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PETROLOGICAL STUDIES IN THE NEIGHBOURHOOD OF STAVSJÖ AT KOLMÅRDEN

GRANITES AND ASSOCIATED BASIC ROCKS OF THE STAVSJÖ AREA

BY

B. ASKLUND

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With one Plate

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B. ASKLUND

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PREFACE.

The field-work for the most considerable part of the present investigation was carried out during the summer of 1919. Thanks to the courtesy of the Geological Survey of Sweden, the investigation was somewhat extended during 1922 and 1923, and the region already mapped was carefully gone over again.

The material collected was worked up during different periods, first at the mineralogical department of the Royal Technical College, Stockholm, and later at the Geological Survey. In the course of this work it was found of interest to submit a number of the rock types to a more thorough investigation by means of chemical analyses, which were carried out in part by Dr. Naima Sahlbom, Stockholm, at the instigation of the author, and in part by Dr. A. Bygdén, Chemist at the Geological Survey.

In now presenting the results of his investigations, the author wishes to tender his grateful thanks to the Director of the Geological Survey, Dr. A. Gavelin, thanks to whose courtesy and kindness it has been possible to complete the present work. For valuable guidance and information in the matter of the microscopical study of the various rock types, the author tenders his thanks to Professor P. J. Holmquist and to Dr. N. Sundius, State Geologist. In particular, the author owes a debt of gratitude to Dr. H. E. Johansson, State Geologist, who has with great interest followed, above all, the theoretical studies connected with the investigation, and whose wide experience in the questions involved has enabled him to call the author's attention to valuable points. Professor H. G. Backlund has been kind enough to give the author a number of suggestions as to the presentation of the matter and has proposed partial extensions of certain parts of the work, thanks to which it has gained considerably in perspicuousness and form.

The microscopical illustrations of rock types have been executed with his usual care by Mr. A. H. Olsson, and in the translation from the Swedish original Dr. P. Geijer, State Geologist, Reader at the Stockholm Högskola, has placed his linguistic attainments at the author's disposal as regards the correct rendering of the technical terms. Lector S. J. Charleston has displayed both interest and energy in the task of revising the English of the translation and in reading the proof-sheets.

To all the above-mentioned, as well as to those who have promoted the completion of the work by their personal interest, the author wishes to express his deep sense of gratitude.

Geological Survey of Sweden, Stockholm March, 1925.

Bror Asklund.

Introduction.

In his very valuable work, »Description of the Stavsjö Section», A. G. Nathorst[1] has pointed out the very great variety of types which characterise the granites of the northern part of the section. This part belongs to the region of Kolmården, the beautiful forest-clad table-land composed of pre-Cambrian rocks, which, owing to the fault along the Bråviken arm of the Baltic, rises above a peneplaned Archean area to the south, dipping towards the north—the flat country round the town of Norrköping. The greater part of the area occupied by the Stavsjö section has been the object of my investigations during several years (1916—1923), and in this paper I propose to give a petrological description of one of the most interesting parts — the Stavsjö area. In order to introduce the petrology and geology of the granites and associated rocks of the Stavsjö area to the reader, I submit an introductory summary, chiefly dealing with the distribution of these rocks and their mutual relations, as I have understood them.

The western parts of the section are in part occupied by the great granite-massive at Graversfors with its coarse granite types, among which two comparatively minor types, the dark labradorising, pyroxene-bearing, and the red — or rather reddish — quartz-rich granites, are well-known from their use as building-materials. The main type of the massive is a coarse, generally pinkish, granite with long rounded microcline-perthite crystals of more than one inch in length, and often with well-individualised quartz-crystals of a blue or bluish colour. Towards the south-eastern contact, this main type changes to a very distinctly porphyritic granite, with rectangular microcline-perthite crystals and considerably poorer in quartz. This type is very similar to the coarse granite described below, which appears as a fairly well-bounded small massive N. W. of Stavsjö. Towards the north, the coarse granite of the Graversfors massive passes over to a medium-grained granite, which, according to Nathorst, can scarcely be distinguished from the red gneisses which are distributed over the north-western parts of the Stavsjö section.

In the central parts of the Stavsjö section extends the granite area — abundant in types — which is here the subject of a closer description. From the middle of the area, with its small massive of the above-mentioned porphyritic type, the granite area is closely connected by medium or fine-grained granite species with the great Graversfors massive and also extends towards the north-west as far as to Lake Fläten. The north-western and northern parts are cha-

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[1] Beskrifning till kartbladet »Stafsjö» av A. G. Nathorst, Sveriges Geologiska Undersökning, Ser. Aa, no. 57.

racterised by Nathorst as pinkish granite-gneisses, a collective name for those, in part, slightly deformated or foliated, alternating granite species which are more or less directly connected with the typically granite-structured rocks of the central part of the area. To the north-east also the area extends through medium or fine-grained species towards Virå, over districts indicated by Nathorst as »red gneiss» or »red granite-gneiss», which indeed are also more or less foliated granites belonging to the other granites. N. of Virå the granites of the Stavsjö area are consequently directly connected with the granite area at Lake Enaren marked on the Stavsjö section. The latter area, however, in scattered outcrops of fine-grained granites, shows a direct continuation in the important granite-massive that extends to the northern part of the boundary between the Stavsjö and Nyköping[1] sections.

The Stavsjö area presents a number of varied granite types. In addition to the medium to fine-grained granites described in detail in the following pages, there also appear types differing from the leading Graversfors type. Of these, a coarse porphyritic, characteristically pinkish, granite is the main type. It is characterised by the usual fluidal arrangement of the one to two inches long, rectangular, microcline-perthite crystals that compose the greater part of the rock. The quartz-percentage is generally relatively low, as are also the percentages of the ferro-magnesian constituents, muscovite and biotite. Only seldom does the quartz-percentage become higher, in which case the mineral appears as rounded blue crystals. This rare species appears in the form of occasional dikes in the medium-grained granites to the west of the valley between Lakes Björnsjön and Strålen. The dikes present similarities to the coarse quartz-rich granites of the Graversfors massive, but the rectangular form of the microcline-perthite is still characteristic. To the west the coarse granite of the central type is bordered by a gray and more basic granite with a not unimportant percentage of ferro-magnesian minerals, among which hornblende and biotite are characteristic. The microcline-perthite crystals of this granite, which is very similar to the »Filipstad granite» of the southern parts of the province of Östergötland, are more rounded and do not constitute so great a proportion as in the coarse central granite. Closely connected with the hornblende-biotite granite, there occur quartz-syenitic granites, quartz-diorites, and noritic gabbros. Unimportant, but very interesting, rock species are some alkaline epidote-feldspar rocks, helsinkites (Laitakari), which occur allied with the quartz-syenites.

With reference to the deformation-structures and their geognostical appearance, the various differentiates of the Stavsjö area present very great differences. Thus the medium or fine-grained granites are moderately to strongly foliated over extensive districts, especially close to the boundaries of the older rocks. They appear as parallel-textured rocks similar to gneiss-granites. Their limits towards the pegmatite-rich older rocks present some difficulties, but on a careful examination they are quite clear. As shown on the petrological

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[1] Sveriges Geologiska Undersökning, Ser. Aa, no. 23.

map, Plate I, the strike of the deformation-structures generally follows the rock-boundaries. There are, however, also deviations from this rule. In the central parts of the area now mapped, medium to fine-grained granites also occur in a massive-textured habitus, though almost always with a fluidal arrangement of the microcline-perthites in the more porphyritic-textured species. The fluidal texture is parallel to the more decided schistosity along the boundaries, and, with gradual transitions, manifestly has the same origin as the pronounced foliation. In parts, also, the fluidal texture appears very clearly in the coarser granites, among which the hornblende-granite (the »Filipstad granite») sometimes obtains a gneissic habitus similar to an »augen-gneiss». The coarse central granite, which, with regard to its direct zonal connection with the medium-grained or hornblende-bearing granites, seems — broadly considered — to represent an interior and more deeply situated, last solidified, part of the granite, sometimes also cuts the other granites. In some not inconsiderable areas this younger granite shows a very distinct fluidal texture, with large microcline-perthite crystals arranged in parallel. This fact unmistakably indicates that the deforming forces were still operative during the solidification of the younger granites.

The granite area of Lake Enaren is occupied by a grayish-red, medium-grained granite, rich in biotite and very similar to the usual medium-grained granites.

The great granite area S. W. of Lake Yngaren[1] also presents a number of granite types and associated gabbros and dioritic or quartz-syenitic rocks, all of the same types as the series of differentiates of the Stavsjö area. The principal granite is similar to the coarse Stavsjö granite, and consequently it also appears as a coarse porphyritic granite with rectangular microcline-perthites. In the same manner are represented also the curious epidote-feldspar rocks, the »Helsinkites».

Taking a retrospect of the distribution of the granite rocks in the district referred to, it will be found that they form a broad band in a S.W.—N.E. direction distributed over large parts of Kolmården.

In this band occur three more massive-like areas, made up of coarse granites. These massives, the Graversfors massive, the Stavsjö massive, and the Yngaren massive, contain similar rocks, or their rock-types are connected with one another by transitional types. Each of them constitutes the youngest member of a parallel differentiation sequence in the different districts.

Different members of this sequence are also met with outside the areas mentioned. In the northern and western border-districts of the great limestone area at Kolmården, the Marmorbruket field, there occur fine-grained granites which are directly connected with the rocks of the Stavsjö area. The granites of the Marmorbruket field are followed by tourmaline-bearing pegmatites, which, in their frequently very sharp contacts towards the older rocks, present

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[1] The author has studied this granite area in company with Fil. Lic. G. Ekström, while making a rapid revision of the latter's careful investigations of Valinge Manor, in the province of Södermanland.

perfect analogies with the »cutting granites» distinguished by A. E. Törnebohm and P. J. Holmquist. These granites are indicated by A. G. Högbom as »serarchean granites», the latest granite-formation of the Archean.

In a better-known area — and from the geological point of view a neighbouring area — the Tunaberg field, there also occur pegmatites in sequence to cutting granites, which have long been referred to as »Serarchean granites»[1].

Consequently, at Kolmården we meet with a couple of granites which in many respects belong to each other, but which present great differences geognostically.

However tempting it might be to give a monograph of all the granites of this extensive area, the author has had to let the matter rest in favour of other tasks connected with the Geological Survey of Sweden. In a few words, however, the author has, later on in this work, indicated his conception of the present question of the relations between the granites of the Småland-Filipstad group and the Serarchean granites. This problem may perhaps find its most evident solution at Kolmården. — This work is for the most part occupied with a discussion of the petrology of the Stavsjö area. To this discussion the author has added some petro-chemical studies of more general interest. In part these studies require a more detailed development. They have been included as forming a basis for some theoretical studies of the crystallisation and differentiation of the present rocks.

CHAPTER I.

Earlier Geological Works on the Stavsjö Area.

During the eighteen-seventies the geological section of Stavsjö was surveyed by the Geological Survey of Sweden. The chief geologist employed on the work was A. G. Nathorst, who seems to have shown great interest in this area. The results are developed in detail in the Explanation of the Stavsjö Sheet (no. 57). Subsequently the area was studied and briefly described by A. E. Törnebohm. In the collections of the Geological Survey of Sweden there are some specimens which evidence his interest in the petrography of the rocks around Stavsjö. The following review — as regards the area mapped by the present author — brings out the fact that Nathorst possessed clear conceptions in his work on the Archean. But it also shows the great difficulties encountered by the older geologists in the interpretation of the gneissic derivatives of the granites at a time when the theory of metamorphism was not so generally accepted as it is to-day. Consequently, in the following pages we fully recognise the old conflict between gneiss and granite, and we also realise the hesitation

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[1] H. E. Johansson, Om Tunabergs kopparmalmsfält, Sveriges Geologiska Undersökning, Ser. C, no. 221.

with which an objective field geologist accepted the Neptunistic explanation of the gneissic rocks.

As evident granites Nathorst accepted only the coarser granites between Lakes Björnsjön and Stavsjön, the medium-grained granites between Lakes Gullvagnen and Skiren, and their continuation as a red aplitic granite S.W. and S. of Lake Gullvagnen, towards the Marmorbruket field. Granitic or more gneiss-granitic rocks N.W. of the valley between Lakes Björnsjön and Strålen were surveyed as »pinkish granite-gneiss» and »pinkish gneiss» respectively.

With reference to the »pinkish granite-gneiss», it seems to the author very probable that Nathorst has given it a special indication only with deference to the objectivity of the map. The description very clearly shows the granite character of the rock. »The texture is variable: sometimes medium-grained, sometimes fine-grained. The feldspar, orthoclase, seems to predominate and occurs as lengthened portions (crystals) of pinkish colour; the weathered surface is often whitish, possibly owing to the presence of oligoclase. On account of the presence of this mineral, it acquires some similarity to some of the granites in the area. The amount of the quartz is unimportant; its colour is light. The mica is dark, sometimes more abundant (in which case the rock is darker), sometimes more scarce (in which case the rock is lighter and generally similar to a granite). In the area W. of Lake Björnsjön the rock is quite similar to a granite. No stratifying is visible, and the mass is completely homogeneous.» The rock encloses numerous fragments, which extend in the same direction (W.N.W.—E.S.E.) as the schistosity of the granite-gneiss. This fact led Nathorst to doubt whether he was in the presence of a real granite. On the other hand, it cannot be considered to be a real gneiss, as the inclusions in several localities »continue neither downwards nor laterally; that is, their agreement with real inclusions seems to be complete». In other areas, the rock acquires a gneissic habitus, »even though the mica-flakes do not form any lengthened strips». Also in this rock we can observe the above-mentioned inclusions of fine-grained gneiss. One gneiss-inclusion presents very sharply foliated layers and is very similar to the banded gneiss at Krokek.

Over the whole Stavsjö sheet Nathorst distinguishes the »pinkish gneiss» into two varieties, »one often distinctly stratified, but never so evidently banded as the other». The other type occurs both N. and S. of Krokek and is »a pinkish well-banded gneiss. Its northern area lies between two granite areas to the E. of Engelsholm and extends from that place eastwards to Lake Stavsjön. The southern area includes all gneisses to the south of a line drawn from Lake Gullvagnen through Tranmossen to the north of Skilnan, the northern part of Lake Lövsjön, and further towards the south-east. On the other hand, it does not seem to occur to the west of the frequently mentioned valley from Lake Virlången to Bråviken Firth. This fact would indicate a fault along the valley.» The banded gneiss towards the boundaries of the »eurite» (an older term subsequently changed to »leptite») becomes very similar to it. »The banded appearance is caused by an alternation in structure and composition of unequal layers of unimportant thickness, generally only about one inch.

Some layers are composed of dark mica only, other layers again are very rich in feldspar and are more reddish, and yet others are more rich in quartz *etc.* A specimen of this gneiss (a layer rich in mica) from the east of Engelsholm has given:

SiO_2 . . . . 63.26 %.»

The above-mentioned type, the »pinkish gneiss», occurs in the present area mostly to the west of the Virlången-Bråviken valley. »In the more evidently stratified type, the mica-flakes present lengthened strips; in another type, which may correspond to the so-called iron-gneiss, it is only the fact that the mica-flakes are arranged in the same direction that indicates stratifying or schistosity. A specimen of such a gneiss from the west of Lake Strålen (in the parish of Krokek) contains:

SiO_2 . . . . 74.59 %.»

In some areas the »pinkish gneiss» becomes very similar to a granite, recalling the fine-grained (aplitic) granites. This is the case with the »pinkish gneiss» round Lake Fläten (N.W. of the present area). Sometimes, towards the contacts of the coarser granites, there occur layers of »augen-gneissic» habitus, which are very similar to the coarse-grained granites.

Among the granites of the Krokek-Stavsjö area Nathorst distinguishes some leading types. The coarsest type is that mentioned above between Lakes Björnsjön and Stavsjön. Towards the north-west it may pass over to the granite-gneiss; S.W. of Smedsbygget it changes into a hornblende-granite of darker colour containing a minor percentage of quartz[1]. »Towards the north the rock becomes more fine-grained; black schillerising mica is concentrated in rather thick *tabulae*, which occur as rather black and lengthened spots on the surface of the rock. In this matrix some twin crystals of feldspar are visible. Towards Halsbråten and Eskilstorp the rock becomes more fine-grained, similar to a diabase.

Determinations of silica in the different species of this rock have given the following results:

	$Si\,O_2$
Hornblende-granite from the southern-most outcrop	56.04 %
The rock with the black mica-tables	61.19 %
More fine-grained dioritic rock S. W. of Halsbråten	52.04 %
Still more fine-grained rock, similar to a diabase, S. E. of Eskilstorp . .	50.77 %»

The other granite type extends from Lake Gullvagnen to Lake Skiren. Its texture is medium-grained or fine-grained; the colour is reddish. As a result of weathering, the rock has acquired a whitish tinge like the coarse granite. A determination of silica in this rock (the specimen taken N. of Svartgöl) has given:

SiO_2 . . . . 72.42 %.

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[1] *Op. cit.*, p. 28.

The rock often presents a banded or schistose structure, thereby acquiring similarity to a gneiss. However, it presents sharp contacts to the pinkish banded gneiss and to a large extent brecciates it.

A third granite type is the fine-grained reddish granite which extends from the south-west of Lake Gullvagnen to Lakes Strålen and Böksjön. »It is often characterised by its deficiency in mica, a circumstance which makes it similar to a fine-grained pegmatite with a hard and polished, smooth surface. A specimen of this rock from a hill to the east of Torp» (towards the south-west of the present map) »contains:

SiO_2 . . . . 80.02 %.»

The rock is very similar to an »iron-gneiss», »and its extension as a continuation of the iron-gneiss-like rock from the west» (W. of Lake Strålen) »does not speak against the assumption that it is such a rock. On the other hand, however, the complete absence of stratification and inclusions indicates the rock to be a granite. In a hill W. of Skinnargärde» (in the Marmorbruket field S.W. of the present map)» there also occur dikes of a quite similar granite cutting a typical iron-gneiss».

In addition to the granites mentioned, Nathorst also describes granites occurring as dikes, which are in some respects similar to the coarse granite of the Stavsjö area. In their rounded feldspar eyes, other dikes show similarity to, or identity with, the leading granite of the Graversfors massive.

This, in its time, very outstanding description of a granite family was followed by another from the pen of A. E. Törnebohm[1], who — probably partly owing to its gneissic habitus — referred the family to the »urgranites», the oldest granites of the Archean in Sweden. In the generally two-mica-bearing granite of Stavsjö he saw an equivalence to the two-mica-bearing »urgranite» of Regna, in the northern part of the province of Östergötland. However, he also pointed out its character of »younger» urgranite.

Törnebohm made a microscopical examination of those hornblende-bearing granites mentioned by Nathorst and referred them to the gabbrodioritic rocks. The fine-grained type was composed of diallage, dark-pigmented plagioclase, some hypersthene, hornblende, dark mica, apatite, and magnetite. Törnebohm characterised the type as a fine-grained gabbro.

The opinion of Törnebohm[2] with reference to the age of the coarse two-mica-granite has been expressed subsequently by him. In Törnebohm's review of his »Explanation *etc.*» already cited, the rock is said to represent a group between the »urgranites» and younger granites. And in his explanation of the general petrological map of Sweden (1901, 1908), the coarse granite of Stavsjö is referred to the first granite group analogous to the frequently occurring »urgranites» of the north-western parts of the province of Östergötland. On the contrary, in the explanation of the map of Bergslagen, the Gravers-

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[1] Geologisk öfversiktskarta öfver Mellersta Sveriges Bergslag, Blad n:o 8, Beskrivning, pp. 20 and 39.

[2] Geologiska Föreningens i Stockholm Förhandlingar, vol. VI, p. 339.

fors granite was referred to the »Filipstad granite» group. On the other hand, the medium-grained granites were indicated as being granite-gneisses or »ur-granites».

Probably Törnebohm did not make very careful field investigations in the present area. Otherwise he certainly would at least have classified the coarse granite of the Stavsjö region as a »Filipstad granite» or a younger granite.

CHAPTER 2.

Classification of the Rocks and Petrological Description.

The present area is made up of two formations, widely separated with regard to their ages: first, the older Archean, composed of veined gneisses belonging to the »leptite-formation», and secondly, cutting these, the younger gabbro-granite series. They are both penetrated by some post-Archean dikes of diabase. With regard to texture and mineralogical composition, the older gneisses are for the most part uniform. The intrusives, again, are very variable.

The petrological classification of the rocks is set out in the following scheme:

I. Veined leptite gneisses.
II. Gabbro-granite series:
  A. Basic rocks:
    1. Noritic gabbro and its hornblende-bearing derivatives.
    2. Quartz-diorite.
  B. Granite-textured rocks:
    1. Quartz-syenitic granite and associated helsinkites.
    2. Hornblende-bearing granite.
    3. Medium-grained granites.
    4. Aplitic, salic granites.
    5. Coarse granites.
      a. Coarse two-mica granite.
      b. Coarse quartzy granite (»Graversfors granite»).
III. Diabase.

In order to accommodate the petrological description to the geological occurrence of the rocks, the author has not followed this classification exactly, and it consequently refers to the map. The divergence comprises chiefly groups B. 1. and B. 4., which occur partly more independently, associated with the medium-grained granites, or are more intimately connected with some small differentiates occurring as a boundary complex between the hornblende-bearing granite and the gabbros. In the latter case B. 1 and B. 4. are described under the heading »Boundary-rocks of the hornblende-bearing granite towards the basic rocks», (p. 37). In connection with the petrological description also, the mutual contact-relations between the different species of the intrusives are described. A summary of these relations, the contact-relations between the intrusives and the older Archean, and a description of the general tectonic-geognostical observations are reserved for a later chapter.

I. Veined Leptite Gneisses.

With regard to petrology and structure the leptite-formation of the Stavsjö area shows a variable character. Along the northern side of the Bråviken Firth there runs a sequence of very variable leptite strata, intercalated with crystalline limestones and iron-ores. All the leptites are very rich in potash, which is extremely concentrated in some sparsely occurring reddish potash-leptites. Probably this very persistent sequence constitutes an upper part of those strongly pegmatite-veined leptite gneisses which extend towards the north and east over considerable parts of the Stavsjö section.

Structurally the leptite gneisses are mostly veined gneisses, *i. e.* they are, down to the minutest parts, split into alternating micaceous bands and pegmatite or aplite veins. Intercalated in the veined gneisses there sometimes occur rather large, but generally very unimportant, layers of leptitic texture, which present very vague boundaries against the veined gneisses, and in the field-direction are often replaced by veined gneisses. The veined gneisses often contain bands of amphibolite, which have been divided by the stress.

The leptite gneisses of the area have not been submitted to a thorough petrological examination. A more detailed classification cannot be effected by field-work alone. Often there is to be observed a detailed alternation between gray micaceous gneisses, very sparsely veined, and more salic reddish veined gneisses, lined with innumerable veins of pegmatitic or aplitic composition. This material sometimes becomes predominant; in this case, the leptitic skeleton only reduces to micaceous lenses or bands rich in cordierite or sillimanite (cf. p. 56). On the other hand, when the pegmatite-aplite material sometimes occurs more sparsely, the rocks become more fine-grained, presenting real leptitic texture and boundary-zones, rich in mica, towards the pegmatite or aplite-veins.

Petrologically the leptite gneisses belong to the very little known or discussed variable leptite group which seems to occur widely in the provinces of Södermanland and Östergötland. They are mostly micaceous with a slight percentage of quartz and about equal percentages of microcline-perthite and plagioclase (generally oligoclase-andesine). Cordierite, sillimanite, and muscovite, are common. On microscopical examination the pegmatite-aplite material indicates a very variable granularity, ranging from pegmatitic to aplitic. The composition is strongly salic with an extremely small admixture of biotite. The feldspars are predominant, though the percentage of quartz is always important. The feldspars are acid and occur for the most part as equal amounts of a perthitic microcline and plagioclase (albite-oligoclase to oligoclase). Their respective amounts cannot be exactly determined by a geometric analysis (according to Rosiwal's method). A thorough knowledge of the chemical character of the vein-material consequently involves chemical analyses of larger specimens.

