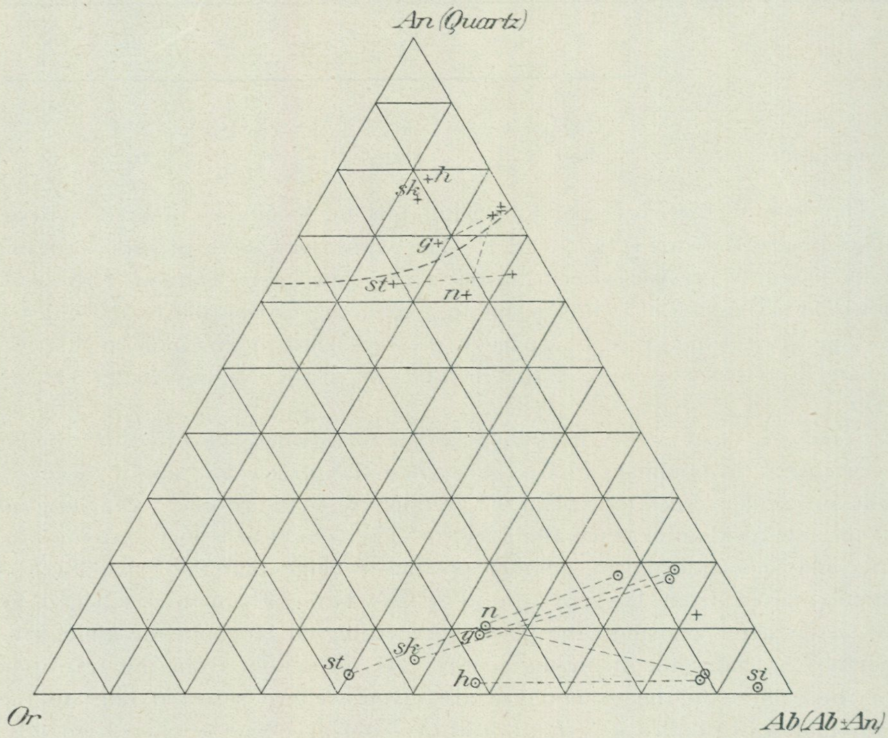

Fig. 6. For the signification of the circles and the crosses cf. the fig. 3.

of the albitic border phases seem to be inconsiderable. From a partial analysis the formula of the feldspars in this albitic phase is calculated and is reproduced together with that of the granite in the diagram (h).[1] From the description by Magnusson, it appears that the relations of the microcline and the albite in the granite vary, both sometimes building microperthite, but more generally they are separated partly or wholly as free grains. In the analysed specimen from the boundary a very subordinate amount of Mi is intergrown with the albite. From the same ore district an isolated intrusive mass of albite granite is also described.

Another example of a plagioclase-rich boundary zone of a red urgranite is mentioned by G. Lindroth from the Garpenberg's district in Central Sweden.[2] From the Riddarhytte district P. Geijer mentions albite extreme granites.[3] According to this author rocks of this kind also may occur in the Norberg district. Of interest is the general occurrence of rutile among the accessories of the plagioclase rocks from Riddarhyttan. From the

[1] From the microscopical determination of the phenocrysts an approximate amount of 2 % of anorthite was estimated for the whole rock.

[2] G. F. F. 46, p. 595 and 606

[3] Kungl. Kommers koll. Beskrivningar över mineralfyndigheter 1. Riddarhytte malmfält, Stockholm 1923, p. 30.

description of Geijer, it further follows that the white aplites here are partly connected with Or-richer urgranites as boundary phases. Besides, they occur as independent intrusions in the leptites. No analyses are available from this district.

From the two analyses of Lindroth the approximate actual minerals of the Garpenberg rocks were calculated, and the points in the diagram found (g). Unfortunately no details are given, and it remains uncertain whether the analysed gneiss is the rock immediately connected with the plagioclase aplite or not. The course of the connecting line, however, is quite similar to that found by the writer. From the figures of the analyses those of (Fe Mn)O and MgO may be quoted, this being the only instance where these oxides have been determined in the analyses given in this chapter. In the red rock we find (Fe Mn)O : MgO = 1.37 : 0.36. In the grey rock the relation is 1.04 : 1.18. A distinct enrichment of MgO has thus occurred in the plagioclase rock.