Without entering upon an exhaustive discussion of the origin of the veined leptite gneisses, it may be pointed out that the proportion of the vein-material evidently depends upon the chemical composition of the leptite. The presence of equal amounts of the microcline and plagioclase, together with a large percentage of mica and a not unimportant percentage of quartz, seems to favour a vein-structure. The predominance of one of the feldspars and small amounts of mica or a high percentage of quartz, on the other hand, seems to favour a conservation of the leptitic texture or to lead to a medium-grained or granulitic texture.

Towards the granite contacts the granularity of the veined gneisses grows coarser, and there also occurs a more distinct distribution of the pegmatitic material and of the micaceous leptite material. No increase in the quantity of the vein-material is observed. This is also the case with the leptite inclusions in the granites. These often also show a very large percentage of mica or occur as snarled leptite *residua*, which are rich in mica and are surrounded by zones of aplite or pegmatite. These are indistinctly separated from the granites. On the contrary, there are also inclusions of leptites showing a distinct contact against the surrounding granites, which cut their schistosity. In this case their composition usually differs from the average composition of the leptites.

In the inclusions of leptite gneisses there often occur bands or veins of amphibolite. When the leptites have changed into pegmatite and micaceous *residua*, these amphibolites often still remain in the form of lens-shaped remnants lying in lines. Here and there their origin is clear on account of some small attached leptite fragments.

In the granite types, which are chemically very different from the pegmatitic or aplitic material of the veined leptite gneisses, there are no difficulties in the way of distinguishing them from the gneisses. On reaching the aplitic granite, it is very difficult to distinguish them. Regarding the northern part of the area mapped (round the southern arm of Lake Virlången), the aplitic granites enclose very few fragments of leptitic material. In the southwestern part (N.W. and N. of Stubbetorp), however, there is an intimate alternation between aplite and veined leptite gneisses. Here a distinct contact between veined gneiss and aplitic granite cannot be drawn, because, on the one hand, aplite occurs intermingled with the gneiss, and on the other hand, the granite contains innumerable inclusions of leptite gneiss. Their aplitic or pegmatitic material is intimately incorporated with the granite and cannot be distinguished from it. In this part of the area mapped, the granite seems to have been diluted with material from the leptites. This dilution has probably not changed the composition of the granite much. The mixed rock, which sometimes is more homogeneous, is marked by the strong action of stress and consequently shows a gneissic habitus with lamellar quartz (*»quarz-feuilleté»* structure). It is not at all surprising that Nathorst has indicated this rock (W. of Lake Strålen and Stubbetorp) as a »pinkish gneiss». However, he points out its similarity to the fine-grained granites. A distinction between these rocks, whose gradually progressive differences are caused by the varying amounts of inclusions retained and by the increasing rock-deformation towards the western boundaries of the granites, seems to the author to be unjustified.

However, he wishes to point out that, owing to its strong intermingling of aplitic granite and leptite gneiss, the area N. of Lake Lilla Älgsjön requires a more careful survey than has been made, and therefore it has been left uncoloured on the map. The author has not been able to find time for the tedious work involved. In principle, however, it presents nothing beyond what has been indicated in this paper. The dikes of granite have been indicated on the map.

On a microscopical examination, the lenses of amphibolite which occur in the leptite gneisses present a very usual type. The chief minerals are plagioclase (andesine-labradorite) and common hornblende. Quartz and biotite are common. Among the accessories apatite and magnetite are usually found.

Geologically these rocks are obviously connected with the common amphibolitic layers of the area of Marmorbruket and the areas N. of that place[1]. Their age has not yet been determined. Probably they were intruded as sills in the leptite-formation before or at the same time as the latter was influenced by the orogenetic movements which have given their characteristic tectonics to the coast-lines of the provinces of Östergötland and Södermanland[2]. If this conception should be right, the amphibolites seem to be equivalent in some respects to the formation of metabasitic dikes which occur in the coast regions of South-Eastern Sweden, and in some areas might be allied with the gabbros which are supposed to be the fore-runners of the younger Archean granites. Accepting such a conception, the amphibolitic layers would in some degree correspond to the gabbros occurring in more intimate connection with the granites. It must be pointed out that there are some petrological similarities between the rocks mentioned, which favour such a conception. A fuller discussion of this interesting question must be reserved for a more regional description of the areas concerned.

II. The Gabbro-Granite Series.

A. BASIC ROCKS.

Basic rocks occur mostly in the southern part of the present area of eruptives. They also compose the northern parts of the complex of differentiates round the farms called Aspetorp and Kopparbolstorp. The rock-complex at Kopparbolstorp seems in some respects to represent a great inclusion in the younger, coarse granite. A small inclusion of amphibolised gabbro also occurs between two pools, St. Krankgölen and Skärgölen, in the western part of the area mapped.

Both from a petrographical and geological point of view, the basic rocks can be divided into two groups: noritic gabbro and quartz diorites. Amphibolised species of both groups are also met with.

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[1] B. Asklund, Om en kisförekomst bunden till grönsten från Krokeks socken i Östergötland, Geol. För. i Stockholm Förh., vol. 43, p. 403.

[2] B. Asklund, Några urbergstektoniska problem från Östergötland, *ibid.*, p. 596.

In the following pages, the author has referred to »Geol. För. i Stockholm Förhandlingar» as »G. F. F.». — The publications of Sveriges Geologiska Undersökning are indicated by »S. G. U.».

Noritic gabbro [1].

Fresh and perfectly unmetamorphosed gabbro is generally met with in the central parts of the southern area of basic rocks, *i. e.* between the farms called Halsbråten and Smedsbygget[2], and towards Eskilstorp. This area is fairly rich in outcrops of only a tolerably dense, grayish-green, noritic gabbro, similar to a diabase. Its lighter colour, as distinguished from the darker amphibolised gabbros, is due to the fresh pyroxenes. Even on a macroscopical examination a gabbro-diabase texture is visible. The rock is also characterised by its yellowish-brown weathering-surface, with white laths of plagioclase. Here and there the noritic gabbro shows parallel-epipedical jointing. This is the case with the rock S. of Eskilstorp, where it occurs as a cliff of five or six metres high. Here also bedding-joints are met with, dipping 30° W., and consequently indicating that the gabbro overlies the granite.

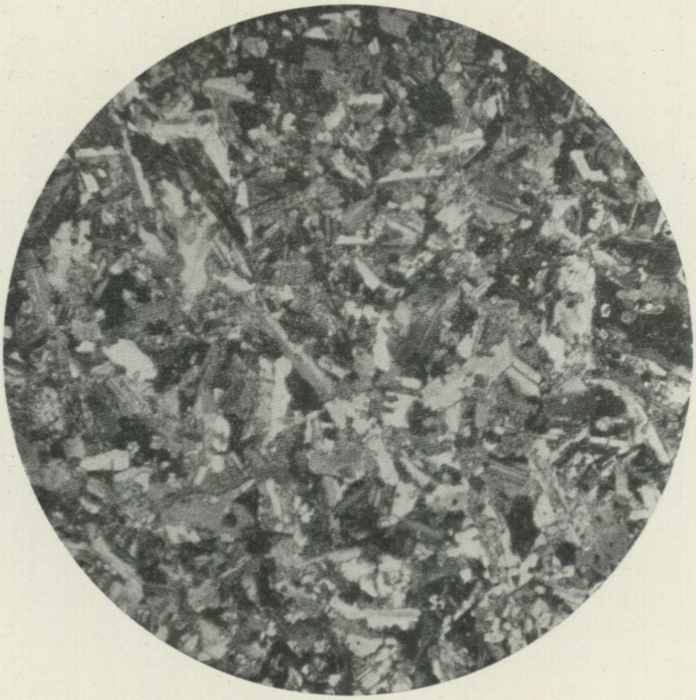

Fig. 1. Noritic gabbro, 600 m. S. of Eskilstorp. Microphoto., crossed nicols, × 16.

The noritic gabbro (fig. 1) is composed of orthorhombic and monoclinic pyroxenes, plagioclase (andesine-labradorite), biotite, and some microcline and quartz. Of accessory minerals there occur magnetite and apatite, both common. The orthorhombic pyroxene has a short prismatic habitus with

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[1] The author has used the term 'noritic' in order to lay stress upon the relatively high percentage of hypersthene. Cf. Rosenbusch, Elemente der Gesteinslehre, Dritte Auflage, Stuttgart, 1910, pp. 175 *etc.*

[2] As regards the situation of the farm called Smedsbygget, cf. »*Correction to the Map*», p. 122.

Fig. 2. Grains of hypersthene in the noritic gabbro. Microphoto., × 70. Shows the enclosed *lamellae* elongated parallel to c-axis and (001). Nicols ||. Gabbro 600 m. to the south of Eskilstorp.

rounded corners. The birefringence is low and the optical character negative, and consequently the mineral is a hypersthene. It is pleochroic, ranging from rose-tinted to colourless. The reddish tinge may be due to the occurrence of a dark brown mineral (fig. 2), which occurs as inclusions in the hypersthene. The inclusions consist of oblong *lamellae*, elongated parallel to the c-axis, or short *lamellae* following (001). Towards the centre of the hypersthene these *lamellae* sometimes become so abundant that they give the mineral a reddish-brown colour in transmitted light. The hypersthene is often surrounded by monoclinic pyroxene and also often contains small inclusions of the same mineral. Sometimes these inclusions are so frequent that an »antiperthitic» structure results. The border zones of monoclinic pyroxene present variable and undulous extinction up to 41°—44°, but often very small down to 12°—15°. The inclusions of monoclinic pyroxene clearly show smaller extinction-angles than common augite — about 30°. The author has not succeeded in determining these border zones and perthitic inclusions optically, but probably the present monoclinic pyroxene is a hypersthene-augitic[1] pyroxene. This assump-

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[1] In order to emphasize the relatively high percentage of ferrous iron in these minerals (cf. H. E. Johansson, Die eisenerzführende Formation von Grängesberg, G. F. F., vol. 32, p. 370), the author has, after H. E. Johansson, used the group-name »hypersthene-augite», instead of »enstatite-augite». W. Wahl, Die Enstatitaugite, Tschermaks Min. und Petrogr. Mittheil., 1907—1908.

tion is supported by the observation of pyroxene grains with smaller optic angles than those of common augites; in some cases the optic angle tends towards 0°. However, only one pyroxene grain with a small optic angle has been observed containing a kernel of orthorhombic pyroxene, and consequently it is uncertain whether the hypersthene-augites always occur as margins of the hypersthenes. But, on the other hand, there are indications (from the calculations of the rock analyses) that a not unimportant percentage of femic lime must enter into the composition of the hypersthenes and their margins. Some attempts at measuring the optic angle (according to the method of F. Becke: *camera lucida* and revolving drawing-table) were not successful, owing to the smallness of the pyroxene grains. The independent monoclinic pyroxene presents a more distinct relief and is pleochroic from pale rose-coloured to greenish tints. It also contains inclusions of the same dark brownish mineral which occurs in the hypersthene. The inclusions are not at all so common as in the hypersthene and are confined to the centre of the mineral. Diallage-cleavage is observed, and consequently the mineral is distinguished as a diallage-like greenish augite. $C : \gamma = 44°$.

The plagioclase generally forms fairly lengthened, divergent-radiating laths, giving rise to the diabase-texture of the rock. The plagioclase shows a fairly distinct zonary structure. The centre is occupied by a dark-pigmented labradorite ($Ab_{49}\,An_{51}$)[1] of tabular character. The labradorite is surrounded by an andesine ($Ab_{69}\,An_{31}$), and this zone also is bordered by a more acid plagioclase ($Ab_{75}\,An_{25}$). The andesine zone has caused the lengthened character of the plagioclase. The biotite occurs as tables or minor scales. Its contours are irregular, fimbriated, and notched. The mineral is beautifully pleochroic from pale yellow to dark reddish-brown. It usually contains inclusions of small pyroxene grains or apatite prisms and magnetite grains. Sometimes also a much darker biotite forms reaction rims round small, free magnetite grains. On the boundaries between the biotite and pyroxene there often occur myrmekite-like margins of thin quartz spindles in the biotite. The biotite has often grown into the plagioclase and microcline, and also in these cases myrmekitic margins occur in the boundaries of both minerals. Microcline and quartz are common as allotriomorphic fillings. The accessory minerals, apatite and magnetite, occur as prisms and grains, generally included in the biotite or in quartz and microcline.

»Phenocrysts» and veins in the noritic gabbro. Here and there, there occur, rare, rather large, phenocryst-like plagioclases in the norite. The composition of the plagioclase is about $Ab_{70}\,An_{30}$, and is thus considerably poorer in anorthite than the centres of the main plagioclase of the gabbro. As distinguished from these, the larger plagioclases often contain a multitude of small rounded pyroxene grains, zonally arranged towards the margins of the plagioclase. Very characteristic is also the antiperthitic structure, the »phenocrysts» pre-

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[1] All plagioclase measurements are taken on sections perpendicular to P and M, and the chemical proportions are calculated according to the extinction-angle curve of F. Becke (Denkschrift. der k. Akad. d. Wiss., Math.-Naturw. Klasse, vol. 75, I, p. 106).

senting a patchy structure, due to the occurrence of irregular spots of microcline. The plagioclase substance also seems to be inhomogeneous in polarised light, with lighter and darker spots. No zonal structure is to be observed. The composition of different individuals is similar. By Rosiwal's method it has been calculated to be $An_{24}\,Ab_{56}\,Or_{20}$.

Here and there, these pseudo-phenocrysts show graphic intergrowths with quartz towards their margins. Often one and the same quartz individual which is intergrown with plagioclase also presents a graphic intergrowth with microcline, which occurs in connection with the pseudo-phenocrysts. Sometimes these pegmatitic growths are fairly large. In that case they are to be macroscopically recognised as small pegmatitic streaks, one or two inches long.

Rock-texture and chemical character. The rock tends to both a gabbro-like and a diabase-like texture. Analogously to the gabbros, the pyroxenes crystallised earlier than the more acid plagioclase; they never constitute a filling between the plagioclase laths. The pyroxenes occur as a multitude of small, often rather idiomorphic, grains. A radiating arrangement of small centres of hypersthene prisms is sometimes to be seen. The textural similarities to a diabase are caused by the plagioclase laths and their mutual intergrowth into radiating clusters, among which quartz and microcline form crystallisation remains.

The chemical character of the rock is shown by the following analysis and calculations:

Table 1. Analysis of typical *quartz-biotite norite* (anal. N. Sahlbom). The specimen was taken 600 metres S. of Eskilstorp, in the parish of Kila, in the province of Södermanland. Specific gravity (determined by Dr. A. Bygdén) 2.932.

	Molecular proportions[1]	Norm	Actual Composition (Weight %)	Volumetric Composition
SiO_2 . 52.79	880	Or . 8.90	Quartz 2.53	Quartz 2.8
TiO_2 . 1.12	14	Ab . 26.20	Microcline · . . 1.39	Microcline 1.6
Al_2O_3 . 13.79	135	An . 19.18	Plagioclase 42.66	Plagioclase 46.8
Fe_2O_3 . 1.91	12	Σ sal 54.28	(An_{51} Ab_{49} 19.53	(An_{51} Ab_{49} 21.2
FeO . . 8.13	113		An_{31} Ab_{69} 19.17	An_{31} Ab_{69} 21.2
MnO . 0.09	1		An_{25} Ab_{75} . . . . 3.96)	An_{25} Ab_{75} . . . . . 4.4)
MgO . 8.34	209	Di . 18.48	Σ sal 46.58	Σ sal 51.2
CaO . 8.84	158	Hy . 16.31	Hypersthene + Hypersthene-augite . 27.09	Hypersthene + Hypersthene augite . . . 23.7
Na_2O . 3.12	50	Ol . 5.26	Diallage-like augite 18.24	Diallage-like augite . 16.4
K_2O . 1.48	16	Mt . 2.78	Biotite 6.57	Biotite 6.4
P_2O_5 . 0.29	2	Il . . 2.13	Magnetite 3.19	Magnetite 1.8
$H_2O+105°$ 0.20		Ap . 0.67	Apatite 0.54	Apatite 0.5
		Σ fem 45.63	Σ fem 55.63	Σ fem 48.8
$H_2O-105°$ 0.12		H_2O . 0.32		
100.22		100.23	102.21	100.0

Calculated sp. gr. 3.001.

An : Or : Ab = 34.5 : 16.0 : 49.5 MgO : CaO : FeO = 55.1 : 21.6 : 23.3.

Quantitative system: Camptonose.

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[1] According to H. S. Washington, Chemical Analyses of Igneous Rocks, U. S. Geol. Surv., Prof. Pap., 99, 1917.

In order to arrive at a comparison between the norm and the actual composition after Rosiwal's method, the measured volumetric composition of the rock and the following specific gravities of its minerals have been the basis of the calculation.

The norite	2.932 (A. Bygdén).
Quartz	2.65 [1]
Microcline	2.55 [1]
Labradorite	2.70 [1]
Andesine	2.65 [1]
Oligoclase	2.64 [1]
Biotite	3.01 [1]
Magnetite	5.20 [1]
Apatite	3.16 [1]
Hypersthene	3.35 (Un. States Geol. Surv. Bull., no. 28, p. 23).
Diallage-like augite	3.26 (» » » » » », p. 21).

The specific gravities of the hypersthene and the diallage-like augite have been supposed to be the same as the specific gravities of the isolated pyroxenes from a hypersthene-gabbro from Gwynn's Fall, Baltimore, described by G. H. Williams. With regard to the $MgSiO_3 : FeSiO_3$ proportions, the minerals in question correspond closely to the mean of the same proportions that can be calculated from the Stavsjö norite. These similarities are clearly set forth in the following table, where the mentioned proportions are expressed as a comparison with the calculated proportions of the Stavsjö norite. In the calculation of these proportions FeO equal to TiO_2 and Fe_2O_3 are allotted for ilmenite and magnetite, according to the norm calculation.

Composition of the pyroxenes from gabbro, Gwynn's Fall.							Molecular proportions.	
SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Sum		MgO : FeO
52.12	1.69	20.94	—	21.56	3.20	99.51	Hypersthene . .	65 : 35
51.414	4.323	9.307	0.043	15.138	20.600	100.825	Augite	75 : 25
							(Stavsjö norite .	70 : 30)

In order to obtain a general view of the crystallisation, based upon the molecular proportions from the geometric analysis, the author has made some attempts to illustrate the displacements of the molecular proportions of the magmatic phase during the gradual separation of the different minerals. For that purpose, the course of the crystallisation of the feldspars and the pyroxenes, which are fairly independent of each other, have been plotted into different triangle diagrams, illustrating the crystallisation of the components of each group.

Hornblende-bearing derivatives of the noritic gabbro. Towards the sharper boundaries between the norite and the granites (*e. g.* in the neighbourhood of

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[1] According to Rosenbusch and Wülfing, Mikr. Physiographie der petr. wicht. Mineral., I: 1, pp. 49—50. Stuttgart 1904.

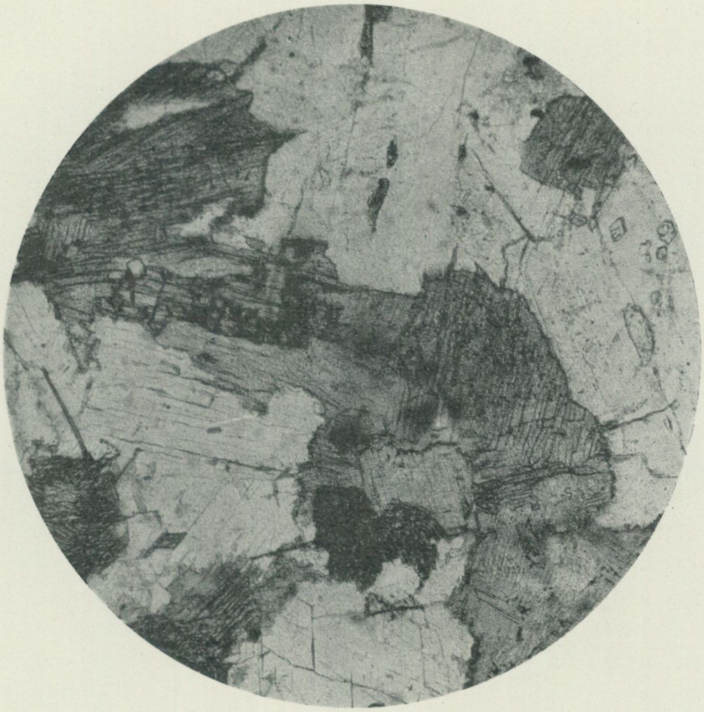

Fig. 3. Noritic gabbro changing to a cummingtonite-bearing amphibolite. To the left there occurs a remnant of hypersthene surrounded by a pale amphibole, cummingtonite. The green amphibole is darker. Microphoto., × 35. Nicols ||. — The specimen was taken at the granite-contact to the west of Smedsbygget.

Smedsbygget), and also towards the quartz-diorites, the norite changes into a hornblende-bearing gabbro, texturally very similar to the above-described quartz-biotite norite and evidently a metamorphic phase of this rock. Possibly the original norite may here have been somewhat richer in hypersthene than the central type.

The appearance of the hornblende in varying amounts may be studied from a slightly hornblende-bearing gabbro of the central type down to a real hornblende-gabbro. The hornblende grows into the pyroxenes from their margins. The diallage-like augite seems to change directly into a common, dirty-greenish amphibolite hornblende. The change in the hypersthene is of a very different character. Next to the remnants of hypersthene there occurs an often rather broad zone of colourless or pale greenish amphibole, which, towards its margins, changes into a regular or mottled green hornblende. The pale amphibole presents a high birefringence, is optically positive, and also shows repeated cleavage parallel to (001). Evidently this pale amphibole is a cummingtonite originating from the hypersthene[1] (fig. 3).

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[1] Such an alteration of a hypersthene to a pale amphibole has been described by G. H. Williams (The Gabbros and Associated Hornblende Rocks Occurring in the Neighbourhood of Baltimore, Bull. of U. S. Geol. Survey, no. 28, pp. 42 *etc.*). In a typical norite Williams

When the alteration is more advanced, the pyroxenes completely disappear. The diabasic texture is still preserved. The plagioclases retain their lengthened type and are still arranged in radiating clusters. However, the green hornblendes are usually grown into the margins of the plagioclase, and its straight limits have disappeared. The hornblende individuals are mainly studded with small quartz grains or small vermicular quartz aggregates, often very thin. This intergrowing structure clearly recalls myrmekite (fig. 4)[1].

In contrast to the main norite, the plagioclase of the present gabbro is much poorer in anorthite and presents a rather variable composition. A mean value may be expressed in the composition $Ab_{70}\,An_{30}$ (the mean of the analysed norite being $Ab_{63}\,An_{37}$).

For the interpretation of the hornblende-myrmekite this lower anorthite-percentage of the plagioclase is very important. Assuming that the chemical composition of the present hornblende-gabbro is very similar to that of the fresh norite (as indicated both by geological appearance and microscopical examination), the difference between the metasilicatic proportions of the rock and the same proportions of common amphibolite hornblendes (this comparison is shown by a diagram [fig. 5] constructed in the following way: the metasilicatic proportions of the norm, expressed in molecular proportions, are represented by 100 and plotted in the diagram, and analogously the metasilicatic proportions of the hornblendes are plotted, without, however, allotting any FeO and CaO for normative magnetite, ilmenite or anorthite [or, in this case, $CaO\,.\,Al_2O_3\,.\,SiO_2$]) is very striking. The lime-percentage of the common

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has found that the diallage changes directly into a common hornblende. The hypersthene, on the other hand, alters into pale fibrous amphibole, which only changes to a common greenish hornblende towards the boundaries of plagioclase. Similar alterations of pale amphibole have also been described by A. E. Törnebohm, who, in the hyperite from Ölme (in the province of Värmland), has found olivines whose margins have been altered to a colourless amphibole (probably a tremolite, according to Törnebohm), which tends towards the boundaries to a green hornblende (A. E. Törnebohm, Die wichtigeren Diabas- und Gabbrogesteine Schwedens. Neues Jahrbuch für Min., Geol. und Palaeontol., 1877, p. 384). The author has examined Törnebohm's thin sections and has found the colourless amphibole to be a cummingtonite, optically positive. A similar amphibole originating from olivine has also been described by F. Becke (Die Gneissformation des niederösterreichischen Waldviertels, Tschermaks Min. u. Petr. Mittheil., vol. IV, 1881—1882. And *ibid.*, p. 450, Hornblende und Anthyphyllit nach Olivin). In an olivine-gabbro from Loisberge, Waldviertel, the olivine is surrounded by a zone of a colourless mineral with oblique extinction, possibly an amphibole. More amphibolitic species of the olivine-gabbro present large quantities of this mineral, here yellowish-green needles, which behave like a tremolite. In gabbro boulders from Rosswein the olivine is surrounded by an inner brownish zone of anthophyllite and an external zone of pale greenish hornblende recalling the greenish hornblende (smaragdite) which occurs in amphibolites from Waldviertel.

Alteration of enstatite into a pale talc-like mineral is mentioned by Fr. Eichstädt (Pyroxen- och amfibolförande bergarter från Mellersta och Östra Småland, Bihang till K. Sv. Vet.-Akad. Handlingar, vol. 11, no. 14, p. 26). The enstatite of the gabbros mentioned from the province of Småland alters into strongly polarising, bladed aggregates, which can only with difficulty be determined optically. According to Eichstädt they present oblique extinction.

Recently H. Väyrynen has described an alteration of hypersthene into cummingtonite (Bull. Comm. Géol. de Finlande, no. 57, p. 25, 1923).

The author has quoted this series of alterations of enstatite-hypersthene and olivine in order to call attention to a more thorough examination of the alteration-products composed of varying amphiboles. From a theoretical point of view, there are indications that the abovementioned ferro-magnesian minerals alter more directly into ferro-magnesian amphiboles, which in reaction with lime-bearing minerals (plagioclase) gradually change into lime-bearing hornblendes (*vide* the subsequent discussion).

[1] This structure has also been described by Williams, *op. cit.*, p. 28.

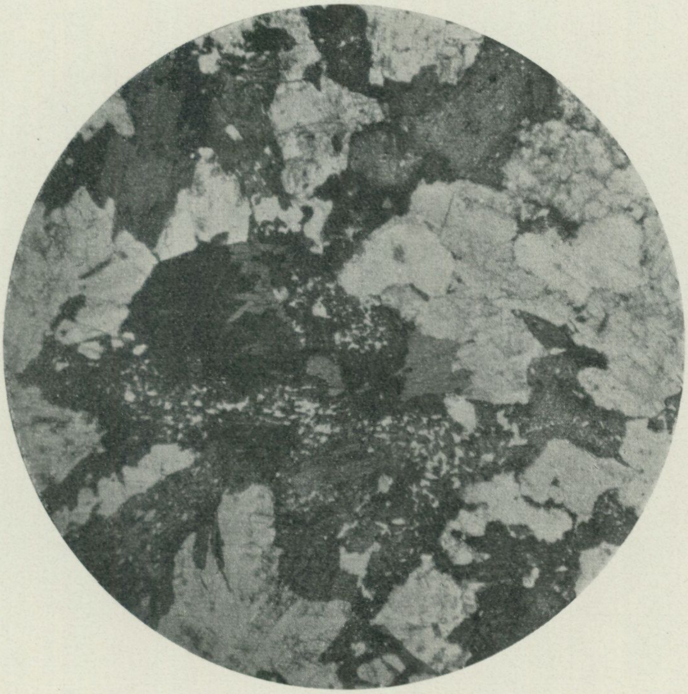

Fig. 4. Amphibolite derived from noritic gabbro. The hornblende individuals are studded with small quartz grains (»hornblende-myrmekite»). Microphoto., × 35. Nicols ||. The specimen was taken about 300 m. to the south-east of Halsbråten.

amphibolite hornblendes is much higher than the femic lime-percentage of the fresh norite. Consequently there are indications that, when the pyroxene-building components of the magma are changing into a common amphibolite hornblende, they must acquire a contribution of $CaSiO_3$ in relation to the original $Mg\,Si\,O_3 - FeSiO_3$ percentage. This contribution of $CaSiO_3$ can only be obtained by a release of anorthite from the plagioclase, which consequently must show a lower anorthite-percentage after the alteration has proceeded. The breaking-up of anorthite to form hornblende together with pyroxene-forming proportions of the magma may be well expressed thus:

Pyroxene-bearing norite $\longrightarrow$ Amphibolite

$(CaO,\ MgO,\ FeO)\ SiO_2 + CaO\ .\ Al_2O_3\ .\ 2\ SiO_2 = [(CaO,\ MgO,\ FeO)\ SiO_2\ +$

Pyroxenes + Anorthite $\longrightarrow$ Hornblende

$+\ CaO\ .\ SiO_2 + Al_2O_3] + SiO_2$

\+ Quartz

As there is nothing to indicate that the amphibolite hornblendes are more siliceous than required for metasilicatic proportions (naturally there are also indications, however, that Na_2O may have entered as glaucophane molecules, and consequently the arguments here set forth only refer to the Ca — Mg — Fe-silicates), we see that, at the same time as the breaking-up of anorthite ($CaO\ .\ Al_2O_3\ .\ 2\ SiO_2$) to form hornblende happened, one molecule of SiO_2 for

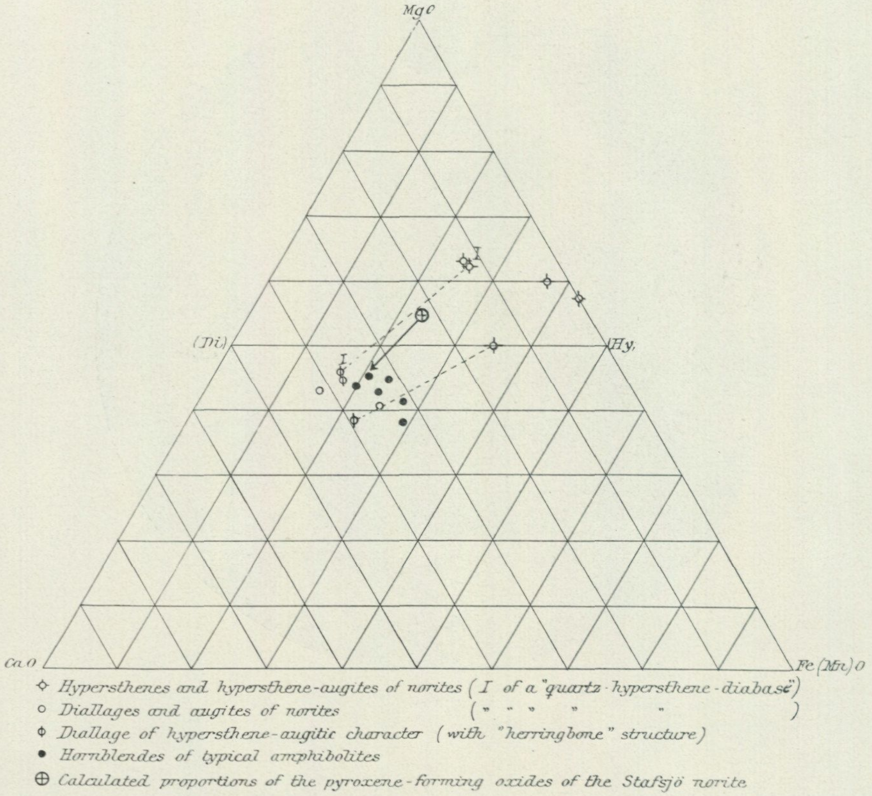

Fig. 5. Proportions of metasilicatic minerals from noritic rocks and common amphibolites. The arrow indicates the addition of anorthite-molecules to the metasilicatic proportions of the Stavsjö norite during its change into an amphibolite.

every molecule of hornblende was set free. Probably the alteration may be interpreted as a reaction proceeding in solid phase. During the course of this reaction, the quartz had been set free within the hornblende. It is in this way that the hornblende-myrmekite seems to have arisen. Such an intergrowth has also been described by G. H. Williams, whose illustrations are very similar to those of the present rock (cf. *op. cit.*).

Since the percentage of intergrown quartz seems to be too high, there are also reasons for thinking that albite has been broken up in the same way. In the case of an analogous breaking-up of alkalifeldspar, the percentage of quartz set free must be considerably higher (albite = $Na_2O . Al_2O_3 . 6 SiO_2$).

In reality, the formation of quartz only comes about through the reaction between plagioclases and hypersthenes; the augite changes into hornblende more directly. In the case of a more intensive granulation of such a changing rock, there certainly will exist »equalisation-reactions»[1] between the amphi-

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[1] In order to express the German term »Ausgleichungs-reaktionen» the present author has ventured to use »equalisation-reactions».

boles originating in different ways, and consequently in real amphibolites there occur homogeneous amphiboles whose origin may often be as complicated as that sketched above.

It must be pointed out that an alteration of a pyroxene-bearing gabbro to an amphibolite, as just described, has also been explained in an analogous way by P. Eskola[1]. This author, however, attaches the chief importance to the equilibrium-reactions between the orthorhombic and monoclinic pyroxenes, together forming a hornblende, as expressed by the following equation:

$$2\ RSiO_3 + RCaSi_2O_6 = R_3CaSi_4O_{12}.$$

And by the following equation he expresses that »if more aluminous amphiboles are formed, considerable amounts of anorthite must be destroyed, and the remaining plagioclase must be more albitic»,

$$9\ RSiO_3 + 3\ CaAl_2Si_2O_8 = R_3CaAl_6Si_4O_{21} + 2\ R_3CaSi_4O_{12} + 3\ SiO_2.$$

However, there are indications afforded by many hornblende analyses — and especially by those showing much alumina — that the ratio just quoted (MgO, FeO) : CaO'' (femic lime) = 3 : 1 is essentially exceeded in favour of CaO. Also the amphibolite hornblendes in question show ratios that are most nearly comparable to an augite. Consequently, differing from Eskola, the author states that also rocks with the femic ratio (MgO, FeO) : CaO = 3 : 1, and even with higher CaO-content, must show a breaking-up of plagioclase in forming hornblende. The present norite with (MgO, FeO) : CaO = 78.4 : 21.6 (or nearly 3 : 1) vindicates such a statement.

From this discussion it will be clear that chemical alterations mostly affect the hypersthenes and plagioclases. As already found by Williams, however, the augite changes into hornblende directly.

This destruction of plagioclase, evidently passing on in solid phase, will be exactly similar to the magmatic breaking-up of anorthite, which gives the pyroxenes their Al_2O_3-percentage (cf. p. 69). Both reactions result in the setting free of small quantities of quartz. They must be considered to be an essential explanation of the appearance of rocks with small quantities of quartz, though their norms indicate the occurrence of olivine.

Hornblende-bearing and cummingtonite-bearing gabbro from the western part of the area mapped. E. of the little pool of Skärgölen there occurs a small area of hornblende-bearing gabbro showing some similarities to the hornblende-bearing gabbro just described. Microscopically the rock shows some similarity to a diabase, owing to its lath-shaped plagioclases and richness in interstitial hornblende.

Under the microscope there appear remnants of a hypersthene-augite-like pyroxene, very similar to the hypersthene-augite described later on from some quartz-diorites. The mineral shows a repeated cleavage parallel to (001) and is pale greenish, tinged with brown. It often presents the characteristic »herring-

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[1] On the Petrology of the Orijärvi Region in South-Western Finland, Bull. Comm. Géol. Finl., no. 40, pp. 121 *etc.*

bone» structure (cf. p. 24) emerging from the polysynthetic twinning parallel to (100) and (001). In order to obtain a more thorough knowledge of the mineral, the refractive indices were determined by the immersion method. The indices are:

$$\gamma_{Na} = 1.748$$
$$\beta = 1.719 — 1.720$$
$$\alpha = 1.719\ (1.7185)$$

From these values 2V is calculated to be 0°—26°. In the thin sections of the rock no sections perpendicular to the acute bisectrice were observed. In the powder used for measuring the refractive indices, however, several observations of such sections were made, and here the optic axial angle was measured to be 0° or very small. A maximum value was measured according to Becke's method (*camera lucida* and revolving drawing-table) : $2\,E = 60°$, and 2V about 34°. $C : \gamma$ was observed to be about 42°. Some efforts to isolate this very interesting hypersthene-augite for chemical investigation were unsuccessful, owing to the similar specific gravities of the amphiboles and the very intimate association with these minerals. The hypersthene-augite is strongly altered to fibrous or bladed amphiboles as spots of brown-greenish or very pale yellow-greenish colour. Towards the boundaries of the original hypersthene-augite, the fibrous aggregates change into regular crystallised hornblendes, made up of intergrowths of a pale cummingtonite and a brownish-green common hornblende. Those intergrowths occupy the greatest volume of the femic minerals.

The cummingtonite shows $c : \gamma = 18°$. The birefringence is higher than that of the brownish hornblende : $\gamma - \alpha$ about 0.030. The optic character is negative. Cleavage parallel to (001) is observed, but it is not very distinct. In order to find the composition of the cummingtonite, its refractive indices were determined by the immersion method as:

$$\gamma_{Na} = 1.687$$
$$\alpha = 1.659$$

According to the elaborate scheme for a discrimination of the various cummingtonites given by Sundius[1], the mineral is found to have a composition of about $(MgSiO_3)_{40}\ [Fe(Mn)SiO_3]_{60}$ — thus a cummintonite quite rich in ferrous iron.

The common hornblende is distinctly pleochroic with α dirty green and β and γ greenish, with an olive-brown tint. $C : \gamma$ about 22°. Twinning parallel to (100) is common, and cleavage (001) is observed. Reddish-brown biotite is rather common; generally it is bleached round small spindles of a mineral with high birefringence, occurring as alteration-products arranged parallel to the cleavages (prehnite?).

The plagioclase is rather acid (An_{28-30}) and shows some alteration into saussuritic products. Also under the microscope it shows a lath-like habitus, and

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[1] N. Sundius, Zur Kenntnis der monoklinen Ca-armen Amphibole (Grünerit-Cummingtonite-Reihe), Geol. För. i Stockholm Förhandlingar, vol. 46, 1924, p. 154.

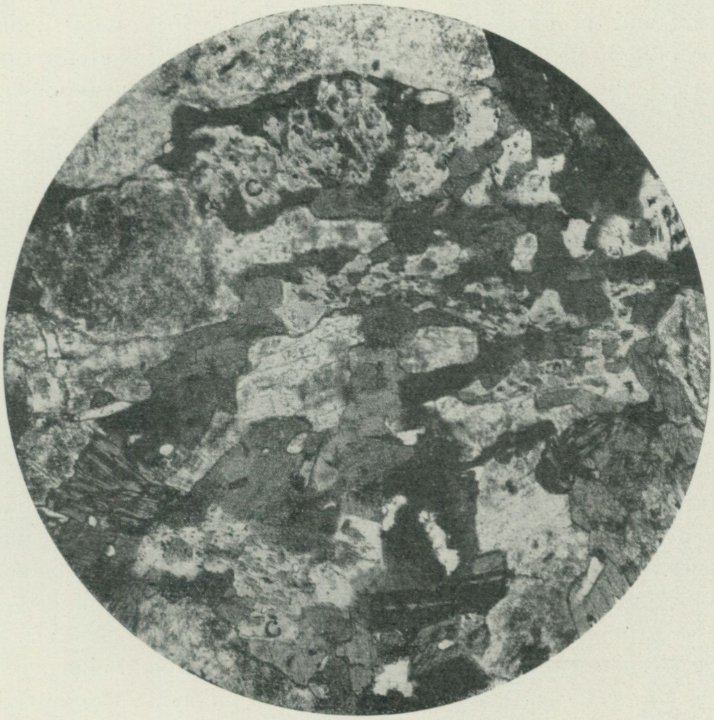

Fig. 6. Cummingtonite-bearing gabbro, from the east of Skärgölen. C indicates the cummingtonites with flecks of brownish-green hornblende. Some bleached micas are to be observed. Microphoto., × 35. Nicols ||.

to some extent it is arranged into divergent clusters. Interstitial quartz is common. As regards accessories, quantities of apatite and some leucoxenic titanite are observed. Calcite also occurs sparsely.

In mineralogical composition the rock shows some similarities to a cummingtonite-amphibolite which occurs to the south of the area mapped, in connection with a small occurrence of chalcopyritic pyrrhotite[1].

In the present hypersthene-augite-bearing cummingtonite-gabbro we meet with a new type of the altered basic rocks of the area. As distinguished from the above-mentioned amphibolitic gabbros (which, from a fresh norite, pass over to cummingtonite-bearing altered norites and gradually change into an amphibolite, with only common hornblende indicating the equilibrium of the alteration and metamorphic diffusion), this cummingtonite-bearing gabbro tends to an equilibrium, marked by intergrowths of cummingtonite and common hornblende. This amphibolite type is not uncommon in the Fenno-Scandia Archean. It seems to have been first described by A. E. Törnebohm[2]. Later on H. E. Johansson called attention to such rocks from the

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[1] B. Asklund, Om en kisförekomst bunden till grönsten från Krokeks socken i Östergötland, G. F. F., vol. 43, p. 403.

[2] Om Falu grufvas geologi, G. F. F., vol. 15, pp. 635 *etc.*

Grängesberg and the Flogberget ore-fields[1]. Also in these rocks, »clinoanthophyllite-amphibolites», common hornblende and cummingtonite occur as intergrowths. Subsequently cummingtonite-amphibolites were described by P. Eskola[2], P. A. Geijer[3], and the present author (*vide* p. 27).

Regarding the interpretations of the cummingtonite-amphibolites, Johansson explains them as differentiated members of an amphibolite-series which is distinctly marked by its »abnormative» mineralogical composition. Törnebohm, Eskola, and Geijer, state that the forming of cummingtonite must be due to metamorphic processes. The last two authors claim the »cummingtonitisation» to be due a metasomatic replacement of lime by iron oxides and magnesia.

In order to get an explanation of those femic proportions which may predispose to the forming of cummingtonite, we must make a rather extensive petro-chemical excursion.

First of all, it is necessary to get an approximate knowledge of the chemical composition of the hypersthene-augite. Since W. Wahl published his elaborate study of the enstatite-augites, there have been added several new optical observations as regards that very interesting mineral-group (especially the studies of H. Backlund[4] and H. Michel[5]). However, as far as is known by the author, only one new natural hypersthene-augite has been subjected to chemical investigations side by side with the optical measurements, *viz.* the very interesting hypersthene-augite from a »glassy rock» from Beinn an Lochain, Pennygael, Mull, Scotland[6], described by A. F. Hallimond. An augite ($2V = 51^\circ$) from an augite-andesite described by Z. Starzynski may also be classified among the hypersthene-augites. From the, at present, very scanty knowledge of the augites poor in CaO, efforts have been made by the present author to construct a determination-scheme, which obviously is still quite provisional. As regards the clinoenstatite-diopside series, the elaborate study of the artificial pyroxenes given by N. L. Bowen is used. Starting from the very remarkable fact, found by W. Wahl, that the small optic axial angles characterise as well some magnesia as some iron-rich members of the series, it is not enough to use the axial angles for determination. However, experience shows there are also great variations of the refractive indices of the enstatite-augites (these being higher for the iron-rich members), and using both these criteria we may get a knowledge, still approximate however, of the chemical compositions from the optical investigations[7]. The method of plotting the present diagram (fig. 7)

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[1] Die eisenerzführende Formation von Grängesberg, and, The Flogberget iron mines. G. F. F., vol. 32, 1, pp. 313 and 416.

[2] Orijärvi Region, p. 221 (*vide* p. 25).

[3] Per Geijer, Falutraktens berggrund och malmfyndigheter. — Zusammenfassung in deutscher Sprache, S. G. U., Ser. C, no. 275, pp. 127 *etc.* and 314.

[4] Über einige Diabase aus arktischem Gebiet, Tscherm. Min. u. Petr. Mitth., 26, 1907—08, p. 357.

[5] Zur Kenntnis der Pyroxene der Meteoriten, Ann. d. k. k. Naturhist. Hofmuseums, 27, 1913.

[6] Geol. Surv. Great Brit., Summary Progress 1913, p. 81, and A. F. Hallimond, Optically uniaxial Augite from Mull, Min. Magazine, 17, 1913—16, p. 97.

[7] In a work recently published, A. N. Winchell has drawn several determination-schemes as regards the pyroxene group. However, Winchell's scheme for the hypersthene-augites, owing

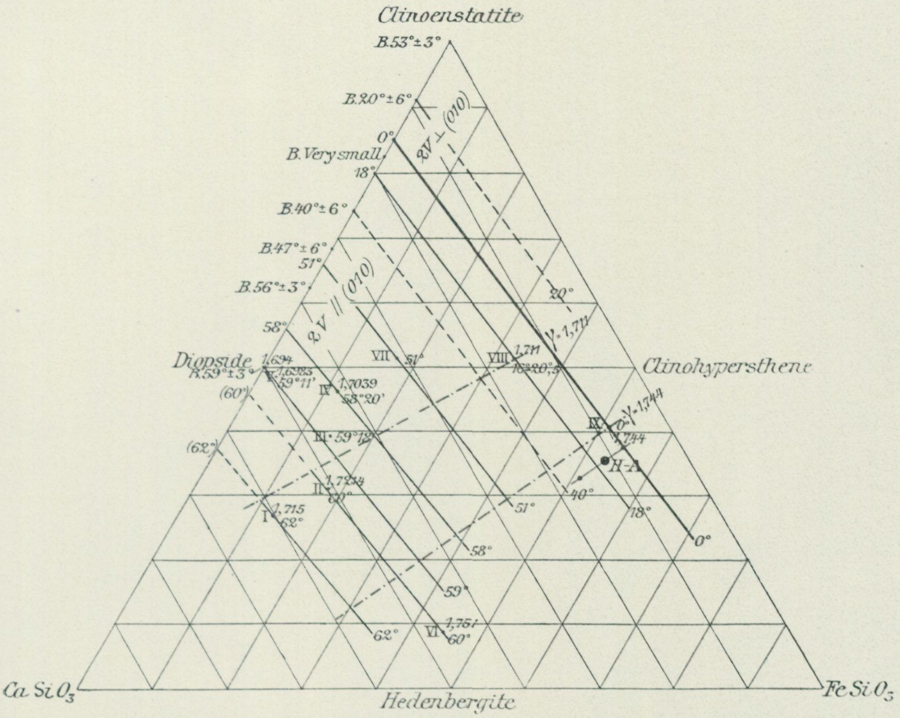

Fig. 7. Provisional determination-scheme for monoclinic pyroxenes.

H—A indicates the composition of the hypersthene-augite from the Skärgölen gabbro. For the discrimination of the varying pyroxenes 2 V and γ have been entered. The broken and dotted straight lines indicate $\gamma = 1.711$ and 1.744.

The material optically investigated is the following:

B. Synthetic pyroxenes by N. L. Bowen, Am. Journ. of Science, 4th Ser., 1914, p. 250.
I. Diopside from the limestone, Mansjön. H. v. Eckermann, G. F. F., 44, p. 353.
II. Black diopside, Pargas. A. Laitakari, Bull. Comm. Géol. Finlande, no. 54, p. 46.
III. Diopside, Type II Nordmarken. G. Flink, Zeitschrift für Krystallographie, XI, p. 463.
IV. Diopside (»Mansjöite»). H. v. Eckermann, G. F. F., 44, p. 355.
V. Diopside, Montreal chrome pit. E. Poitevin and R. P. D. Graham, Canada. Dep. of Mines, Geol. Surv. Museum Bull., no. 27, p. 41.
VI. Hedenbergite, Tunaberg. E. A. Wülfing, Beiträge zur Kenntnis der Pyroxenfamilie, Hab.-Schrift, Heidelberg, 1891, pp. 33 and 48.
VII. Augite from Andesite, Bering Island. Z. Starzynski, Bull. Int. de l'Acad. des Sciences de Cracovie, 1912, no. 7A, p. 666.
VIII. Enstatite-augite, Föglö. W. Wahl, Tscherm. Min. Petr. Mitth., 26, p. 16.
IX. Uniaxial augite, Mull. Mineralogical Magazine, 17, p. 97.

of the principal components is exhaustively discussed later on. For the present, it need only be mentioned that the molecular proportions of the total $MgSiO_3$, $FeSiO_3$, and $CaSiO_3$, are represented by 100 and plotted into a triangle-diagram. Here the author has only chosen some very representative and optically thoroughly investigated material of monoclinic pyroxenes. The optical variables of the diagram are 2V, and the highest refractive index (γ), two functions whose projection-lines for the same values cut one another.