Incomplete as they are, the facts referred to show, however, that the differentiation occurring may be of the same kind as that described more particularly in the foregoing. Also the same tendency to a concentration of the plagioclase rocks at the borders of the granites is generally met with, as this border phase also — in the form of independent injections — intrudes the wall rock. Evidently phenomena of this kind are widespread in the Swedish urgranites, though the aplite species rich in plagioclase are seldom of any considerable dimensions and therefore have previously escaped the attention of the geologists. All known instances thus date from the last six or seven years. For the complete understanding of the processes occurring more detailed descriptions are necessary.

An instance of a similar differentiation is described from the younger archean granites of Sweden by B. Asklund from the Stavsjö district.[1] The geological site of the rocks is not sufficiently definite from the description, according to which the red rock seems to form irregular streaks and lumps in the greyish plagioclase-rich rock. This latter is not quite comparable to the ordinary white aplites, being rich in biotite (about 17 %). At the same time the amount of free microcline must be essential (according to the analysis, 7—8 %). Petrographically it is comparable with the grey rock from Marieholm. Both the rocks from Stavsjö are reproduced in the diagram of fig. 6 (st). The splitting up of these rocks was explained by Asklund (p. 109) on the theory of the discontinuity area of Johansson.

P. Eskola describes a marked enrichment of plagioclase from Finland in the boundary phase of the well-known Orijärvi oligoclase granite.[2] A plagioclase-extreme but more albitic phase also occurs as separate dikes in the side rock. In fact, this is the first described instance in Fennoskandia of an enrichment of plagioclase towards the contact line of a granitic mass. The mother rock here being a plagioclase granite, itself very poor in micro-

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[1] S. G. U. Ser. C. No. 325, pp. 44—45.
[2] Bull. Géol. Comm. Finlande.

cline, the mineralogical development of the different rock phases is not comparable with the instances here dealt with, and the whole differentiation process may be of quite a different kind. Possibly it forms an analogy to the separation of the white aplite bands and stripes occurring in the amphibolite and plagioclase granites described in the first part of this paper.

Probably the same is the case with the rock named »Krageröit» by Brögger. This rock forms a dyke in the vicinity of Kragerö[1] in Southern Norway. It is regarded by Brögger as a gabbro aplite. The large amount of rutile is curious, amounting in the analysis to 25 % by weight. The feldspar formula of the rock is Or_5 Ab_{87} An_8. The quartz-content is only 7.7 per cent.

Some applications to the leptites and hälleflintas.

The facts referred here seem to be applicable to the curious relations found in the ore-bearing leptites and hälleflintas of Middle Sweden.[2] Chemically these rocks occupy a unique position among eruptive rocks through the very extreme differentiation of the alkalies, the rocks at the same time being very salic. In this latter respect they are comparable with aplites. With the leptites and hälleflintas are connected a great number of iron ores, being partly deposited as banded quartz (jasper) hematite ores during the time of the building of the volcanic formation. Partly they originate from metasomatic replacements of carbonate layers. A corresponding concentration of ore substances in the aplites and pegmatites or to alkalic and aplitic parts of the rocks is also known from the urgranites.[3] The distribution of the ores, furthermore, exhibits a certain chemical analogy to what was found in the femic minerals of the differentiated aplites, the ores occurring in the Or-rich members of the formation being distinguished by a large amount of (Mn Fe)O, and those in the Ab-rich members being extremely poor in MnO, in most cases also in FeO.

The whole leptite complex may thus be regarded as a formation predominantly built up of effusive forms of aplitic magmas including a high percentage of solutions containing metallic oxides, especially oxides of iron. No doubt water played an important part in these solutions. The rocks of the formation are to a great extent extremely rich in albite or rich in Or, though

[1] For analysis and reference see Watson, Bull. U. S. G. S. No. 580, p. 412.

[2] As »hälleflintas» are designated dense rocks of the same composition as the leptites, the only difference being the stronger metamorphism of the latter and a correspondingly coarser grain. The hälleflintas show to a large extent the primary structures, well preserved, that mark them as quartz porphyries or as vitroclastic tuffs or tuffits.