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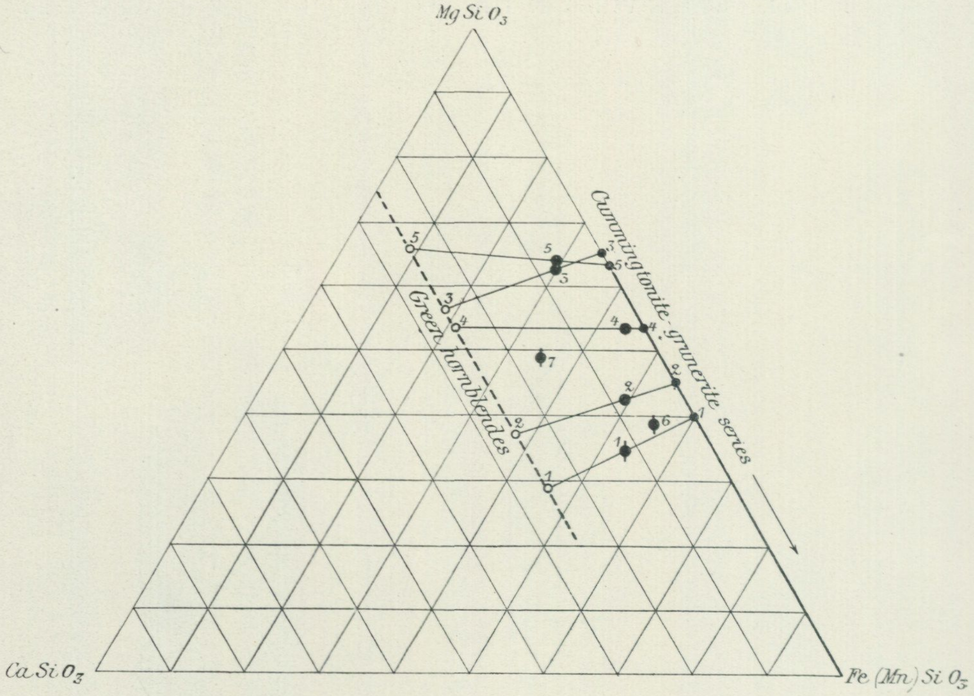
to its complex character, does not seem to be favourable. Also the material plotted on the diagram seems to be too scanty. — A. N. Winchell, Studies in the Pyroxene Group, Am. Journ. of Science, 5th Ser. 6, 1923, p. 504.



Large filled circles = metasilicatic proportions of the rocks.
Small filled circles = » » of the cummingtonites.
Open circles = indicated green hornblendes.

Fig. 8. Diagram showing the chemical proportions of cummingtonite-bearing amphibolites and hypersthene-augite-bearing basic rocks. The material entered in the diagram is the following:

1. Cummingtonite-bearing gabbro, Skärgölen. Hypersthene-augite $(Mg\ SiO_3)_{35}$ $(Ca\ SiO_3)_{12}$ $(Fe\ SiO_3)_{53}$. Cummingtonite $(Mg\ SiO_3)_{40}$ $(Fe\ SiO_3)_{60}$, according to Sundius.

2. Cummingtonite-amphibolite, Flogberget, hanging wall of Mine I. H. E. Johansson, The Flogberget iron mines, G. F. F., vol. 32, part I, 1910, p. 414. Metasilicatic ratios of the rock MgO : CaO : FeO = 42.6 : 7.7 : 49.7. Cummingtonite: $(Mg\ SiO_3)_{45}$ $(Fe\ SiO_3)_{55}$; $\alpha = 1.653$, $\gamma = 1.683$ (det. by the present author).

3. Mixture of cummingtonite and green hornblende, Orijärvi, p. 222. Cummingtonite: $\beta_{Na} = 1.642$ and $\gamma - \alpha = 0.026$ (approx.), det. by P. Eskola [pp. 222 and 112]; composition according to Sundius $(Mg\ SiO_3)_{65}$ $(Fe\ SiO_3)_{35}$.

4. Cummingtonite-amphibolite, Nordpolen, Falu mine. Analysis and rock-specimen obtained from H. E. Johansson (the rock-specimens for 4 and 5 are from the collections of the late Prof. Hj. Sjögren and are preserved in the collections of the Mineralogical Department of Naturhistoriska Riksmuseet, Stockholm). Metasilicatic ratios of the rock MgO : CaO : FeO = 53.3 : 2.5 : 44,2. Cummingtonite: $(Mg\ SiO_3)_{53}$ $(Fe\ SiO_3)_{47}$; $\alpha = 1.648$, $\gamma = 1.674$ (det. by the present author). The analysis of 4 and 5 are published in the appendix to the present section.

5. Cummingtonite-amphibolite, Bockskägget, Falu mine. Analysis and rock-specimen obtained from H. E. Johansson. Metasilicatic ratios of the rock MgO : CaO : FeO = 63.6 : 6.5 : 29.9. Cummingtonite: $(Mg\ SiO_3)_{63}$ $(Fe\ SiO_3)_{37}$; $\alpha = 1.641$ $\gamma = 1.666$ (det. by the present author).

{In the diagram the conjugated green hornblendes are also indicated, assumed to be situated where the conjugation-lines of cummingtonite and rock cut the projection-line of the theoretical hornblende-composition [3 (Mg, Fe) SiO_3 + 1Ca SiO_3]. However, as the metasilicatic proportions of the rock are plotted from the normative calculations (which imply FeO for Fe_2O_3 and TiO_2), the real proportions of FeO will only enter when the magnetite and ilmenite-proportions of norm and mode are equal. But, when the real FeO-proportions can be obtained, the conjugation must be almost exactly correct. Naturally varieties of the Ca SiO_3-percentage are also common. Analogously also the cummingtonite may take up some Ca SiO_3. The diagram, however, illustrates the typological character of the cummingtonite-amphibolites}.

6. Augite-bearing »blue» segregation bands, rich in pyrite, in a diabase, Caribber Quarry. J. D. Falconer, The Igneous Geology of the Bathgate and Linlithgow Hills, Transact. Royal Soc. Edinburgh, vol. XLV, 1908, p. 147.

7. Norite, Chreigton Mine. Sudbury, Ontario. A. P. Coleman, Rep. Bur. Min. Ontario XIV (III). Also in A. P. Coleman, The Sudbury Laccolithic Sheet, Journal of Geology XV, 1907, p. 759.

As to an approximate chemical determination of the present hypersthene-augite, we are of opinion that it is somewhat richer in iron and lime than the uniaxial augite from Mull (IX), and that it must be somewhat variable in its composition. The variation-limits must be about $(MgSiO_3)_{38}(CaSiO_3)_8(FeSiO_3)_{54}$ — $(MgSiO_3)_{33}(CaSiO_3)_{16}(FeSiO_3)_{51}$. From these figures a mean value of about $(MgSiO_3)_{35}(CaSiO_3)_{12}(FeSiO_3)_{53}$ may be estimated.

Converted into an amphibole, this hypersthene-augite is too poor in lime to form a common hornblende $\{[CaSiO_3]_{25} : [(Fe, Mg)\ Sio_3]_{75} = \text{ratio } 1 : 3\}$ and too rich in lime for an amphibole of the cummingtonite-grünerite series (diagram, fig. 8). Consequently the mineral must break up into *two* hornblendes, the observed intergrowths of a green hornblende and of an iron-rich cummingtonite, which latter, judging from its optical properties, closely corresponds to the augite. From these results it may also be concluded that the brownish hornblende is rich in iron [about $(MgSiO_3)_{30}(FeSiO_3)_{70} + X\ CaSiO_3$].

Plotting the metasilicatic proportions of the available analyses of the above considered cummingtonite-amphibolites, it may also be pointed out that their dots fall within the area of the diagram characterised as an area of discontinuity between the series tremolite—actinolite—common hornblende—hastingsitic hornblende and the cummingtonite-grünerite series. From the mineralogical point of view, also, these rocks must contain two hornblende species as predisposed from their concentration ratios (fig. 8).

Yet the very remarkable fact may be touched upon that these cummingtonite-amphibolites do not change their lime-poorer amphiboles into common hornblende by taking-up $CaSiO_3$ from the plagioclases. The interpretation of this fact seems to the author to be the following: In a breaking-up of anorthite to form hornblende and quartz during the reaction with the femic minerals, as was before stated (p. 23), not only one molecule of $CaSiO_3$ goes into the pyroxenes, but also one molecule of Al_2O_3 must be taken up. Certainly, however, there must exist a maximum-limit for the hornblendes in taking up Al_2O_3. Probably this limit in the cummingtonite-amphibolites is really reached (cf. the analysis of 3 in the diagram), and then the reaction discussed will cease before all the cummingtonite has changed into common hornblende.

On the other hand, according to Eskola and Geijer, cummingtonite-amphibolites may originate by an addition of (Fe, Mg)O to a normal amphibolite, and in view of what has been pointed out above, the metasilicatic proportions of such a rock must be removed into the mentioned area of discontinuity also in this case. However, it is very remarkable that the cummingtonite-amphibolites of the metasomatic sulphide-ore areas are, as regards the metasilicatic proportions, quite similar to those of the pyroxene-bearing gabbros or diabases closely connected with magmatic sulphide-ores. For instance, the augite and pyrite-bearing segregation veins of the diabase-sills of the Bathgate and Linlithgow Hills, Scotland, are characterised by similar proportions. (fig. 8, no. 6.) Also the norite of the Creighton Mine, Sudbury, Ontario (no. 7), contains similar proportions of metasilicates.

If altered into an amphibolite, at least no. 6 certainly would contain two hornblendes, originating without any addition of ferro-magnesian metasilicates to the rock.

Appendix.

The analyses of both the cummingtonite-amphibolites from Falu Mine quoted in the table of fig. 8 are the following:

1. Quartz-magnetite amphibolite containing cummingtonite, Nordpolen 1, Falu Mine. Analyst K. Schröder.
2. Quartz-cummingtonite amphibolite, Bockskägget 5, Falu Mine. Analyst K. Schröder.

	1	2.
SiO_2	54.20	53.58
TiO_2	0.92	1.00
Al_2O_3	18.35	16.10
Fe_2O_3	2.26	4.36
FeO	8.09	7.48
MnO	0.22	0.30
MgO	4.24	5.52
CaO	8.37	7.85
Na_2O	2.14	1.77
K_2O	0.48	0.62
P_2O_5	0.06	0.24
S	0.08	0.17
H_2O+	0.66	1.29
	100.07	100.28

Quartz-diorites.

In all parts of the area where the transitions between the noritic gabbro and the granites are gradual and gentle (as generally along the western, south, and eastern boundaries of the great norite area) there occur narrower or broader zones of quartz-diorites. These mottled rocks near to the noritic gabbro present a very heterogeneous structure. Thus along the boundaries between the rocks noritic segregations occur, very diffusedly bounded against the dioritic matrix, and consequently they cannot be interpreted as fragments which have entered by stoping. Microscopically also this segregation structure is to be observed: small nodules, sometimes only one cm. long, show the typical norite-texture, with diverging clusters of lath-shaped plagioclases and remnants of orthorhombic and monoclinic pyroxene in patchy hornblendes. The surrounding diorite-matrix is generally even-grained. Very characteristic of the boundary-zones, also, are the occasionally abundant nodules (sometimes 2—3 inches long) comprising intergrowths between plagioclase of andesine character, microcline, and quartz.

These intergrowths are rounded. Microscopically they show a graphic texture (fig. 9). Some parts are made up of antiperthitic intergrowths between andesine and microcline-perthite ($Or_{80}Ab_{20}$); other parts are made up of this complex feldspar in graphic intergrowth with quartz. Small inclusions of

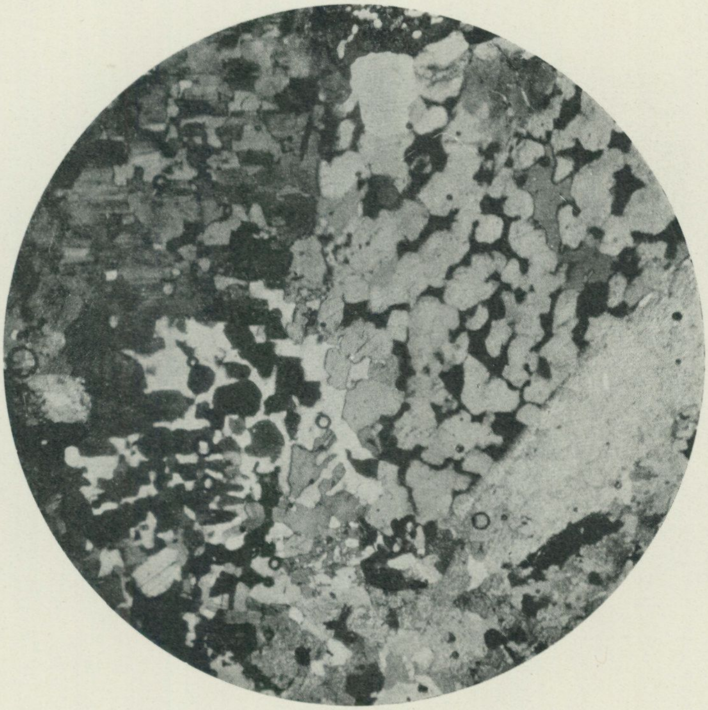


Fig. 9. Quartz-feldspar nodule in quartz-diorite from about 600 m. N.E. of Engelsholm. Microphoto., × 16. Nicols +.

hornblende, biotite, magnetite, and apatite, are also observed. These complex nodules, which evidently represent a separate rock-phase, show the following chemical composition:

Table 2. Analysis of a quartz-feldspar nodule from quartz-diorite, N. E. of Engelsholm. Analyst A. Bygdén.

		Mol. prop.	Norm.	
SiO_2	67.05	1,117	Q	22.38
TiO_2	0.14	2	Or	13.34
Al_2O_3	18.61	182	Ab	36.68
Fe_2O_3	0.62	4	An	24.19
FeO	0.53	7	C	0.10
MnO	0.02	—	Σ sal	96.69
MgO	0.18	5	Hy	0.63
CaO	4.96	89	Mt	0.93
BaO	0.18	1	Il	0.30
Na_2O	4.36	70	Cc	0.30
K_2O	2.29	24	Σ fem	2.16
P_2O_5	0.03	—	H_2O	0.12
CO_2	0.14	3		98.97
S	—			
$H_2O + 105°$	0.12			
	99.23			

An : Or : Ab = 31.4 : 17.5 : 51.1.

Quantitative system: Yellowstonose.

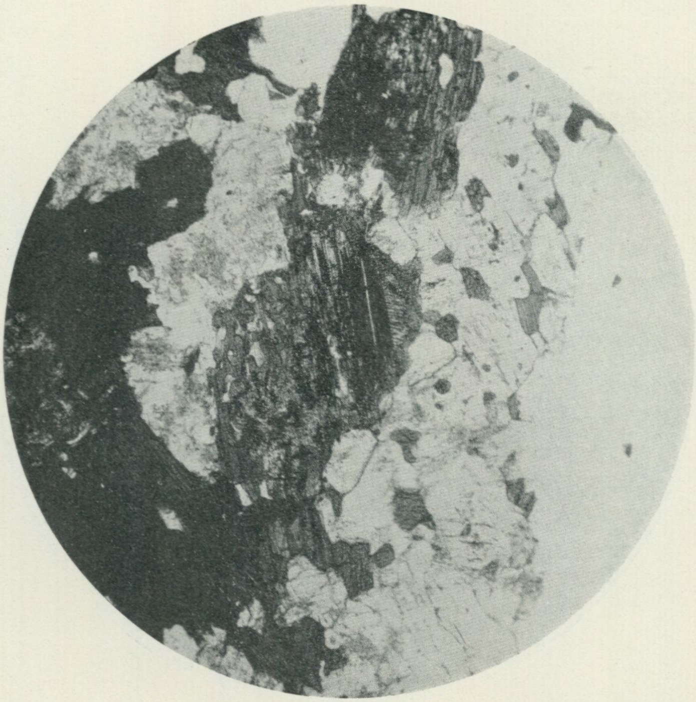


Fig. 10. Quartz-diorite from the north-east of Engelsholm. Microphoto., × 35. Nicols ||. Hypersthene-augite occurring as remnants in hornblende. The lamellar cleavage parallel to (001) is to be observed.

The more homogeneous quartz-diorite is a black-and-white, speckled, medium-grained rock, often containing large pœcilitic hornblendes and large biotite flakes. Its essential minerals are: remnants of pyroxenes, hornblende, biotite, plagioclase, microcline, and quartz. The pyroxenes (orthorhombic and monoclinic) occur as remaining individuals surrounded by hornblende, which sometimes acquires the hornblende-myrmekitic character previously described. In the real quartz-diorite no orthorhombic pyroxene occurs (this is only present in the noritic segregations), but sometimes grains of a pale green pyroxene have been observed. It shows repeated lamellar cleavage parallel to (001) and is sometimes twinned parallel to (100); thus it resembles the hypersthene-augites (see fig. 10). C : γ is large, about 43°; but the optic axial angle is somewhat smaller then that of normal diopsides (2V 59°—60°). The axial angle 2 E was measured to be 88°, and supposing β to be about 1.70, 2V is about 48°. The measurement was made according to the method of Becke (*camera lucida* and revolving drawing-table). Evidently this mineral belongs to the very little known hypersthene-augites which form the transition-members between the »enstatite-augites» and the normal diallages and diallage-like augites[1] (fig. 5).

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[1] Similar hypersthene-augitic diallages were described by M. Websky (diallage from gabbro, Volpersdorf, with $2V = 47° 51'$), Zeitschr. Deutsch. Geol. Ges., 1864, p. 533; L. Henderson (diallage from norite, Zwaartkoppies Transvaal, showing cleavage parallel to (100) and (010) and repeated lamellar cleavage (001). Twinning parallel to (100) is common, often polysynthetic.

Probably the rather distinct colour indicates a higher percentage of ferrous iron (cf. the analyses quoted in the foot-note). Unfortunately, the hypersthene-augite is too scanty to be separated. Efforts have been made to measure the refractive indices, and, employing the immersion method, α was measured to be between 1.69 and 1.70. From this value the composition of the pyroxene, according to the scheme of fig. 7[1], may be approximated to be about $(MgSiO_3)_4 (CaSiO_3)_3(FeSiO_3)_3$.

The hornblende usually presents a pœcilitic character and contains small grains of quartz. It differs from common hornblende in its brownish-green colour. The absorption scheme is : γ brownish-green, β olive green, α pale green. The biotite is strongly pleochroic from pale brown to dark brown. It differs from the biotite of the norite in the occurrence of magnetite dust, evidently originating as an alteration-product. This magnetite is situated especially along the enclosed apatite-needles, which in its neighbourhood seem to be altered into leucoxene. The plagioclase occurs occasionally as small lath-shaped individuals or rounded grains with rough and corroded contours. The composition varies somewhat ($Ab_{65}An_{35}$—$Ab_{75}An_{25}$); a mean lies about $Ab_{70}An_{30}$. Also larger antiperthitic individuals occur; these often present the character of nodules and look like the above-described nodules. Microcline-perthite is common; sometimes it is of some size and rather well-shaped; generally, however, it is shapeless. Quartz is fairly abundant as large pœcilitic individuals containing inclusions of the other minerals. As accessories occur apatite, magnetite, and some titanite.

These more basic rocks continuously pass into more acid, granodioritic[2] rocks. In these the pyroxene completely disappears; also the percentage of hornblende becomes lower. It is similar to the hornblende just described; however, the margins assume a bluish-green colour, indicating a higher percentage of iron-silicates. The absorption-scheme: γ dark green with blue tint, β dark brownish-green, α yellowish green. $C : \gamma = 19^\circ$—20°. The biotite is grayish-brown and is

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Combined with the characteristic cleavage (001) arises the so-called »herring-bone» structure, often described by English and American authors. The lime-poor diallage mentioned has been analysed, its femic proportions are: $MgO : CaO : FeO = 38.6 : 39.2 : 22.2$ [cf. the diagram fig. 5, p. 24]), Norites, Gabbros and Pyroxenites and Other South African Rocks, Inaug. Diss. in Leipzig. London 1898; W. S. Bayley (green faintly pleochroic pyroxene from gabbro, Granite Falls, Minnesota; shows a variable extinction angle [maximum 43°], lamellar cleavage parallel to /001/). U. S. Geol. Surv. Bull., 150, 1898, p. 286; A. N. Winchell (»pigeonitic» pale green to colourless augite. $2E = 56^\circ 36'$, maximal extinction 45°. Partly converted into dark hornblende. The metasilicatic proportions of the rock are: $MgO : CaO : FeO = 32.8 : 22.0 : 45.2$). Am. Geologist, XXVI, p. 293.

Recently such a hypersthene-augitic diallage was described by V. Hackman, who found in pyroxene-bearing granodiorite from Kakskerta, Finland, an augite with $2E = 91^\circ$, $2V = 49^\circ 40'$. Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikationen, Bull. Comm. Géol. de Finlande, no. 61, 1923, p. 8.

[1] Instead of γ we can, of course, also use α, in this case, entering all the α-values in the scheme.

[2] In conformity with the newer terminology, these rocks would more correctly be termed »granodiorites». However, this term has not yet been used in Swedish petrology, and consequently the author has preserved the term quartz-diorites for the more acid rocks. The introduction of »granodiorite» and the determination of its meaning would certainly be of advantage for Swedish petrology. The first attempt in this direction was made by A. Gavelin. (Beskrivning till kartbladet Tranås, S. G. U., Ser. Aa, no. 135, p. 11).

similar to the biotites of the granites. The plagioclase shows the same character as mentioned before. Microcline-perthite ($Or_{75}Ab_{25}$)[1] occurs partly as small shapeless individuals, and partly as larger individualised grains, with albite spindles. Also in this type of rock complex nodules of antiperthitic plagioclase, graphically intergrown with quartz, are observed. The composition of the plagioclase in the nodules is somewhat more acid ($Ab_{64}An_{36}$) than in the analysed nodule. Myrmekite is common. The wealth of accessories is rather striking. Titanite, apatite, magnetite, and zircon, are common. Often the magnetite grains are surrounded by titanite rims. Orthite is also observed.

This granodioritic type of the quartz-diorites was analysed by Dr. N. Sahlbom.

[Contents: hornblende, biotite, plagioclase (An_{35}-An_{25}), microcline-perthite ($Or_{75}Ab_{25}$), quartz. Nodules of antiperthitic plagioclase, intergrown with quartz. Accessories: titanite, apatite, magnetite, zircon, orthite.]

Table 3. Analysis of acid quartz-diorite. The specimen was taken about 500 m. N.E. of Engelsholm.

Sp. gravity 2.826 (A. Bygdén).

		Mol. prop.	Norm.	
SiO_2	61.62	1,027	Q	16.86
TiO_2	2.20	28	Or	18.35
Al_2O_3	15.09	148	Ab	27.25
Fe_2O_3	1.16	8	An	16.96
FeO	6.40	89	C	0.20
MnO	0.12	1	Σ sal	79.62
MgO	2.39	60	Hy	13.13
CaO	4.12	74	Mt	1.86
Na_2O	3.21	52	Il	4.26
K_2O	3.10	33	Ap	1.34
P_2O_5	0.51	4	Σ fem.	20.59
H_2O + 105°	0.45		H_2O	0.46
	100.37			100.67

An : Or : Ab = 26.4 : 28.6 : 45.0 MgO : CaO : FeO = 52.7 : 0.0 : 47,3.

Quantitative system: Harzose.

B. GRANITES.

Generally the basic rocks are connected by gradual transition-types with the more basic granite of the area, the hornblende-bearing granite. Intersecting contacts with brecciation are scarce. Such contacts are only observed W.S.W. of Smedsbygget and along a rather long stretch E. and E.S.E. of Eskilstorp. To the south of Eskilstorp the hornblende-bearing granite shows a gradual contact with the norite, and here rather broad zones of quartz-diorites and quartz-syenites occur. The two-mica granite always cuts the basic rocks. Between the two granite types mentioned no distinct contact is observed, only transition-types. On the contrary, the two-mica granite cuts the boundary-phases of the hornblende-bearing granite towards the basic rocks between

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[1] The composition of the microcline-perthites in the present rocks is approximately calculated from volumetric measurements (according to Rosiwal). The percentages of albite not segregated out as perthite spindles were presumed to be 10 molecular % (cf. E. Mäkinen, G. F. F., vol. 39, p. 156).

Aspetorp and Kopparbolstorp. In this part of the area the two-mica granite probably also cuts the hornblende-bearing granite (S.W. of Aspetorp); however, no contacts are observed.

The boundary-rocks of the hornblende-bearing granite towards the basic rocks.

Towards the quartz-diorite, about 500 m. S.W. of Smedsbygget, there occurs a small zone of quartz-syenitic, hornblende-bearing granite, gradually changing to a diorite. This syenitic rock evidently forms a transition-rock between the diorite and the granite.

Macroscopically these quartz-syenitic rocks are medium-grained with rare characteristic individuals of plagioclase, which show indistinct zonary banding. The centres are composed of about $Ab_{70}An_{30}$; the outsides are somewhat richer in Ab. These larger individuals are usually antiperthitic. The base of the quartz-syenite contains an isometric mixture of plagioclase (about $Ab_{75}An_{25}$), microcline-perthite, and a rather large percentage of femic minerals. Granular quartz is rather common. Among the femic minerals, a strongly coloured hornblende of hastingsite character is predominant. Its optic axial angle is obviously small, 2E about 50°—60°. The axial angle plane shows a symmetric position. Dispersion strong: $\varrho > v$. The absorption is: α yellowish-green, β dark emerald green, and γ bluish-green. $C : \gamma$ about 18°—19°. Scales of biotite are common, their contours are usually fimbriated. The mineral is pleochroic in pale yellowish to faint grayish-brown. Accessories are strikingly common: apatite, magnetite, often with titanite rims, zircon, and some orthite. A few grains of calcite were also observed.

At the southern boundary of the northern areas of the basic rocks, quartz-syenitic transitions to the granites are abundantly developed. Here a strong, but also continuous, alternation occurs between quartz-syenites, altered quartz-syenites rich in epidote, chlorite and epidote-bearing feldspar-rocks (helsinkites) free of quartz, and quartz-rich aplites. No geognostical relations of age can be observed, and in a similar way the complex, without showing distinct boundaries, changes to hornblende-granite which, towards the area of the mentioned alternating types of rocks, grows richer in femic minerals, and consequently is quite similar to the fresher types of the quartz-syenites.

Quartz-syenites. Near the noritic gabbro S. of Aspetorp, this rock is quite fresh, dark grayish-red or faintly coloured; sometimes also small dikes of quartz-syenites occur in the gabbros, as, *e. g.* at Aspetorp and at Kopparbolstorp. S. and S.W. of Aspetorp the quartz-syenites become more reddish, richer in quartz, and usually the femic minerals are strongly altered. Here and there chlorite and epidote occur as anastomosing veins or net-works in the syenites. Sometimes, as, *e. g.* E. of Kopparbolstorp, these veins also occur in the basic rocks; however, we can follow their origin from the syenites. Sometimes the chlorite-epidote veins become so frequent that small zones of breccias similar to »skarn-breccias» arise.

Also on a microscopical examination, the macroscopically fresh quartz-syenite shows itself to be altered. Thin sections were prepared from eight specimens, but none showed a fresh rock. The freshest rock occurring close to the south-west of Aspetorp is characteristic in the occurrence of large-sized rectangular individuals of microcline-perthite (1 to 2 inches long). The rock contains a rather important percentage of quartz; however, the feldspars are predominant. Among them, microcline and plagioclase occur in the same proportions. The former partly forms the above-mentioned rectangular »phenocrysts», and partly it occurs also as shapeless allotriomorphic grains in the medium-grained matrix. The larger microcline individuals are rather rich in albite (about $Or_{75}Ab_{25}$). The plagioclase shows a tabular character and forms grains of varying size. Mostly it is strongly altered, pigmented by reddish dusts, and studded with small patches of sericite and epidote. Here and there, occur remnants of not so strongly altered plagioclases; usually they are antiperthitic and have a rather basic composition (about $Ab_{70}An_{30}$, obtained from several measurements). The sericite dust in the plagioclases is usually scaly. Sometimes the small individuals were congregated as larger scales of muscovite. Myrmekite is rather common.

Among femic minerals, hornblende and chlorite (alteration-product from biotite) form essential constituents. The hornblende occurs as shapeless individuals, often with a pœcilitic character, with inclusions of chlorite (from biotite), plagioclases, and accessories. It evidently belongs to the hastingsites. The optic axial angle is very small; the mineral is nearly uniaxial. The position of the optical axis cannot be determined, owing to the smallness of the axial angle. Assuming the plane of the optic axis to be symmetric, the absorption scheme is: α yellow green, β bluish-green with a tint of olive brown, and γ dark bluish-green. Evidently the mineral was crystallised late, judging from the numerous inclusions (also biotite). In relation to the plagioclase, it is — at least in part — older, judging from the inclusions of hastingsite in the albite. The hornblende is often strongly converted into chlorite; the alteration has especially occurred along the cleavage parallel to the prism. The chlorite is green with bluish tint and is evidently very rich in iron (optically uniaxial penninite). Probably the biotite was originally more common than the hornblende. It is pleochroic in pale grayish-brown to darker grayish-brown. Mostly it is converted into chlorite, which presents a grayish-green colour and may be much richer in magnesia than the chlorite occurring in the hornblende. The alteration follows the cleavage cracks. In the chlorite small needles of rutile are common. Very characteristic, also, is the origin of the microcline in the biotite converted to chlorite (fig. 11). Sometimes this conversion into microcline was complete; however, the original margins of the biotite remain. The insides are usually filled with microcline containing small shapeless inclusions of chlorite and some epidote. There were also observed some dust and small scales of a fibrolite-like mineral, probably a mineral rich in alumina.

The syenites are very rich in accessories. Especially common are magnetite

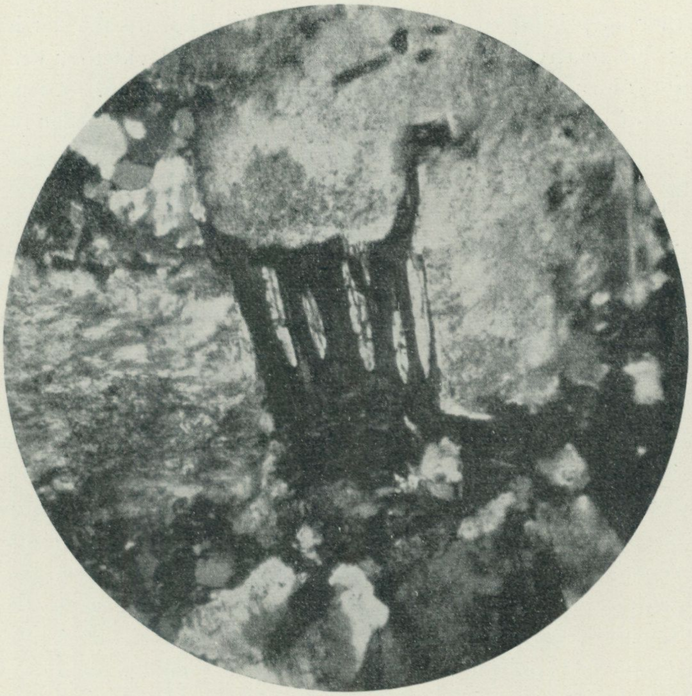

Fig. 11. Origin of microcline in altered biotite. Quartz-syenite from Aspetorp farm. Microphoto., × 35. Nicols +.

with beautiful rims of leucoxene, titanite, and apatite; zircon and orthite are more rare.

The relatively fresh quartz-syenite from Aspetorp was analysed (N. Sahlbom).

(Contents: Microcline-perthite, plagioclase ($Ab_{70}An_{30}$—Ab_{100}), hastingsite, biotite, chlorite, quartz. Accessories: magnetite, titanite, apatite, zircon, orthite.)

Table 4. Analysis of quartz-syenite, Aspetorp.
Sp. gravity 2.703 (A. Bygdén).

		Mol. prop.	Norm.	
SiO_2	60.94	1,016	Q	17.88
TiO_2	1.60	20	Or	23.91
Al_2O_3	15.65	153	Ab	25.68
Fe_2O_3	2.38	15	An	8.90
FeO	5.83	81	C	2.96
MnO	0.11	2	Σ sal	79.33
MgO	2.15	54	Hy	11.74
CaO	2.49	45	Mt	3.48
Na_2O	3.04	49	Il	3.04
K_2O	4.07	43	Ap	1.34
P_2O_5	0.46	4	Σ fem	19.60
$H_2O + 105°$	1.60		H_2O	1.60
	100.32			100.53

An : Or : Ab = 14.8 : 39.8 : 45.4 MgO : CaO : FeO = 52.9 : 0.0 : 47.1.

Quantitative system: Adamellose.

It is rather surprising to find such an iron-rich hornblende as hastingsite, considering the relatively high percentage of MgO. Evidently the latter enters into the biotite and its alteration-product, the chlorite. In the strikingly high amount of normative corund the rock differs from the other rocks of the area. It is certainly due to the alteration of the rock and especially to the breaking-up of anorthite to form lime-rich minerals (epidote), which have left the rock. Epidote and chlorite are also usual as veins in the quartz-syenites.

The strongly altered quartz-syenites have originally shown a composition similar to the fresher type. This fact is indicated by remains of oligoclase, hastingsite, and biotite. Generally the alteration is very complete. The reddish, often antiperthitic, plagioclase is studded with dusts of sericite and epidote. The hornblende is converted into an emerald green chlorite containing small grains of quartz, probably grown during the alteration-process. Often it also contains small grains of magnetite, primary inclusions or alteration-products. The appearance of microcline and chlorite in the biotite is common. The microcline-perthite, the quartz, and the apatite, however, are quite fresh.

Epidote-bearing alkalifeldspar-rocks (*Helsinkites* [1]). In the quartz-syenite S.W. of Aspetorp there occurs a rather large area of rocks rich in epidote and also characterised by the absence, or unimportant occurrence, of quartz. On a microscopical examination, some specimens of this type of rock were found to contain no quartz. They are chiefly composed of feldspars, among which a microcline-perthite ($Or_{80}Ab_{20}$) forms largish individuals, sometimes containing small grains of plagioclase. The plagioclase forms smaller, sometimes rather idiomorphic, grains. Its composition is albitic. The kernels of the plagioclases often contain small aggregates of epidote grains, which were probably formed as alteration-products of earlier crystallised plagioclase richer in anorthite. The interstices between the feldspars are filled up with a mixture of epidote and chlorite. The epidote is evidently rich in iron; it shows a high birefringence and is optically negative. Usually it is lath-shaped and often tends to an idiomorphic habitus. Probably it was partly crystallised in open druses, later on filled up with lamellar chlorite. The chlorite occurs in two types. Of these the lamellar type is most abundant. It forms numerous small lamellar green masses similar to coin-rouleaux or spherulites. Evidently it was crystallised during a very late stage, and it also corrodes the epidote. The pleochroism is very distinct with $\mathfrak{c}$ and $\mathfrak{b}$ emerald green and $\mathfrak{a}$ colourless. The birefringence is very weak, and consequently this chlorite may be a penninite. The other type of chlorite shows a biotite-like appearance; it occurs as large *laminae*, commonly associated with epidote, which is often enclosed in the chlorite. It shows noticeable birefringence (bluish-yellow tints), is optically positive, and has a rather large optic axial angle (2 E about 70°). It may be characterised as a rather iron-rich clinochlore. Titanite and magnetite with titanite rims are usual.

Granular epidote and penninite also occur as thin veins, which are abundant in the rock (fig. 12). When the cracks were formed, the older minerals were to

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[1] In order to mark out the indistinctly bounded areas of helsinkite and aplite occurring to the south of Aspetorp, they are indicated in the map by a dotted line.

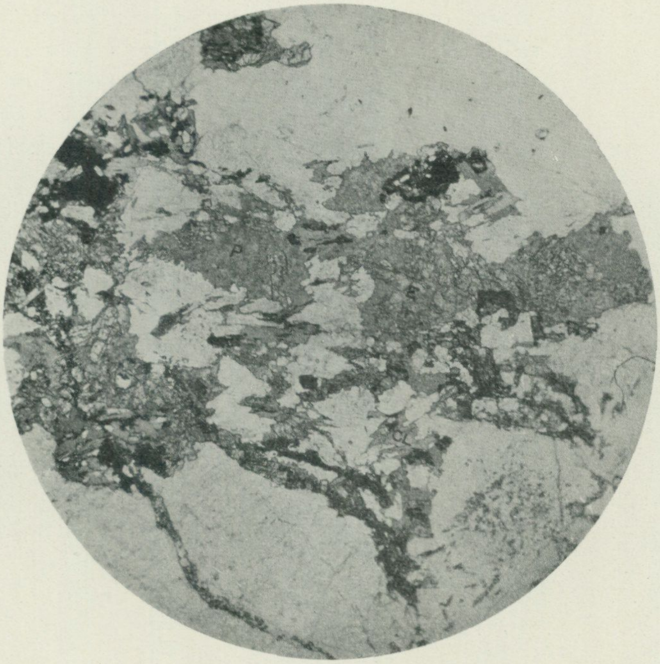

Fig. 12. Microcline-rich helsinkite occurring about 300 m. S. of Aspetorp. P penninite-like chlorite. Cl clinochlore. E epidote. Microphoto., × 12. Nicols ||.

some extent crushed along them. The lamellar chlorite and the epidote do not seem to have been crushed to the same degree, and consequently there are indications that they were not completely crystallised when the brecciation was beginning.

A specimen rich in microcline has been analysed (A. Bygdén). (Contents: Microcline-perthite, albitic plagioclase, epidote, chlorites, titanite, magnetite, and apatite.)

Table 5. Analysis of microcline-rich helsinkite occurring about 300 m. S. of Aspetorp. Sp. gravity 2.827.

		Mol. prop.	Norm.	
SiO_2	57.29	955	Or	51.71
TiO_2	0.75	9	Ab	22.53
Al_2O_3	18.50	181	An	12.51
Fe_2O_3	2.43	15	Σ sal	86.75
FeO	2.22	31	$CaSiO_3$	2.09
MnO	0.09	1	$MgSiO_3$	2.10
MgO	1.06	27	$FeSiO_3$	0.79
CaO	4.09	73	Mg_2SiO_4	0.42
BaO	0.38	3	Fe_2SiO_4	0.20
Na_2O	2.65	43	Mt	3.48
K_2O	8.69	93	Il	1.37
P_2O_5	0.61	4	Ap	1.34
S	tr.		Σ fem	11.79
$H_2O + 105°$	1.23		H_2O	1.23
	99.99			99.77

An : Or : Ab = 14.2 : 58.8 : 27.0 MgO : CaO : FeO = 51.0 : 34.0 : 15.0.

Quantitative system: Vulsinose.

As regards its chemical character, the rock approaches the vulsinites[1]. In this microcline-rich type of the feldspar-rocks there occur small streaks of a rather fine-grained type, poorer in microcline and femic minerals. The abundant albite is here especially strongly polysynthetically twinned. The rock shows a granulitic texture with rather pronounced mortar structure.

This rock has also been analysed (A. Bygdén).

(Contents: Microcline-perthite, albitic plagioclase, epidote, chlorites, apatite, titanite, and magnetite.)

Table 6. Fine-grained helsinkite forming small streaks in the microcline-rich helsinkite. 300 m. S. of Aspetorp.

Sp. gravity 2.664.

		Mol. prop.	Norm.	
SiO_2	60.10	1,002	Or	39.48
TiO_2	0.68	9	Ab	43.49
Al_2O_3	18.60	182	An	5.84
Fe_2O_3	2.32	14	C	0.71
FeO	2.43	33	Σ sal	89.52
MnO	0.07	1	$MgSiO_3$	2.40
MgO	1.09	27	$FeSiO_3$	1.32
CaO	1.45	26	Mg_2SiO_4	0.21
BaO	0.19	1	Fe_2SiO_4	0.10
Na_2O	5.15	83	Mt	3.25
K_2O	6.67	71	Il	1.37
P_2O_5	0.13	1	Ap	0.34
CO_2	0.15	3	Cc	0.30
$H_2O + 105°$	1.13		Σ fem	9.29
	100.16		H_2O	1.13
(S	—)			99.94

An : Or : Ab = 6.1 : 43.3 : 50,6 MgO : CaO : FeO : = 71.0 : 0.0 : 29.0.

Quantitative system: Phlegrose.

From the geological point of view, the rocks just described show intimate resemblances to the »helsinkites» described by A. Laitakari[2]. These rocks were characterised as containing albite and epidote, both primarily crystallised. The designation of those rocks (which obviously differ strongly from the true syenites) by a special term seems to be fully defensible. However, also some of the Finnish helsinkites contain varying amounts of microcline, and thus it seems unneccessary to dwell upon the extreme richness in albite of the helsinkites, and consequently the author proposes the following extension of the term »helsinkite». Following

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[1] H. S. Washington, The Roman Comagmatic Region, Carnegie Inst. Publications, 57, 1906.

[2] A. Laitakari, Einige Albitepidotgesteine von Südfinnland. The term »Helsinkite» was adopted from Helsinki, the Finnish name of Helsingfors. Bull. Comm. Géol. de Finlande, no. 51, 1918.

A rock described by E. Mäkinen is nearly related to these rocks (soda-syenite from Oulainen, Finland, Bull. Comm. Géol. Finl., no. 47, p. 73). Also the aplitic »sviatonossites» from Sviatoy Noss Transbaikalia, described by Eskola, show resemblances to the helsinkites. On the Igneous Rocks of Sviatoy Noss in Transbaikalia, Översikt av Finska Vetenskaps-Societetens Förhandlingar, vol. LXIII, Avdelning A, no. 1, 1920—21, p. 62.

Eskola, who has set up the mineral-paragenesis albite and epidote as a special facies of rocks (the helsinkite-facies), the present author lays stress upon this primary paragenesis, neglecting the relative amounts of albite and epidote. In several helsinkites quartz is rather abundant, and therefore a scheme should express also the varying amounts of this mineral. Thus we may draw up a systematic scheme, such as:

I. Quartz-poor or quartz-free rocks with the primary paragenesis albite + epidote.	Potash-rich (prepotassic). Potash-helsinkites.	Equal amounts of potash-feldspar and albite (sodipotassic). Intermediate helsinkites.	Soda-rich (presodic). Soda-helsinkites.
II. Rocks with the primary paragenesis albite + epidote, containing an important percentage of quartz.	Potash-quartz helsinkites.	Intermediate quartz-helsinkites.	Soda-quartz helsinkites.

To this group of rocks, probably, belong some of the Central Maryland granites described by Ch. R. Keyes[1]. These contain primary epidote and also allanite. However, there is no information as to whether albite is also present. Indeed, albite may be suspected, considering the high percentage of epidote, and consequently the rocks under investigation may belong to the quartz-helsinkites just suggested.

Regarding the sequence of crystallisation of the helsinkites, the author refers to the papers of Mäkinen, Laitakari, and Eskola. For the Stavsjö helsinkites, the following crystallisation sequence may be sketched. The »phenocryst» of microcline began to crystallise early, followed by plagioclase, which would primarily have been an oligoclase. During the course of crystallisation, the latter broke up into albite and epidote (which forms small grains in the kernels of the albite individuals). Probably already during the crystallisation of the feldspars, biotite was solidified, later on being converted into clinochlore. The independent epidote was probably chiefly crystallised after the feldspars and in the interstices between them; partly in small druses, which were later on filled up by the penninite-like chlorite. Some druses, however, were not filled up, and are still rather abundant. The epidote and chlorite were partly crystallised along small cracks (joints?) as mineral veins.

The conditions of the formation of the »helsinkites» have been discussed by Mäkinen, Eskola, and Laitakari. Mäkinen believes that the epidote-formation of the anorthite was probably due to later pneumatolytical actions, which followed closely on the magmatic period of the rocks. Eskola explains the appearance of epidote as due to the great percentage of water in these magmas. The great amounts of water would have lowered the crystallisation-temperature of the rocks to a stage at which the epidote could crystallise directly. In close

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[1] Origin and Relations of Central Maryland Granites, U. S. Geol. Surv., Fifteenth Ann. Rep., 1893—94, pp. 685 *etc.*

agreement with this view, Laitakari found it probable that the helsinkites arose through late crystallisation of magma-solutions associated with pegmatites. To this discussion the present author has below (see p. 74) added some points of view.

Aplites. Reddish aplitic boundary-rocks of the hornblende-bearing granite extend in close connection with the quartz-syenites already described. They occur as irregular masses among the quartz-syenites in the neighbourhood of Aspetorp, here and there concentrated as small homogeneous areas. An unimportant area occurs at the boundary of the quartz-syenites N.E. of Engelsholm; N. of Smedsbygget small dikes of aplite are seen in the norite. A larger area of aplite also occurs to the south of Kopparbolstorp.

The aplites are decidedly salic, with a rather high percentage of quartz. The texture is typically aplitic; quartz, microcline-perthite, and plagioclase, appear as an even-grained base of isometric minerals, among which only the plagioclase sometimes tends to an idiomorphic habit. The microcline-perthite usually exceeds the abundant antiperthitic plagioclase in quantity. The former usually has the composition $Or_{80}Ab_{20}$; the plagioclase varies from $Ab_{75}An_{25}$ to $Ab_{68}An_{24}Or_8$ (the antiperthitic plagioclase was calculated from geometrical measurements). Myrmekite is very common on the boundaries between the plagioclase and microcline. Among the femic minerals, biotite is very rare and is often converted into microcline and chlorite (cf. p. 38). Scattered grains of a brownish epidote are only sometimes observed, and muscovite is also rare; in some thin sections it was found to form margins round the biotite. Among accessories, apatite, zircon, magnetite, and fluorite, occur sparsely.

A potash-rich aplite was observed about 600 m. S.W. of Aspetorp, at the boundary of the hornblende-bearing granite. The aplite forms streaks or lumps in a grayish, mostly hornblende-free, variety of the hornblende-bearing granite. The chief mineral in this aplite is microcline-perthite ($Or_{80}Ab_{20}$). Plagioclase ($Ab_{85}An_{15}$) with albitic rims is common. Biotite is accessory. The minor constituents above mentioned also occur. This aplite was analysed (N. Sahlbom) as follows: [Contents: microcline-perthite ($Or_{80}Ab_{20}$), quartz, plagioclase ($Ab_{85}An_{15}$) Accessories: apatite, zircon, magnetite, fluorite.]

Table 7. Analysis of microcline-rich aplite occurring about 600 m. to the south of Aspetorp. Sp. gr. 2.60 (A. Bygdén).

		Mol. prop.	Norm.		Actual composition (from geom. analysis)			Volumetric composition
SiO_2	74.15	1,236	Q	26.46	Quartz	23.5		23.1
TiO_2	tr.	—	Or	42.26	Microcline-perthite	55.0	Or 44.7 Ab 10.3	55.9
Al_2O_3	13.91	136	Ab	27.77				
Fe_2O_3	0.15	1	An	1.95	Plagioclase	20.1	Ab 17.0 An 3.1	19.8
FeO	0.43	6	Σ sal	98.44				
MnO	0.01	—	$CaSiO_3$	0.12	Biotite	1.3		1.1
MgO	0.18	5	$MgSiO_3$	0.50	Apatite	0.1		0.1
CaO	0.60	11	$FeSiO_3$	0.66		100.0		100.0
Na_2O	3.28	53	Mt	0.23				
K_2O	7.12	76	Ap	0.34				
P_2O_5	0.06	1	Σ fem	1.85				
H_2O + 105°	0.27		H_2O	0.27				
	100.16			100.56				

An : Or : Ab = 2.7 : 57.3 : 40.0

(Calculated from the analysis.)

Calculated sp. gr. 2.60. *Quantitative System:* Liparose.