[3] Cf. the description to the Skrikerum sheet. Regarding the presence of solutions of (Fe Mn Mg) O in aplitic and alkalic varieties of the granites cf. the descriptions of the red ore-bearing gneiss at Åtvidaberg (S. G. U. Ser. C, No. 306, p. 39 and summary p. 113) and the Silverknut granophyre (S. G. U. Ser C, No. 312, p. 224 and summary p. 344). In these rocks the dark minerals were formed after the separation of the quartz and feldspars, and were fixed during metasomatic replacement of the feldspar. Similar relations are exhibited by certain aplitic and pegmatic rocks containing greater amounts of epidote and chlorite. These rocks have been named »helsinkites». (B. Asklund, Ser. C. No. 325, p. 40, H. von Eckermann G. F. F. 47, p. 504, and other authors referred to in these papers.)

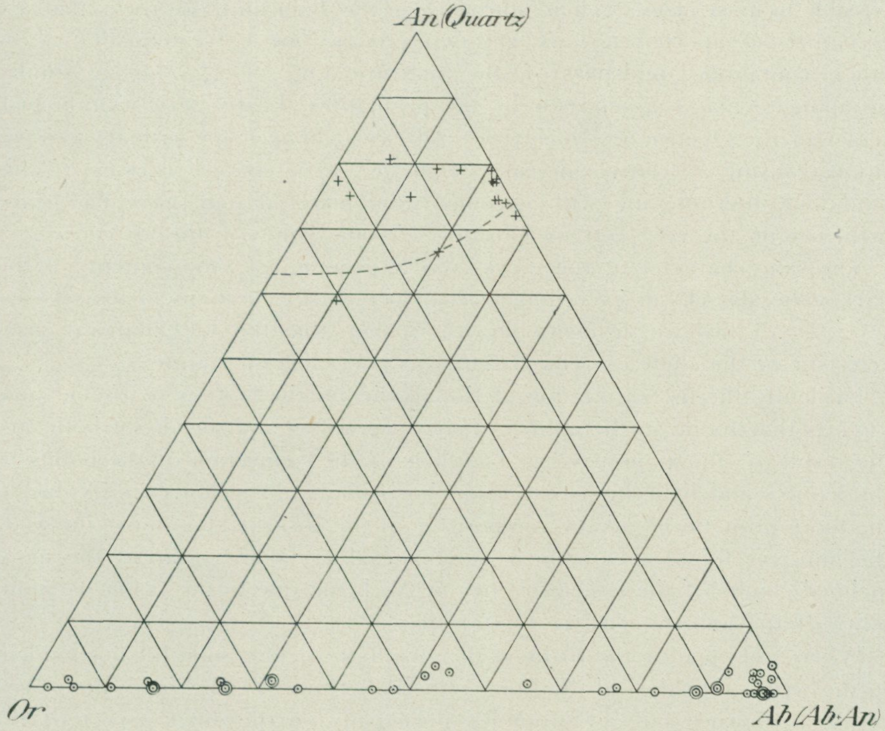

Fig. 7. Combined diagram of the leptites and hälleflintas of the Grythytte- and Persbergs fields. For the signification of the circles and crosses cf. fig. 3. Double circles = quartz porphyries.

this latter compound is seldom enriched to the same degree as the albite. Rocks of this differentiated composition seem to predominate, although more intermediate species are not lacking.

As an illustration of this, the analyses from two neighbouring and similarly built fields, the Persberg and Grythytte fields, both mapped in detail are reproduced in the diagram of fig. 7.[1] This figure does not quite give a right conception of the rocks of the fields, as some of the analyses were made for the special purpose of showing the existence in the formation of intermediate feldspar mixtures. Notwithstanding, the aggregating of the points to the Ab-corner is well demonstrated. Quantitatively the mixtures of about $Or_{50}Ab_{50}$ to $Or_{15}Ab_{85}$ play a rather subordinate part in the rocks of both fields.

In volcanic rocks, furthermore, it is to be expected that the vitroclastic sediments may to some extent be re-arranged and mingled with decomposition products. Even mixtures of differently composed rocks may result in the same way. This would be avoided by choosing only quartz porphyritic rocks. In the Grythytte field a distinction between tuffs and porphyries is

[1] The points lying on the alkali line refer to incomplete analyses. In both fields the CaO-content of the rocks throughout is very low and seldom higher than in the complete analyses. The analyses are compiled from the two works referred on p. 37.

possible in most cases. When indicating on the diagram those rocks that are recognized as porphyries, we get two groups, one extremely albitic, the other containing feldspars of the mixture Or_{68}—Or_{84}, thus a similar grouping to that characteristic of the pegmatites. Lastly sericitisation processes in the Or-members has in several cases changed the primary composition, causing a relative increase of the K_2O-content. Processes of this kind and intermingling with decomposition material may have had some influence on the very extreme position of some points in the Or-corner.