Soda-rich granite. The curious hornblende-free granite which surrounds the above-mentioned potash-rich aplite is very rich in plagioclase and may be classified as a »soda-granite». It presents an unimportant extension. The chief mineral is an evidently zonary banded, mostly idiomorphic, plagioclase, whose kernels are composed of $Ab_{65}An_{35}$. The nuclei are irregularly but distinctly bounded towards the outside rims, which are homogeneous, with the composition $Ab_{80}An_{20}$. The outside rims also differ from the kernel in their more simple twinning (only albite-striation; the kernels, further, show pericline-striation). Microcline only occurs as an accessory (0.5 vol.%), partly as sparse antiperthitic inclusions in the exterior zones of the plagioclase, partly as small grains situated outside. Among femic minerals, only a strongly pleochroic biotite (pale brownish to brownish-black with a tint of reddish-brown) occurs as tables or scales, the latter sometimes enclosed in the exterior zones of the plagioclase. This fact indicates that at least the biotite had begun to crystallise before these rims. Quartz forms large allotriomorphic fields, mostly granulated. Myrmekite is rather rare. Accessories are apatite, magnetite (about 1.8 vol.%), zircon, and titanite. The rock was analysed by A. Bygdén.

[Contents: Plagioclase ($Ab_{65}An_{35}$ — $Ab_{80}An_{20}$), biotite, quartz. Accessories: microcline-perthite, apatite, magnetite, zircon, and titanite.]

Table 8. Analysis of soda-rich granite occurring about 600 m. to the south of Aspetorp. Sp. gravity 2.733.

		Mol. prop.	Norm.	
SiO_2	66.02	1,100	Q	21.66
TiO_2	0.80	10	Or	13.34
Al_2O_3	15.58	153	Ab	36.68
Fe_2O_3	0.83	5	An	12.79
FeO	4.71	65	C	1.33
MnO	0.13	2	Σ sal	85.80
MgO	1.24	31	$MgSiO_3$	3.10
CaO	2.94	53	$FeSiO_3$	6.86
BaO	0.05	—	Mt	1.16
Na_2O	4.36	70	Il	1.52
K_2O	2.25	24	Ap	0.67
P_2O_5	0.34	2	Σ fem	13.31
S	0.01	—	H_2O	0.96
H_2O + 105°	0.96			100.07
	100.22			

An : Or : Ab = 19.7 : 20.5 : 59.8.
MgO : CaO : FeO = 37.3 : 0.0 : 62.7.
(Calculated from the analysis).

Quantitative System: Dacose.

Some small parts of the soda-granite present, macroscopically, a darker, dioritic appearance, due to the essential percentage of hornblende. Under the microscope this type is quite similar to the type analysed; however, there occurs a strongly pleochroic hornblende (yellowish-green to bluish-green), which, owing to its rather small optic axial angle, bears a resemblance to the hastingsitic hornblendes. In this type no free microcline was observed.

Quartz-syenitic granite from Skogsbyn.

In addition to the quartz-syenites just described from the east of Lake Björnsjön, quartz-syenitic granites also occur in an area in the neighbourhood of Skogsbyn, closely connected with the medium-grained granites and passing into such granites without any distinct boundaries. Macroscopically the quartz-syenitic granite shows a speckled grayish-red colour, due to the rather abundant occurrence of femic minerals.

Under the microscope the rock presents a medium-grained texture and is chiefly composed of plagioclase, microcline, quartz, hornblende, and biotite. The proportion of accessories is large. Magnetite, apatite, titanite, and zircon, were observed. The plagioclase is tabular and rather idiomorphic. Sometimes it tends to a lath-shaped habit. The zonary banding is fairly distinct. The composition of the kernels varies from $Ab_{65}An_{35}$ to $Ab_{60}An_{40}$. The zone round the kernels is composed of an oligoclasitic plagioclase ($Ab_{75}An_{25}$ — $Ab_{70}An_{30}$), and this zone is surrounded by quantitatively unimportant margins of more acid oligoclase-albite. Microcline-perthite ($Or_{77}Ab_{23}$) forms irregular individuals. Quartz is rather abundant and forms undulous and allotriomorphic masses. Hornblende also occurs as irregular individuals, pleochroic in pale yellow to clear green. The optic axial angle is the normal one for common hornblendes. Pœcilitic individuals with inclusions of biotite and accessories are often observed. Biotite is abundant. The pleochroism is distinct, from pale yellow to brown with a reddish-brown tint.

In order to get a knowledge of the chemical character of the rock, a volumetric analysis (according to Rosiwal) was made. From this, calculations were made to get a general view of the feldspar-proportions expressed in the usual triangle of the molecular proportions. However, to compare these values with those calculated from the analyses, the K_2O-percentage of the biotite was also taken into consideration and was set at 8 % of *the weight-percentage* of the biotite[1]. An analogous calculation of the anorthite broken up to enter into hornblende seemed too indefinite and was consequently neglected. It is to be remarked that the quartz-percentage here calculated must be greater than that found from a chemical analysis (here 20 %; in the analysed quartz-syenite 17.5 %), when we consider the differences in silica of the modal biotite and of the normative orthoclase.

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[1] The Or-quantity occurring in solid solution in the plagioclase was neglected. But the Na_2O-percentage of the biotite was also neglected. Obviously these factors of inaccuracy counterbalance one another.

Table 9. Volumetric analysis and calculations of medium-grained quartz-syenitic granite from Skogsbyn.

Sp. gravity 2.807 (A. Bygdén).

	Volume %	Sp. gr.[1]	Weight %		Mol. prop.
Quartz	21.3	2.65	20.0		
Microcline-perthite $\left\{ \begin{matrix} Or_{77} \\ Ab_{23} \end{matrix} \right\}$	12.1	2.57	11.1	Mi 8.7	K_2O 16
				Ab 2.4	Na_2O 45
Plagioclase $\left\{ \begin{matrix} Ab_{65} \\ An_{35} \end{matrix} \right\}$	34.7	2.66	32.8	Ab 21.0	
				An 11.8	CaO 43
Hornblende	9.2	3.12	10.2		
Biotite	18.3	3.01	19.6	(1.56 K_2O)	K_2O 17
Magnetite	1.9	5.20	3.5		
Apatite	1.4	3.16	1.5	An : Or : Ab = 21.6 : 33.1 : 45.3.	
Titanite	1.1	3.48	1.5		
	100.0		100.2		

Calculated sp. gr. 2.813.

Hornblende-bearing granite.

Grayish-red hornblende-bearing granites, fairly coarse, occupy large parts of the central region of the area mapped. They usually surround the basic rocks. The contacts with the latter vary somewhat. About 400 m. S.W. of Smedsbygget the hornblende-bearing granite gradually changes into quartz-syenite and quartz-diorite; however, only about 100 m. N.E. of this point the boundary becomes abrupt, and the granite sharply cuts the norite, which is amphibolised and brecciated towards the contact. Towards W.S.W. the contact between granite and quartz-diorite is hidden. Probably the small area of aplitic granite[2] N.E. of Engelsholm forms a boundary-facies of the hornblende-bearing granite, which cuts the aplite as well as the quartz-diorites.

N. of Smedsbygget hornblende-rich granite occurs as indistinct dikes or lumps, in an amphibolised norite in the outcrops round the deserted homestead called Bergsäter. E. of this place there occurs no hornblende-bearing granite, and here the noritic gabbro is cut by the two-mica granite, which has consequently cut away possibly pre-existing hornblende-bearing granite. Towards the north, along the road from Smedsbygget to Eskilstorp, there occur small outcrops on both sides of the road. This area is very favourable to an interpretation of the boundary-relations between the basic rocks and the hornblende-bearing granite. About a hundred m. to the west of the road, noritic gabbro appears in several outcrops (here it was that the specimen analysed was taken). Towards the western side of the road the norite gradually changes to a speckled quartz-diorite with sparse plagioclase-quartz nodules. The quartz-diorite also changes gradually to a hornblende-rich quartz-syenite, which latter rock shows no distinct boundaries towards the hornblende-bearing granite. Here we may, consequently, see a gentle differentiation-contact between

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[1] According to Rosenbusch-Wülfing (cf. p. 20).

[2] This area is indicated in the map by a dotted line.

norite and hornblende-bearing granite and their transition-types. Towards N.E. this type of contact can be followed along a short stretch; however, further to N.E. it changes to an evident brecciated contact, which curves back to W. and may be traced to Eskilstorp farm. Here again the contact becomes very interesting: S.E. of the farm, in a rather high, extensive outcrop, lengthened streaks of a basic type of hornblende-bearing granite[1] are enclosed in the noritic gabbro. At a first glance at these mixtures, the granite streaks show resemblances to dikes; thorough investigations, however, prove that they are actual streaks. These contain inclusions of norite. In the south-western part of the outcrop on which Eskilstorp farm is situated, occurs an intimate mixture of bands of granite and a rather coarse gabbrodiorite, characterised by large pœcilitic hornblendes, together with some aplite. Towards N.E., in the same outcrop, the hornblende-bearing granite becomes homogeneous and extends towards Lake Björnsjön and Aspetorp farm.

Basic hornblende-bearing granite from Eskilstorp. Also in the outcrop S.W. of the village, the streaks of basic hornblende-granite are surrounded by thin zones, 1 to 2 dm. broad, of a dark quartz-diorite of the type mentioned. On microscopical investigation, this rock shows a somewhat heterogeneous structure. Some quartz-poor centres present resemblances to a norite, owing to radiating clusters of plagioclase-laths and small grains of »myrmekitic» hornblende, probably derived entirely from pyroxenes, which occur as sparse remnants. The plagioclase is faintly zoned, with kernels $Ab_{60}An_{40}$ and margins $Ab_{75}An_{25}$. These noritic centres float in a more acid matrix, made up of large pœcilitic hornblendes, microcline, and quartz. The hornblendes are studded with small laths of plagioclase, which have strongly corroded and irregular contours. These hornblendes contain no vermicular quartz. They are strongly pleochroic with α olive green, β and γ dark brownish-green. Biotite occurs sparingly as large pœcilitic flakes, with included grains of plagioclase. The mica is pleochroic from pale yellowish-brown to dark grayish-brown, and contains specks of magnetite and granular titanite. The boundaries against the plagioclase are often rich in myrmekitic intergrowths. Small scales of mica are sometimes included in the hornblendes. The quartz and the microcline-perthite ($Or_{75}Ab_{25}$) form large pœcilitic individuals, studded with the minerals mentioned and rich in magnetite and zircon grains and abundant apatite prisms.

A review of the crystallisation-courses of this rock shows a distinctly marked hiatus. The partly lath-shaped plagioclases, the pyroxenes, magnetite, and apatite, may be regarded as an earlier gabbroic phase of crystallisation. Much younger is the granitic crystallisation-phase. In this the biotite began to crystallise, followed by the hornblendes. During this stage of crystallisation the pyroxenes were probably converted into hornblende (at the same time some vermicular quartz was formed, cf. p. 23). Quartz and microcline-perthite were formed last. The crystallisation-courses and the microscopically observed uneven distribution of the gabbroic and the granitic phases, indicate that

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[1] In the map these streaks are shown schematically. The basic hornblende-bearing granite in the map is indicated as quartz-dioritic granite.

these thin zones of rocks represent inhomogeneous mixtures of magmas, fixed by crystallisation already at a stage when they were not completely differentiated.

On the other hand, these narrow zones may be supposed to represent reaction rocks, originating through an action of granitic magma upon an already solidified gabbro, as described by N. H. Magnusson[1] from an area in Central Östergötland. However, the similarities between these unimportant rocks and the inhomogeneous quartz-diorites previously described, indicate that they were not originated by such reactions.

The basic hornblende-bearing granite shows a rather decidedly porphyritic texture, due to the abundant occurrence of reddish phenocrysts of microcline-perthite and occasional larger plagioclases. Microscopically the plagioclase seems to be the principal mineral. It usually shows an idiomorphic habit and occurs as crystals of varying size. The zonary structure is rather indistinct. The antiperthitic kernels are composed of $Ab_{65}An_{35}$. The percentage of microcline in the kernels was estimated at about 10 %, and consequently the kernels have a composition of about $Ab_{59}An_{31}Or_{10}$. The margins are rather acid, about $Ab_{75}An_{25}$, and usually contain no antiperthitic inclusions. Microcline-perthite forms the large phenocrysts, but it also occurs as sparse allotriomorphic grains associated with quartz in the interstices of the rock. The microclines often contain small inclusions of plagioclase (saussuritised). The albite of the spindles and in the perthite occurs in varying amounts, maximum about 15 %. Towards the margins of the perthites there usually occur inclusions of myrmekite. In one case from a section perpendicular to P and M the myrmekite-plagioclase was determined as $Ab_{85}An_{15}$. The allotriomorphic microcline of the ground-mass is very pure. The quartz forms rather rare and large pœcilitic grains, which are only slightly granulated.

The femic minerals hornblende and biotite are rather abundant. The hornblende forms partly small grains, often enclosed in plagioclase, partly larger individuals, allotriomorphic against the plagioclase. These small grains are »hornblende-myrmekitic» and probably originate from altered pyroxene. The larger hornblendes are dark greenish-brown, similar to that of the quartz-diorites. The mica occurs as large flakes, strongly pleochroic from pale yellowish-brown to dark grayish-brown (paler than the biotite of the quartz-dioritic zones already described). Probably it is younger than the plagioclase, which sometimes seems to be corroded by it. The hornblendes and micas usually contain included accessories, apatite, titanite, magnetite, and zircon.

The sequence of crystallisation is very evident. The kernels of plagioclase and some pyroxene (rhombic?) crystallised first, followed by the accessories, later on followed by the microcline-perthite phenocrysts and the more acid rims of the plagioclase. The femic minerals, biotite and hornblende, form a later generation, followed by some feldspar and quartz.

Common hornblende-bearing granite. Macroscopically this rock shows great

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[1] Beskrivning till kartbladet Mjölby, S. G. U., ser. Aa, no. 150, 1922, p. 20.

resemblances to the so-called Filipstad granite, the very characteristic hornblende-bearing porphyritic granite of Southern Sweden. In particular, the present rock is similar to the rather quartz-poor Filipstad granite of Southern Östergötland, a type somewhat deviating from the quartzy Filipstad granite of the classical areas in the western parts of Bergslagen.

The rock shows a porphyritic texture with phenocrysts or »eyes» of microcline-perthites about one inch through, which, according to geometrical analyses, seems to contain about 25 % of albite. The perthite spindles of the phenocrysts are often combined with small spots of a saussuritised plagioclase, probably primarily rather anorthite-rich. These spots may also be perthitic segregations. Along the margins of the microcline-perthite, small myrmekitic individuals of plagioclase are common, and sometimes a multitude of such individuals are attached to the boundaries of the microcline-perthites, something like plagioclase strings, as may sometimes also be observed macroscopically. The placioclase occurs roughly in the same quantities as the microcline-perthite. However, the individuals are much smaller and the idiomorphism fairly well developed. Occasional plagioclases are larger, similar to phenocrysts. The centres of the plagioclases often contain small antiperthitic segregations of microcline (about 5 %). The composition is about $Ab_{70}An_{30}$; the marginal zones are indistinct and have a composition of about $Ab_{75}An_{25}$.

The ferro-magnesian minerals, hornblende and biotite, occur in varying amounts. The mica shows pleochroism from pale yellowish-brown to grayish-brown. It is obviously paler than the biotite of the basic hornblende-granite. Generally the mica forms scales with irregular outlines. Probably it was crystallised later than the plagioclase in most cases. The hornblende occurs as irregular individuals of varying size, generally associated with biotite and the accessories. It is strongly pleochroic with α yellowish-green, β brownish-green, and γ dark bluish-green. The optic axial angle is rather small, and consequently the mineral belongs to the hastingsitic hornblendes.

The percentage of accessories is unusually high. Especially brown titanite and magnetite, with rims of titanite, are common; apatite and zircon more sparse. The accessories and ferro-magnesian minerals are generally enclosed by the allotriomorphic quartz, which forms strongly granulated individuals. The feldspars are usually well-bounded against this complex.

A typical specimen (about 2 kg.), taken about 100 m. N.E. of Eskilstorp, was analysed (N. Sahlbom).

[Contents: Microcline-perthite ($Or_{75}\,Ab_{25} + An$), plagioclase ($Ab_{70}\,An_{30}$ — — $Ab_{75}\,An_{25}$), quartz, hornblende, biotite. Accessories, titanite, magnetite, apatite, zircon.]

Table 10. Analysis of hornblende-bearing granite from about 100 m. N.E. of Eskilstorp. Sp. gravity 2.706 (A. Bygdén).

		Mol. prop.	Norm.	
SiO_2	65.02	1,084	Q	18.42
TiO_2	1.30	16	Or	27.24
Al_2O_3	15.27	150	Ab	28.30
Fe_2O_3	1.24	8	An	13.07
FeO	4.24	58	Σ sal	87.03
MnO	0.09	1	$CaSiO_3$	0.12
MgO	1.14	29	$MgSiO_3$	2.90
CaO	3.25	58	$FeSiO_3$	4.62
Na_2O	3.34	54	Mt	1.86
K_2O	4.62	49	Ap	1.01
P_2O_5	0.45	3	Il	2.43
$H_2O + 105°$	0.47		Σ fem	12.94
	100.43		H_2O	0.47
				100.44

An : Or : Ab = 18.6 : 38.7 : 42.7. MgO : CaO : FeO = 44.6 : 1.5 : 53.9.

Quantitative System: Adamellose.

Medium-grained granites.

The bulk of the granites of the area mapped form a variable series of medium-grained granites, which, compared to the syenitic or hornblende-bearing granites previously described, are much poorer in femic minerals and generally contain plagioclases poorer in anorthite. The chief mass of the medium-grained granites is allied most closely to the hornblende-bearing granite, and there actually occur structural transition-types between them. However, the porphyritic texture of the former types largely disappears, especially in the more salic granites, which gradually acquire a rather distinct medium-grained habit, characterised by very indistinctly bounded microcline-perthites. When these are absent, the rocks often acquire an aplitic texture. At the boundary between the medium-grained granite and the coarse two-mica granite W. and N.W. of Lake Kvarnsjön, there occur muscovite-bearing transition-types. Such types sometimes occur also as independent masses, as, *e. g.* between Åbo and Lake Nedre Åksjön. When muscovite is present, the microcline-perthite acquires a rectangular habitus, and the granite in question becomes similar to the two-mica granite described below.

The medium-grained granites of the area show strong deformation influences, and in this case, owing to the mutual parallel arrangement of the minerals, have the appearance of gneiss-granites. On microscopical examination, the deformation-structures are visible as a granulation or bending of the minerals. Especially the quartz frequently shows granulated structure or strain-shadows. The varying deformation-structures associated with the mineralogical and chemical variations necessitate an approximate division, even if this is by no means sharp, or even very obscure, when broad transition-zones occur.

Massive medium-grained granite W. of Lake Björnsjön. Macroscopically this is a grayish-red, indistinctly porphyritic granite, containing large, rather idiomorphic microcline-perthites (1 to 1.5 cm. long). On microscopical examination these seem to appear as Carlsbad twins with strongly bent twin-planes. They are rather rich in veinlets of albite, whose percentage may be roughly estimated at about 15 to 20 % of the microcline-perthite (about Or_{70-75} Ab_{25-30}). The aplitic matrix of the rock consists of plagioclase, quartz, some microcline, biotite, and rather abundant accessories, *viz.* magnetite with titanite rims, titanite, and apatite. Here and there the plagioclase forms large individuals, richer in anorthite and showing a rather distinct zonary structure. The centres are composed of Ab_{65} An_{35}, and the margins of Ab_{75} An_{25}. The numerous isometric grains of plagioclase vary between Ab_{75} An_{25} and Ab_{80} An_{20}. The sparingly occurring, small grains of microcline are poor in albite (rated at Or_{83} Ab_{17}) and are frequently surrounded by small grains of zonary-built myrmekite. Quartz, rather strongly granulated, constitutes 25 % by volume of the rock. The biotite represents the only ferro-magnesian mineral. Its absorption-colours are pale yellow to dirty brownish-green. Sometimes it is converted into chlorite.

Massive medium-grained granite occurring N. of Lake Stavsjön. In contrast to the rock just described, this rock shows a rather distinctly porphyritic texture. The phenocrysts of microcline-perthite are rounded, contain about 30 % of plagioclase, and are frequently surrounded by small grains of myrmekite. The plagioclase is generally rather idiomorphic and indistinctly zoned. The centres show a composition of about Ab_{70} An_{30}, and the margins Ab_{75} An_{25}. A few larger crystals are antiperthitic. The quartz is not very important in amount; it occurs as large granulated fields enclosing the other minerals. In this rock also the biotite is the characteristic femic mineral; it is pleochroic from faintly yellow to grayish-brown. The accessories comprise epidote, magnetite, apatite, and titanite.

Volumetric analyses and calculations have given the following table:

Table 11. Volumetric analysis of medium-grained granite to the north of Lake Stavsjön. Sp. gravity 2.67 (A. Bygdén).

	Volume %	Sp. gr.		Weight %	Mol. prop.	
Quartz	27.1	2.65		26.8		
Microcline-perthite phenocrysts (Mi_{70} Ab_{25} An_5)	27.3	2.58	Mi	19.2	K_2O	34
			Ab	6.0	Na_2O	11
			An	1.1	CaO	4
Microcline-perthite, small individuals Mi_{85} Ab_{15}	1.7	2.57	Mi	1.3	K_2O	2
			Ab	0.3	Na_2O	1
Plagioclase	34.6	2.65	Ab	26.6	Na_2O	51
			An	7.7	CaO	28
Biotite	8.2	3.01		9.2	K_2O	7
Magnetite	0.2	5.20		0.4		
Apatite	0.3	3.16		0.3		
Titanite	0.3	3.48		0.4		
Epidote	0.3	3.40		0.4		
	100.0			99.7		

Calculated sp. gr. 2.65.

An : Or : Ab = 13.0 : 35.3 : 51.7.

Both the types just described are rather closely allied to the hornblende-bearing granite and comprise the greater part of the medium-grained granites. They constitute the areas between Lake Björnsjön and Lake Åksjön and the areas from the west of Lake Stavsjön towards Herrbråten and Kråkvasken. Also the granite area S. of Lake Skiren towards Lake Gullvagnen consists of this type, which also forms the small detached area coloured on the map in the neighbourhood of Lake Enaren.

Grayish-red schistose medium-grained granite 1 km. to the south of Lake Nedre Ålsjön. Macroscopically this rock shows an indistinctly porphyritic texture, with thin rectangular crystals (1 to 1.5 cm. long) of microcline-perthite occurring in a medium-grained matrix rich in plagioclase and mica. Microscopically the microcline-crystals seem to be granulated, and they are often surrounded by numerous myrmekitic grains of plagioclase, giving rise to a structure resembling mortar-structure. The plagioclase occurs in smaller amounts than the microcline. Sometimes it is rather idiomorphic; frequently the twin-striation is feebly developed, and the mineral tends to a simple plagioclase. The zonary structure is indistinct, but chemically rather pronounced. The composition of the centres reaches about $Ab_{68}\ An_{32}$. The margins consist of $Ab_{75}\ An_{25}$. Occasional and larger individuals are often antiperthitic. Biotite and muscovite occur in similar amounts; frequently they form parallel intergrowths. The biotite is rather faintly pleochroic from pale yellow to grayish-brown. Magnetite is common; apatite, titanite, and zircon, are infrequent. Small pale green grains of epidote are common; usually they occur associated with the micas.

This type of rock is predominant in the neighbourhood of the middle zone of Lake Virlången.

Pinkish massive medium-grained granite 300 m. to the south of Bråten. The stroke between the areas of aplitic granites W. of the southern part of Lake Virlången is mainly occupied by a rather salic porphyritic granite, containing thin crystals (1 to 1.5 cm. long) of microcline-perthite. Microscopically the microcline-perthites were estimated to contain about 30 % of oligoclase-albite. The quantity of the independent plagioclase was less than that of the microcline. The zonary structure is indistinct — centres about $Ab_{73}\ An_{27}$ and margins $Ab_{77}\ An_{23}$. The quartz forms extensive allotriomorphic fields, strongly granulated. Biotite, pleochroic in pale yellow to grayish-brown with a chestnut shade, represents the essential femic constituent. *Muscovite* occurs as sparse scales. Accessories are rather common: magnetite, apatite, zircon, titanite, and some small grains of pale green epidote, associated with the micas.

A geometrical analysis has given the following results:

(The anorthite-percentage of the microcline-perthites of Tables 11—13 was roughly estimated at about 5 %, a value which may be somewhat too high.)

Table 12. Volumetric analysis of medium-grained granite S. of Bråten.

		Volume %		Weight %	Mol. prop.	
Quartz		23.0		22.9		
Microcline-perthite	Mi_{70}	43.6	Mi	29.2	K_2O	53
	Ab_{25}		Ab	10.9	Na_2O	21
	An_5		An	1.7	CaO	6
Plagioclase	Ab_{77}	22,6	An	6.0	CaO	22
	An_{23}		Ab	16.5	Na_2O	31
Biotite		8.7		9.8	K_2O	9
Muscovite		0.5		0.6		
Apatite		0.5		0.6		
Magnetite		0.5		1.0		
Titanite		0.4		0.5		
Epidote		0.2		0.3		
		100.0		100.0		

An : Or : Ab = 11.0 : 48.0 : 41.0.
Calculated sp. gravity 2.66.

This type evidently approaches the composition of the two-mica granite. Varying amounts of muscovite can also frequently be observed with the naked eye. This was especially the case with the granite occurring to the west of Kvarnsjön. N.W. of Virlången, towards Ålsjön, this type also occurs alternating with some plagioclase-richer granite described later on.

W. of the hornblende-bearing granite, in the neighbourhood of Skinnarbo Sarvgöl, Vilgölen pools, *etc.*, there occur pinkish medium-grained granites, frequently schistose and rich in quartz. They form the transitions between the muscovite-bearing type just described and the quartzy salic and aplitic granites of the south-western part of the area mapped. Usually these rocks are too coarse for geometrical analyses.

In the rather salic granite mentioned there occur streaks of a fine-grained, grayish granite, rather rich in plagioclase. A specimen was subjected to a geometric analysis:

Grayish fine-grained granite 500 m. N.E. of Lake Holmsjön. Even-grained granite rather rich in quartz. Microscopically the composition of the plagioclase was determined to be about Ab_{78} An_{22}. Femic minerals very rare.

The geometrical analysis was calculated as shown in Table 13.

Table 13. Volumetric analysis of fine-grained granite from Holmsjön. Sp. gravity 2.637 (A. Bygdén).

		Volume %		Weight %	Mol. prop.	
Quartz		31.1		31.2		
Microcline-perthite	Mi_{75}	25.4	Mi	20.7	K_2O	37
	Ab_{20}		Ab	3.2	Na_2O	6
	An_5		An	0.8	CaO	3
Plagioclase	Ab_{78}	39.2	An	9.0	CaO	32
	An_{22}		Ab	30.2	Na_2O	58
Biotite		3.5		4.0	K_2O	5
Magnetite		0.8		1.5		
		100.0		100.6		

Calculated sp. gravity 2.66.
An : Or : Ab = 14.2 : 34.0 : 51.8.

Plagioclase-rich granite occurring to the east of Stavsjö Manor. A medium-grained granite, strikingly rich in plagioclase, occurs as dikes in leptite gneiss about 400 m. E. of Stavsjö Manor (fig. 13). The rock shows an even-grained structure. It is very rich in plagioclase with a mean composition of about $Ab_{78} An_{22}$. Microcline is rather infrequent. Magnetite, apatite, and titanite, occur as accessory constituents.

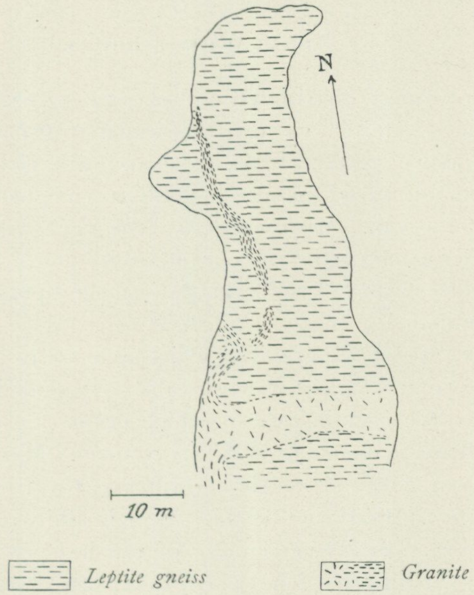

Fig. 13. Granite dikes in veined leptite gneisses to the east of Stavsjö Manor.

The geometrical analysis has given:

Table 14. Volumetric analysis of plagioclase-rich granite occurring about 400 m. to the east of Stavsjö Manor.

Sp. gravity 2.69 (A. Bygdén).

		Volume %		Weight %	Mol. prop.	
Quartz		36.8		36.4		
Microcline-perthite	Mi_{83}	14.9	Mi	11.9	K_2O	21
	Ab_{17}		Ab	2.4	Na_2O	65
Plagioclase	Ab_{78}	41.8	Ab	31.8		
	An_{22}		An	9.5	CaO	34
Biotite		5.4		6.3	K_2O	5
Magnetite		0.5		1.0		
Apatite		0.3		0.3		
Titanite		0.3		0.4		
		100.0		100.0		

Calculated sp. gravity 2.69.

An : Or : Ab = 15.7 : 24.1 : 60.2.

The rock is surrounded by a leptite gneiss (fig. 13), rich in microcline and cordierite, but relatively poor in quartz and plagioclase. Evidently the granite dikes cannot have obtained their characteristic composition through assimilation with the intersected material.

Aplitic, salic granites.

These rocks are widely distributed and occur essentially as two types. The first is fine-grained, aplitic, and exactly similar to the aplite from the neighbourhood of Aspetorp (p. 44). These rocks are fairly rich in quartz and extremely poor in femic minerals, among which biotite, magnetite, and epidote, have generally been observed. Microscopically the rocks show a very uniform composition. Microcline-perthite, poor in albite (Or_{80} Ab_{20}), and plagioclase (generally oligoclase) occur, usually in the same proportions. Sometimes the former is predominant.

The other salic type of the granites, which extends to the west of the valley between Stubbetorp and Lake Strålen, is also very poor in femic constituents. It is generally much richer in quartz, which occurs as smoke-coloured grains or lengthened lenses (*»quarz-feuilleté»* structure). Microscopically the salic granites present an irregular texture, owing to the irregular distribution of quartz and feldspars. Microcline-perthite, poor in albite (Or_{80} Ab_{20}), is generally predominant. The anorthite-percentage of the independent plagioclase may be estimated at about 20. The plagioclase often presents a simple twin-structure. Biotite, with pleochroism from pale yellowish-brown to dark brown, is always rare. As a rule, the only accessory occurring is magnetite, and that sparingly. Sometimes zircon was also observed.

A salic granite from 500 m. to the north-west of Strålsund presents the following volumetric composition, and the figures (owing to its coarseness, a rather large surface of the rock was measured) are:

Table 15. Volumetric analysis of salic granite occurring about 500 m. to the north of Lake Strålen.

Sp. gravity 2.638 (A. Bygdén).

	Volume %		Weight %	Mol. prop.	
Quartz	37.9		38.2		
Microcline-perthite (Or_{80} Ab_{20})	47.7	Mi	35.5	K_2O	64
		Ab	11.0	Na_2O	21
Plagioclase (Ab_{80} An_{20})	11.6	Ab	8.5	Na_2O	16
		An	3.1	CaO	11
Biotite	2.7		3.1	K_2O	3
Magnetite	0.1		0.2		
	100.0		99.6		

Calculated sp. gravity 2.627.

An : Or : Ab = 5.0 : 60.8 : 34.2.

Mica-bearing porphyritic granite.

(Two-mica granite.)

This very beautiful coarse granite, which is usually characterised by its small proportion of muscovite, forms the chief type of the central parts of the area mapped. Macroscopically it is very characteristic, on account of its lengthened phenocrysts of a sanidine-like microcline-perthite, which form reddish Carlsbad twins, generally only about 1 to 1.5 cm. thick, but often as much as 5 cm. in length (generally 3 to 4 cm.).

The contact-relations towards the other members of the plutonic series have already been touched upon. They may be studied in different localities. W.S.W. of Smedsbygget the contact towards the hornblende-bearing granite is hidden; however, here the latter is observed to present a rather salic type, poor in hornblende and with lengthened phenocrysts of microcline-perthite. To the north of Smedsbygget a beautiful contact-breccia between the two-mica granite and the norite is to be seen; somewhat more to the north the contact is hidden. As previously mentioned, we may assume that here the two-mica granite has cut away a border-zone of hornblende-bearing granite, which will have been situated along the quartz-diorites. Further to the north a similar zone of hornblende-bearing granite occurs, and from this place (about 300 m. N. of Smedsbygget) the contact between the granites can be followed to the neighbourhood of Aspetorp. Along this stretch there is always a gradual change between the granites. The hornblende gradually disappears and concurrently the phenocrysts of microcline-perthite develop the lengthened type just described. Small scales of muscovite also become visible. In the neighbourhood of Aspetorp and Kopparbolstorp the two-mica granite becomes decidedly porphyritic, with thin and well-shaped perthites, 4 to 5 cm. long. This type cuts the basic rocks and the boundary-facies of the hornblende-granite. Along the shore of Lake Björnsjön the coarse porphyritic granite contains numerous fragments of aplite, a circumstance indicating that the large inclusion of basic rocks and aplite round Kopparbolstorp may originally have been connected with the similar rocks round Aspetorp. Fragments of leptitic gneisses have also been observed. From this observation we may suppose that at one time the coarse granite reached the gneisses, forming a roof over the top of the plutonic mass.

Along the eastern boundaries the coarse porphyritic granite passes over, without any sharp contacts, to medium-grained, muscovite-bearing facies with a rather indistinctly porphyritic texture. Such is the case, *e. g.* to the west and N.W. of Lake Kvarnsjön. Along the northern boundaries, however, the coarse granite often cuts abruptly through the medium-grained granites (E. and E.N.E. of Storgölet). Only along a rather short stretch (S. and S.E. of Smedsbygget) does the granite come into contact with the veined leptite gneisses. The contact is very abrupt, and along it the granite assumes a more medium-grained porphyritic texture. In the neighbourhood of the contact this type occurs also as small dikes, cutting the veined gneisses. The contact is very similar to the contacts of the general Serarchean granites.

The mineral-content of the typical two-mica granite is very uniform. The lengthened perthite-phenocrysts are rather rich in plagioclase (about 30 % is a mean value of several measurements), which occurs as small four-sided inclusions or thin veinlets. Sometimes it shows twin-structure (albite-striation), and in rare cases it could be measured to contain about 15 % of anorthite. Often there also occur small patches of oligoclase-albite, which present irregular contours and are extended to small veinlets similar to, but larger than, the veinlets just described. Small grains of myrmekitic plagioclase occur, generally arranged in strings round the margins of the microcline-phenocrysts. They show irregular contours against the microcline, and sometimes the strings are surrounded by thin zones of pure albite. Both these marginal plagioclases are often visible to the naked eye in the rock-specimens. The amounts of the free plagioclase are usually rather considerable. The mineral occurs as small tables, often well-shaped, with indistinct zonary structure. The composition of the kernels is about $Ab_{70}\ An_{30}$, and that of the external zone about Ab_{80-83}. The medium-grained base of the rock is made up of small shapeless grains of microcline, plagioclase, and quartz. The isometric microcline-perthite contains about 20 % of albite. The percentage of quartz varies, but generally it is relatively low. The quartz is usually crushed or undulous. Among the other constituents, biotite occurs as the characteristic femic mineral. It presents a common grayish-brown type, which occurs as scales, often converted into chlorite. Generally some muscovite occurs, often as intergrowths with biotite. As accessories, apatite occurs abundantly; magnetite, pinkish titanite, and zircon, more sparingly. Orthite has been observed in some thin sections.

Judging from the structural relations of the minerals, the sequence of crystallisation seems to have been the following: The phenocrysts of microcline-perthite were solidified at an early stage, followed by the kernels of the plagioclases and the biotite, which is sometimes enclosed in the external zones of the large microcline-perthite crystals. Some small grains of quartz, sometimes rather idiomorphic (similar to the quartz grains of rapakivi granites), often show a similar occurrence. Consequently we may suppose a very slow crystallisation of the microcline-perthites, and there are indications that the quartz began to solidify before the crystallisation of the microcline-perthite had been completed. The medium-grained matrix of the rock seems to be separated from the early crystallised minerals by a rather marked hiatus. Its crystallisation obviously progressed in association with strong equalisation-reactions between the crystallised components and the remaining solution.

A typical specimen (about 1 kg) has been analysed (N. Sahlbom).

[Contents: Phenocrysts of microcline-perthite ($Or_{67}\ Ab_{29}\ An_{4}$), plagioclase ($An_{75}\ An_{25}$ — $Ab_{82}\ An_{18}$), microcline ($Or_{80}\ Ab_{20}$), quartz, biotite, muscovite. Accessories: apatite, magnetite, titanite, zircon.]

Table 16. Analysis of two-mica granite. The specimen was taken about 700 m. S. of Storgölet.

Sp. gravity 2.703 (A. Bygdén).

		Mol. prop.	Norm.	
SiO_2	64.79	1,079	Q	15.66
TiO_2	0.60	8	Or	35.58
Al_2O_3	17.20	169	Ab	26.20
Fe_2O_3	1.30	8	An	10.01
FeO	3.64	51	C	1.94
MnO	0.04	—	Σ sal	89.39
MgO	1.02	26	$MgSiO_3$	2.60
CaO	2.13	39	$FeSiO_3$	4.62
Na_2O	3.11	50	Mt	1.86
K_2O	5.96	64	Il	1.22
P_2O_5	0.17	1	Ap	0.34
$H_2O + 105°$	0.54		Σ fem	10.64
	100.50		H_2O	0.54
				100.57

An : Or : Ab = 13.6 : 48.5 : 37.9. MgO : CaO : FeO = 42.0 : 0.0 : 58.0.

Quantitative System: Toscanose.

A somewhat modified type of the rock occurs as dikes (see p. 61).

Coarse quartzy granite.

This rock does not occur in direct connection with the coarser granites of the Stavsjö area. It comprises chiefly the great western granite-massive of the Stavsjö section, and there it occurs in a varying series. A small part of the Graversfors granite-mass projects into the eastern part of the area mapped, and here the coarse granite distinctly intersects the medium-grained granites extending from the east. The coarse quartzy granite occurring in the area mapped, is a beautiful flesh-red to dark reddish-brown rock, containing rounded crystals of microcline-perthite (3 to 4 cm. through), which represent the bulk of the rock. The spaces between the large crystals are occupied by plagioclase, some biotite, and large amounts of quartz, which for the most part forms rounded bluish-coloured crystals about $^1/_2$ cm. long, often with a bipyramidal habit. The margins of the perthites usually enclose small quartz grains, which also frequently present the bipyramidal habit and often form small groups, showing the same orientation and giving rise to a structure similar to the graphic texture of pegmatites. The albite-percentage of the perthite-crystals will generally be about 20 to 25. The margins of the large crystals often enclose also small grains of plagioclase, whose boundaries usually show beautiful margins of myrmekite. The independent plagioclase forms rather large idiomorphic crystals, showing distinct polysynthetical twin-structure. No zonary structure is visible. The composition of the plagioclase is $Ab_{74}\,An_{26}$. The quartz forms the bluish crystals mentioned above, but it also occurs as allotriomorphic granulated portions between the other minerals. Among the dark-coloured minerals occur biotite and hornblende. The former presents a brownish-green colour and is very similar to the hornblendes of the quartz-diorites. The hornblende has a pœcilitic structure, due to the inclusions of the accessories, apatite, titanite, zircon, and magnetite. Grains of quartz and plagioclase are sometimes enclosed. The biotite is pleochroic from yellowish-brown to chestnut, and is usually also rich in enclosed accessories.

The rock shows a strikingly fresh structure, undisturbed by deformation. Owing to the characteristic occurrence of quartz, it recalls the rapakivi-structure. Like the rapakivis, the quartzy granite often tends to weather into a sharp gravel, which is often found heaped along the sides of higher granite-hills.

The granite type here described differs somewhat from the well-known types of Graversfors granite found in the stone-quarries at Graversfors. These types have been described by P. J. Holmquist in his well-known monograph on the granite species of Sweden[1]. From Graversfors chiefly two types have been distinguished and analysed.

From the description given by Holmquist, the following short summary may be made:

Macroscopically the red Graversfors granite seems to be a very pure quartz-feldspar granite, composed of dark red feldspar and beautiful blue quartz. Texturally the rock approaches the perthite-quartz granites distinguished by Holmquist. The feldspars do not form large individualised crystals, but occur as a multitude of irregular grains. The quartz-grains form a coarse network, enclosing the complex of feldspar grains; sometimes, however, the quartz seems to acquire a more independent character in relation to the feldspars. Distinguished from the perthite-quartz granites there occur both an albite-poor microcline and an acid plagioclase. On microscopical examination the quartz but seldom shows a tendency to idiomorphism, and such is also the case with the plagioclase. The microcline completely lacks idiomorphic outlines.

An analysis of the rock (anal. H. Santesson) has given the following figures.

Table 17. Analysis of red Graversfors granite (Washington, Chem. An. of Ign. Rocks, 1917, p. 82).

		Mol. prop.	Norm.	
SiO_2	76.90	1,282	Q	42.48
TiO_2	0.50	6	Or	28.91
Al_2O_3	12.53	123	Ab	19.91
Fe_2O_3	0.99	6	An	4.17
FeO	0.66	9	C	1.84
MnO	0.08	1	Σ sal	97.31
MgO	0.17	4	$MgSiO_3$	0.40
CaO	0.86	15	Mt	0.93
Na_2O	2.36	38	Il	0.91
K_2O	4.92	52	Hm	0.32
H_2O+	0.43		Σ fem	2.56
	100.40		H_2O	0.43
				100.30

An : Or : Ab = 7.7 : 53.3 : 39.0.

Quantitative System: Tehamose.

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[1] Studien über die Granite von Schweden, Bull. Geol. Inst. Uppsala, vol. VII, pp. 166 *etc.*, 1904—05.

According to Holmquist, the dark-coloured Graversfors granite is characterised by the occurrence of bronzite and green hornblende. The rock contains large microcline-perthite crystals of a dark brown colour. They are poor in albite. The independent plagioclase is rather rich in anorthite. On the authority of Holmquist, a section perpendicular to P and M has given an oblique extinction of + 12°, corresponding to a composition of $Ab_{72}\,An_{28}$. Individualised crystals of bluish quartz also occur.

The following analysis may be given (analyst H. Santesson).

Table 18. Analysis of dark Graversfors granite (Washington, Chem. An. of Ign. Rocks, 1917, p. 244).

		Mol. prop.	Norm.	
SiO_2	67.93	1,132	Q	31.02
TiO_2	0.30	4	Or	29.47
Al_2O_3	16.28	160	Ab	15.20
Fe_2O_3	2.85	18	An	13.90
FeO	1.38	19	C	2.86
MnO	0.07	1	Σ sal	92.45
MgO	0.90	23	Hy	2.30
CaO	2.81	50	Mt	3.71
Na_2O	1.80	29	Il	0.61
K_2O	5.02	53	Hm	0.32
H_2O+	0.53		Σ fem	6.94
	99.87		H_2O	0.53
				99.92

An : Or : Ab = 23.5 . 49.5 : 27.0.

Quantitative System: Coloradase, subrang 2.

The feldspar-proportions calculated from the analysis seem remarkable on account of the unusually high percentage of anorthite in a granite so rich in potash. Further, there is no conformity between the calculated and the observed composition of the plagioclase, and consequently we may assume that the analysis is not quite correct.

The coarse granites of the granite dikes.

Both types of coarse-grained granites also occur as occasional large dikes, sharply intersecting the leptite gneisses and the other granites. The largest dike extends from the valley to the north of Peterslund towards the ruined church of Krokek. The dike is made up of the two-mica granite previously described, here also very distinctly porphyritic, with the typical rectangular phenocrysts of microcline-perthites. The percentage of quartz is probably somewhat higher in the dike.

N. of Lake Strålen a dike about 20 m. broad extends towards N.N.W. It is made up of a granite presenting differences from the common two-mica granite. In a medium-grained matrix there occur rectangular phenocrysts of microcline-perthite up to 4 cm. long. Usually they form Carlsbad twins and are rather idiomorphic. Their margins often enclose small quartz grains, which show an indication of bipyramidal habit and usually occur in groups showing the same orientation. Their percentage of albite is rather high, about 25 to 30. Inclusions of plagioclase and biotite occur. The basis of the rock is composed of isometric grains of quartz, microcline, and plagioclase. The plagioclase forms grains of varying size; occasional grains are large and show a rather distinct idiomorphism. The composition is very uniform, about $Ab_{75} An_{25}$. Small shapeless grains of an albite-poor microcline-perthite occur in the same amounts as the plagioclase. The percentage of quartz is large, about 30. Usually the quartz forms small shapeless grains; however, there occur scanty large-sized, rather idiomorphic, crystals of bluish colour, evidently forming phenocryst-like individuals. Among femic silicates biotite is common, and there also occurs a sparingly distributed olive-green hornblende. Accessories are apatite, magnetite, titanite, and zircon. In its characteristic blue quartz grains this rock resembles the Graversfors granites and evidently represents a transition-type between the two-mica granite and the Graversfors granites.

Towards W., in the neighbourhood of Åksjön and Lilla Älgsjön, there occur several dikes of a quartzy and distinctly porphyritic granite. The texture is due to the occurrence of rounded phenocrysts of microcline-perthite, 3 to 4 cm. through, (often surrounded by yellowish-red rims of plagioclase) and idiomorphic (bipyramidal) grains of the quartz ($^1/_2$ to 1 cm. through), in a fine-grained ground-mass. The rock belongs to the real Graversfors granites.

On microscopical examination, the microcline-perthite crystals seem to contain about 27 % of albite. The plagioclase rims often surrounding them show a uniform orientation. They are always strongly altered into saussuritic masses and cannot be subjected to optical measurement. At the boundary between the plagioclase rims and the internal microcline-perthite, there occur graphic intergrowths between the two feldspars. In these intergrowths microcline-perthite grains are often completely enclosed in the plagioclase. In these grains the perthite-structure is quite similar to that of the microcline-perthite kernels, and the albite spindles are here also quite fresh, and consequently differ from the altered plagioclase of the rims. From these observations we may conclude that the formation of the plagioclase rims was independent of the origin of the perthitic structure and is older. Probably they originated during the magmatic stage of the rock. Phenocrysts of plagioclase are not so frequent as the perthites. They are rather well individualised, often saussuritised, and contain antiperthitic inclusions of microcline. A section of plagioclase was determined as having a composition of $Ab_{74} An_{26}$.

The boundaries between the phenocryst-like quartz grains and the ground-mass are well-defined and usually straight. Often the grains present an idiomorphic, bipyramidal habit. The ground-mass is made up of a fine-grained mixture of quartz, altered plagioclase, some microcline, and rather large amounts of femic minerals, among which a brownish-green biotite, often converted into chlorite, is predominant. Some rather idiomorphic grains of a probably primarily crystallised epidote have been observed. Accessorial magnetite, apatite, titanite, and zircon, are common.

III. Diabase.

Narrow diabase dikes are rather common in the area. Usually they have a vertical dip and extend in a direction N.W. to S.E. The diabases are younger than all the other rocks of the area. Generally they follow the long straight valleys extending from N.W. to S.E. These valleys are due to the influences of erosion along pre-Cambrian cracks intersecting the Archean rocks. The cracks were probably formed contemporaneously with the intrusion of the diabases. In a paper previously published[1], the present author has expressed the opinion that this characteristic orography of the provinces of Södermanland and Östergötland originated during the late pre-Cambrian, probably sub-Jotnian, period.

Regarding their mineralogical composition, the diabases usually approach the »uralite»-diabases of Southern Sweden. Generally they form dense black rocks which, on microscopical examination, show an ophitic texture, due to the radiating arrangement of the plagioclase clusters and the occurrences of interstitial uralite masses. The uralite was produced through the alteration of ophitic pyroxenes, probably rich in ferrous iron. The uralite is often converted into chlorite, and magnetite is always abundant.

Some dikes are composed of phenocryst-bearing uralite-diabases. To the north-west of Peterslund, for example, there occur a number of narrow diabase dikes (about 1 m. broad), which contain white and black phenocrysts. The former obviously originate from plagioclases now completely converted into epidote and chlorite. The latter are now composed of uralite, probably an alteration-product of pyroxene. In a narrow dike which intersects the granite dike described above, N. of Lake Strålen, small phenocrysts ($^1/_2$ to 1 mm.) of a colourless hypersthene-augitic pyroxene appear. This pyroxene was proved to have $2E = 81°$ to $88°$, and, giving β the value 1.70, we find $2V = 45°$ to $48°$. Consequently it belongs to the type of augites which have also been observed in the quartz-diorites previously described. This diabase also contains small amygdules of calcite or quartz. The ground-mass is strongly altered into uralitic masses, containing plagioclase laths and grains of iron-ore.