The salic character of the rocks is very pronounced, the content of the dark minerals seldom exceeding a small percentage, perhaps in most cases, 1—2 %. A fact worth mentioning is, further, that the TiO_2 mineral characteristic of the albite-extreme hälleflintas is rutile, not titanite.

Evidently the differentiation of the alkalies in the leptites is of the same kind as that found in the aplites of the urgranites and no doubt both are the result of similar processes. The lines of the connection of the points in the leptites and hälleflintas are about horizontal. This, however, is due to the more pronounced alkalic composition of the rocks. This same course of the line was found also in the very alkalic Horrsjöbergs granite, the more inclined course of the systems richer in An being due to the restricted solubility of the anorthite in the Or-feldspar.

When investigating the rocks of the Grythytte field it soon became evident to the writer that the old division of the hälleflintas of the field introduced by A. E. Törnebohm, and founded principally on the outer aspect of the rocks, also had a deeper petrographic significance, one etage lying on the bottom being composed nearly entirely of the extreme albitic members shown in the diagram, the other etage resting on these albitic rocks representing an Or-rich complex. This vertical distribution holds good on the whole, though albite-extreme members may also occur in the upper etage as Or-rich rocks, though more seldom found in the lower one. The same relations were found by N. H. Magnusson, in his valuable work on the Persberg field, the same rule holding good also here, though Or-richer or intermediary leptites are somewhat more richly intercalated in the lower etage, the upper etage, on the other hand, being more homogeneous.

Somewhat earlier, eight years ago, J. Eklund[1] building partly on the results found in the Grythytte field and the facts known from the Persberg field, as well as on the relations in the lime-bearing zone of Rossvalen-Vikern, and partly also referring to the distribution of the different ore types, tried to show that a similar vertical distribution of the chemically different types of the leptites is general in all parts of the leptite formation, everywhere where a differentiation of the alkalies has occurred. Though this can not at present be decided, yet the rule is shown to hold good for the western part of the formation.

When considering both the fields named, the albite-extreme rocks are found to be greatly predominant. In the Grythytte field they comprise

[1] Lecture in The Students' Association of Natural Science, Upsala. Geol. Division, 1918.

a complex of layers, the width of which, in the parts exposed in the field, amounts to several hundred meters, although the bottom is nowhere seen. This great layer of albite-quartz rocks forms a coherent substratum for both fields and continues farther to the east and north-east, where it underlies the greater part of the leptite area in the Province of Örebro. Probably the same albitic bottom substratum predominates in the whole leptite district, here covering an area of several hundreds of square kilometers, until at the eastern border Or-rich leptites and hälleflintas meet. A further continuation is known to the north and north-east through the works of H. E. Johansson (the Grängesberg district), G. Lindroth (environs of Yxsjö) and I. Högbom (Nyberget). In the leptite-hälleflinta formation the plagioclase-extreme members thus play a very considerable rôle. This splitting of the rocks is not exhibited in all parts of the formation, but alkali differentiated rocks are very widespread and seem to predominate. In the leptite-hälleflinta formation the differentiation of the alkalies has thus developed much more generally and in much greater extension than in the later intruded and consolidated granites. In fact, no analogies are known from later intrusives or extrusives.

On returning to the rocks of the Grythytte field, the writer was earlier led to the conclusion that no differentiation of the alkalies had occurred since the extrusion of the lavas, though an uneven distribution of the quartz had very often occurred in detail during the very act of consolidation. The differentiation of the alkalies, therefore, must have been accomplished in *the supplying magma and thus in the fluid state.* Now, bearing in mind the vertical distribution of the different rocks, this must imply some corresponding vertical inhomogeneity in the upper layers of the supplying magma body. In the work referred to, the writer believed this to have happened through a continuous change in the upper part of the magma. The relations found in the aplites of the urgranites, however, do not speak for a difference as to the time of the two magma parts. On account of this, we may conclude rather that both kinds of magma were contemporaneous and that of albitic composition superincumbent on the Or-rich part, thus forming the uppermost and at the same time the outermost part of the whole magma body. This is in accordance with all experience from deep-seated and intrusive rock exhibiting this differentiation.

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April 1926.

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