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[1] B. Asklund, Bruchspaltenbildungen im südöstlichen Östergötland *etc.*, G. F. F., vol. 45, p. 273.

CHAPTER 3.

The Crystallisation-Types of the Different Rocks.

Before giving a more exhaustive geological and theoretical account of the age-relations and differentiation-relations of the rocks studied, it may be of interest — from the quantitative data already presented and on the basis of the analyses and microscopical investigations — to recapitulate and discuss the crystallisation-types of the different rocks. The chief result of such a discussion is that we find every type of rock shows its clearly limited crystallisation-courses, a fact which is of importance in principle for the understanding and interpretation of the differentiation.

The gabbro-granite rocks of the area have evidently all been crystallised under abyssal conditions. No obviously chilled contact-rocks have been observed. This fact squares with what has usually been found to be characteristic of the younger Archean granites of Fenno-Scandia.

First of all, the slow crystallisation of the rocks caused the extensive equalisation-reactions which passed on between solid and liquid phases, and which resulted in a fairly uniform composition of the rock-minerals; these latter generally show no pronounced zonary structures and there are no real ground-masses.

Crystallisation of the Feldspars.

Usually the different crystallisation-courses of the various magmas or structure-types are not very closely considered. The writer who has most exhaustively discussed the crystallisation of the feldspars seems to be H. E. Johansson[1], whose very valuable investigations regarding »the composition and conditions of formation of the feldspar-minerals» have not yet been sufficiently taken into consideration.

Starting from the assumption that moderate amounts of femic components in a magma tolerably rich in alkalifeldspar, do not essentially influence the crystallisation-courses of the feldspars, Johansson has calculated[2] the molecular feldspar-proportions of a multitude of rocks and plotted them into triangle-diagrams with reference to the three chief components, feldspars of lime, soda, and potash. This diagram has provided the basis for a discussion of different magma types under different cooling conditions. As another basis for this discussion, Johansson has submitted a diagram calculated in a similar way, representing about 470 feldspar analyses, which were sufficiently exact to be used (about 500 rejected). This diagram (cf. fig. 14, p. 66) shows the ternary mixing

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[1] Om fältspaternas sammansättning och bildningsbetingelser, G. F. F., vol. 27, 1905, pp. 338 *etc.* — Cf. also J. H. L. Vogt, Die Silikatschmelzlösungen, Videnskabs-Selskabets i Christiania Skrifter, Math.-Naturvidenskab. Klasse, 1904, 1, pp. 180 *etc.*

[2] The method of calculation is the same as that employed in the quantitative system. Consequently the alkali-oxides are calculated as alkalifeldspars, an amount of CaO equal to the Al_2O_3 remaining from the alkalifeldspars is allotted for anorthite. CaO is also allotted for P_2O_5, *etc.* Cf. H. S. Washington, Chemical Analyses of Igneous Rocks, U. S. Geol. Surv., Prof. Pap., 99, 1917, p. 1162.

boundary of the feldspars and the large area of discontinuity, within which feldspar liquids had to crystallise with two conjugated feldspars.

The feldspar diagram Johansson divides into feldspars deriving from quartz-free or very quartz-poor rocks, and, on the other hand, feldspars deriving from granitic rocks. The feldspars from the latter show »essential limitations regarding the capability for the simple feldspar-silicates to form mix-crystals, caused by the entering of quartz into the magmatic feldspar-solutions». Those feldspars which, in their geological occurrence, indicate a relatively low crystallisation-temperature (feldspars from adularia-veins and ore-veins) show very great limitations in forming mix-crystals. Starting from these conditions, Johansson states »that the usual occurrence of inhomogeneous, perthitic, feldspars in nature must be attributed to a constitutional alteration-process attacking the primary mix-crystals below the original crystallisation-temperature, and at a falling temperature, causing a successive limitation of the ability to form mix-crystals».

Subsequently Johansson has further graphically discussed the differences between the rapid or slow crystallisation of the feldspars[1].

In the case of a rapidly cooling crystallising magma, the equalisation-reactions between the solid and liquid phases must be unimportant, and consequently the crystallisation-line of the ternary feldspar-mixture must take a rather acute dip towards the individualisation-boundary between the potash-richer alkalifeldspars and the plagioclases (cf. fig. 16, p. 70); and the line will follow this boundary simultaneously with a successive crystallisation of more acid plagioclases and increasingly soda-rich potash-feldspars, until a simultaneous crystallisation — through the formation of mix-crystals — will take place, when the composition of the liquid phase corresponds to the composition of the minimum of the liquidus surface of the ternary system, or until under-cooling, with a final formation of a glass-matrix, may supervene. In the case of a slow crystallisation, on the other hand, which is typical of abyssal rocks, very strong equalisation-reactions between the already crystallised and the liquid phases will take place, and consequently the crystallisation-line of the mixture will assume an obtuser dip towards the individualisation-boundary. The course along this boundary, also, will be very short, and the crystallisation will cease long before the minimum or eutecticum is reached (cf. fig. 16).

Johansson has already shown the composition of the feldspar-minimum to lie at the mixing-ratio of about $Or_2\,Ab_3$. This ratio characterises the ideal trachyte ground-masses and also seems to have an equivalence in the eutectic quartz-feldspar mixture, which corresponds to the composition of the genuine obsidians (the phenocryst-free liparites)[2].

In a way analogous to that of Johansson, E. Mäkinen[3] has graphically treated the feldspar analyses available in the mineralogical literature and grouped them into different triangle-diagrams. Of special interest is the diagram of pegmatite-feldspars, which assumes the capacity for forming mix-

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[1] *Op. cit.*, p. 342 and Die eisenerzführende Formation in der Gegend von Grängesberg, G. F. F., vol. 32, I, p. 392.

[2] Om de eutektiska blandningarnas sammansättning, G. F. F., vol. 27, pp. 133 *etc.*

[3] Über die Alkalifeldspäte, G. F. F., vol. 39, pp. 121 *etc.*

crystals in quartzy pegmatites to be essentially reduced[1]. However, there also occur feldspars of quartziferous pegmatites within the discontinuity-area marked by Mäkinen, and consequently this area may be considered to be questionable until further evidence is forthcoming.

Using the calculation tables of Mäkinen, the author has re-grouped the feldspar analyses (fig. 14). All the phenocryst-feldspars are included in one group; the feldspars of plutonic rocks, however, are divided into two groups, one comprising the feldspars of rocks rich in quartz and the other comprising those of the quartz-free or quartz-poorer rocks. The pegmatite-feldspars have also been marked, and in a special diagram the feldspars of druses were plotted (fig. 15). Among the limits for the mix-crystals, only that drawn by Johansson for syenites and gabbros (I) is quite definite.

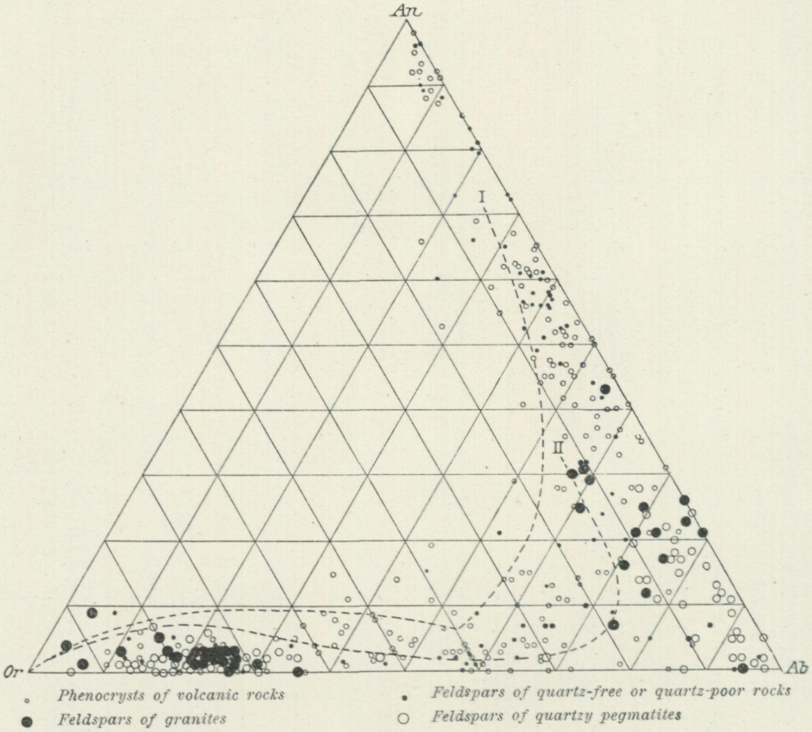

Fig. 14. Feldspar analyses plotted according to Johansson.
I the ternary mixing-boundary according to Johansson.
II provisional ternary mixing-boundary for acid plutonic rocks.

The distribution-area of phenocryst-feldspars evidently indicates the largest distribution of the mix-crystals; an upper limit for this distribution cannot yet be drawn. Essential limitations already affect the feldspars of the quartziferous volcanic rocks (cf. the diagram by Johansson, G. F. F., vol. 27, p. 340).

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[1] The quartz-free pegmatites, on the other hand, chow a complete series of mix-crystals between the alkalifeldspars (cf. Mäkinen).

A division into granite and pegmatite groups does not at present seem to be justified; considering them together, however, the feldspars of these rocks show essential limitations in the capability of forming mix-crystals. Still more evident limitations are presented by the druse-feldspars and analogous low-temperature feldspars (cf. Johansson and Mäkinen).

The individualisation-boundary between potash-feldspars and soda-lime feldspars is drawn after Johansson. It would be very important for petrology if this boundary were also determined for the quartz-rich magmas. The information available is too scanty for such a determination, but the present data vindicate the statement that there are no changes in the proposed individualisation-boundary, even in the case of the acid magmas.

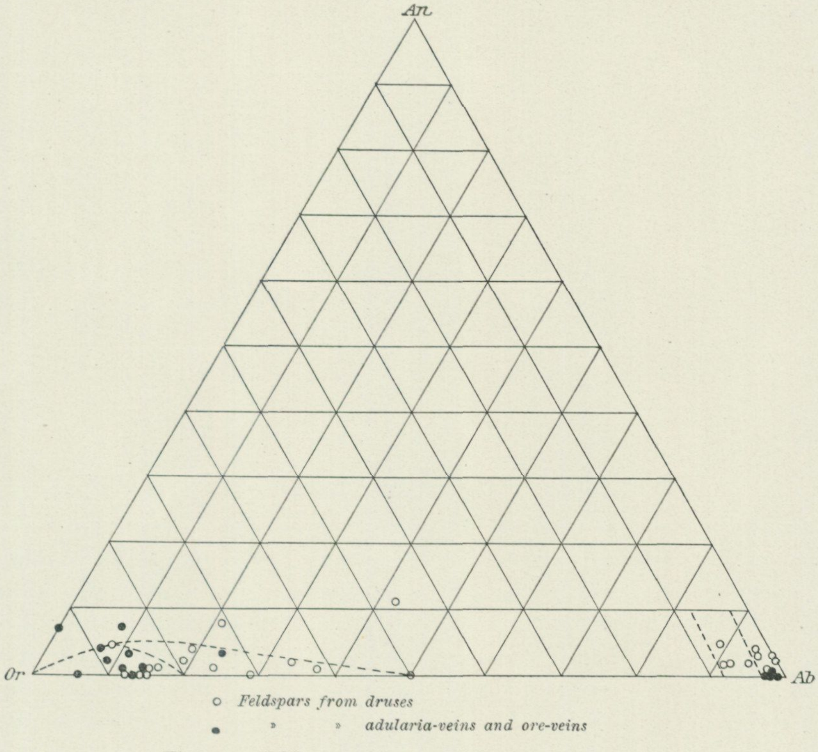

Fig. 15. Feldspar analyses of low-temperature type.

The rocks described in this paper offer much of interest regarding the crystallisation of the feldspars. In this respect the rocks may be divided into basic rocks, granites, and helsinkites.

Basic rocks. The thorough investigations carried out in determining the quantitative proportions of the minerals of the analysed noritic gabbro, are here made the basis of a study of the composition of the feldspar-solutions during the course of the crystallisation of the rock. From the petrological description we may adduce the following table:

Table 1. Analysis of typical *quartz-biotite norite* (anal. N. Sahlbom). The specimen was aken 600 metres S. of Eskilstorp, in the parish of Kila, in the province of Södermanland. Specific gravity (determined by Dr. A. Bygdén) 2.932.

	Molecular proportions[1]	Norm	Actual Composition (Weight %)	Volumetric Composition
SiO_2 . 52.79	880	Or . 8.90	Quartz 2.53	Quartz 2.8
TiO_2 . 1.12	14	Ab . 26.20	Microcline 1.39	Microcline 1.6
Al_2O_3 . 13.79	135	An . 19.18	Plagioclase 42.66	Plagioclase 46.8
Fe_2O_3 . 1.91	12	Σ sal 54.28	An_{51} Ab_{49} 19.53	An_{51} Ab_{49} 21.2
FeO . . 8.13	113		An_{31} Ab_{69} 19.17	An_{31} Ab_{69} 21.2
MnO . 0.09	1		An_{25} Ab_{75} 3.96	An_{25} Ab_{75} 4.4
MgO . 8.34	209	Di . 18.48	Σ sal 46.58	Σ sal 51.2
CaO . 8.84	158	Hy . 16.31	Hypersthene + Hypersthene-augite . 27.09	Hypersthene + Hypersthene augite . . 23.7
Na_2O . 3.12	50	Ol . 5.26	Diallage-like augite 18.24	Diallage-like augite . 16.4
K_2O . 1.48	16	Mt . 2.78	Biotite 6.57	Biotite 6.4
P_2O_5 . 0.29	2	Il . . 2.13	Magnetite 3.19	Magnetite 1.8
$H_2O+105°$ 0.20		Ap . 0.67	Apatite 0.54	Apatite 0.5
		Σ fem 45.63	Σ fem 55.63	Σ fem 48.8
$H_2O-105°$ 0.12		H_2O . 0.32		
100.22		100.23	102.21	100.0

Calculated sp. gr. 3.001.

Quantitative system: Camptonose.

From this table, according to Johanson's method of calculation and diagram-plotting, we may re-calculate the following figures of the feldspar-components of the rock. In order to simplify the calculations, the probably very unimportant percentage of potash-feldspar in the plagioclases is not taken into consideration. From the measured and calculated quantities of biotite (6.57 weight percentage), we may assume about 10 % to be K_2O, *i. e.* about 0.66 weight percentage. This value corresponds to about 7 molecules of the molecular proportions of the rock. In the amount of microcline (1.39 weight percentage) about 3 molecules of K_2O are taken up. Consequently about 6 molecules of K_2O may have entered into the plagioclases, a quantity not at all affecting the correctness of the following calculations.

We now get:

	Weight percentage	Feldspar-forming		oxides	Proportions of feldspars	
		CaO	K_2O	Na_2O	An : Or : Ab	
The norite (feldspars)	54.28	69	16	50	34.5 : 16.0 : 49.5	(N)
Labradorite	19.53	37	—	18	51 : 0 : 49	(L)
Andesine	19.17	22	—	25	31 : 0 : 69	(A)
Oligoclase	3.96	4	—	6	25 : 0 : 75	(O)
Microcline	1.39	—	3	—	— : 100 : —	

[The letters (N), (L), *etc.*, appear in fig. 16].

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[1] According to H. S. Washington, Chemical Analyses of Igneous Rocks, U. S. Geol. Surv., Prof. Pap. 99, 1917.

Subtracting those oxides entering into the feldspars from the sum of the oxides of the rock, we get the following data regarding the quantities of feldspar oxides entering the biotite and the pyroxenes:

The biotite has taken up 13 molecules K_2O (7 mol., cf. p. 68)
The pyroxenes have taken up $\begin{cases} 6 \text{ » } CaO \\ 1 \text{ » } Na_2O \end{cases}$

Now we can approximately follow the quantitative courses of the continuously crystallising magma, its solid phases, and the remaining liquid phase. For the following calculated proportions, the feldspar-quantities broken up to enter into the biotite and the pyroxenes were taken into consideration. Still we must consider the crystallisation-intervals of those minerals in relation to the feldspars. With regard to the pyroxenes, they seem to have been entirely crystallised quantitatively before growing out of the andesine borders round the labradorite nuclei. The crystallisation-interval of the biotite is rather more difficult to estimate; probably the greater part of the mineral was crystallised after the andesine, pyroxenes, and accessories. However, there are indications that some small quantities of dark-brownish biotite crystallised very early as reaction rims round early crystallised titaniferous magnetite. Evidently the crystallisation-interval of the biotite is very extended and probably ceased after the crystallisation of the microcline, judging from the myrmekitic (or synantetic) intergrowths with quartz, which occur at the boundaries between biotite and microcline, and which probably originated after the crystallisation of the microcline. However, the feldspar-proportions present during the final stage of the crystallisation of the rock may be fixed as lying between two limits. Assuming, on the one hand, all the biotite to have grown out contemporaneously with the andesine, and, on the other hand, all the biotite to have crystallised after the andesine, we get following general view—bearing in mind the above calculations.

The feldspar-composition of the remaining liquid,

1) after the crystallisation of labradorite and pyroxenes

CaO	K_2O	Na_2O (molecules)	An : Or : Ab
26	16	31	21.7 : 26.7 : 51.6 (R_I)

2 a) after the crystallisation of the andesine. All the biotite is assumed to have crystallised *contemporaneously* with the andesine.

CaO	K_2O	Na_2O (molecules)	An : Or : Ab
4	3	6	18.2 : 27.3 : 54.5 (B_I)

2 b) after the crystallisation of the andesine. All the biotite is assumed to have crystallised *after* the andesine.

CaO	K_2O	Na_2O (molecules)	An : Or : Ab
4	16	6	8.3 : 66.7 : 25 (B_{II})

(The symbols R_I *etc.* appear in fig. 16.)

The results are graphically represented in fig. 16. Here also the quantities of the different phases are taken into consideration; the diameters of the circles are proportionate to the molecular quantities in question. Entering the individualisation-boundary on the diagram and drawing a junction-line between the limits B_I and B_{II}, we get an intersection which should exactly correspond to the feldspar-proportions at the end of the crystallisation (the intersection R_{II} on the diagram corresponds to $An_{15}\ Or_{41}\ Ab_{44}$). The fact that some microcline occurs in the rock indicates that the individualisation-boundary was certainly reached, and from this fact it is also evident that some biotite was crystallised after the microcline had begun to grow out. Thus, under special circumstances, biotite may crystallise during a very late stage of rock-crystallisation, a fact also discussed by Sundius[1] and others.

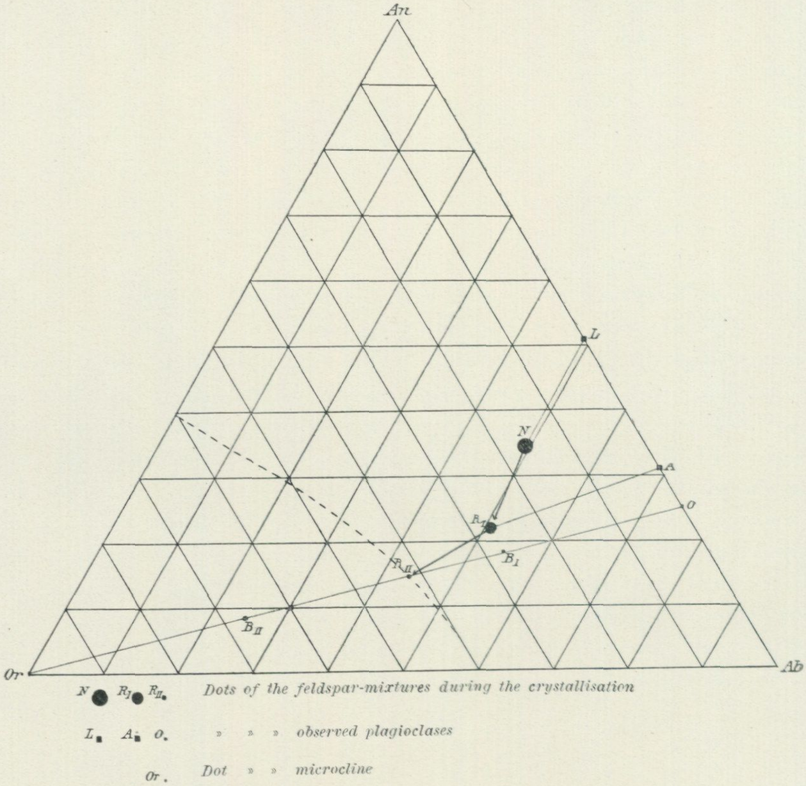

Fig. 16. Survey of the crystallisation of the feldspars in the noritic gabbro.

Among the basic rocks, the quartz-diorites — as far as concerns their feldspar-crystallisation — approach the granites. There is only one detail to be mentioned, *viz.* the complex composition of the quartz-plagioclase »nodules» of the diorites. Like the pseudo-phenocrysts of the noritic gabbro, they show a strongly com-

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[1] Åtvidabergstraktens geologi och malmfyndigheter, Sveriges geologiska undersökning, Ser. C, no. 306, pp. 39 *etc.*, and 113 (summary).

plex composition, primarily crystallised out of the magmas. Later on, they become subject to the perthitic breaking-up, probably at a very early stage, as characterised by a double perthite-structure: an antiperthitic coarser intergrowth and a later perthite-separation of albite in the already separated microcline inclusions. Feldspars of this complex type are lacking among the granite-feldspars. In the syenitic magmas they are represented by the rhomb-feldspars[1], whose composition indicates that these feldspars were crystallised at a much higher temperature than that of the crystallisation-interval of the granites. Their occurrences in the present rather quartzy rocks, on the other hand, show that the ternary mixing-area which separates the granites from the more basic rocks is probably characterised in nature by a continuous limitation, owing to the temperature-lowering influence of the other liquid components present.

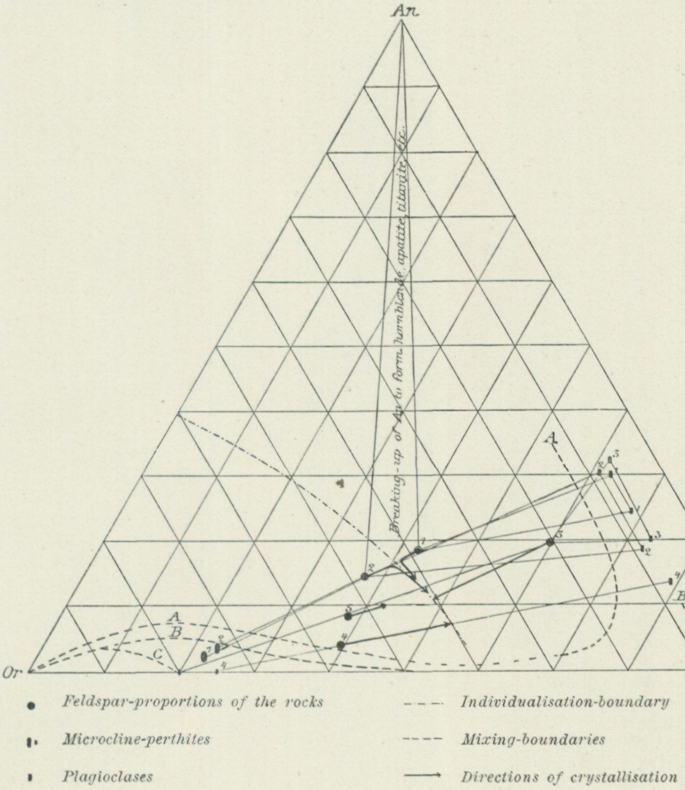

Fig. 17. Survey of the feldspar-crystallisation of the analysed granites. A, B, and C, mixing boundaries.

1. hornblende-bearing granite. 2. two-mica granite. 3. soda-rich granite. 4. aplite. 5. red Graversfors granite.

(As regards no. 3., cf. the discussion on p. 74.)

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[1] Cf. H. E. Johansson, G. F. F., vol. 32, p. 375.

Granites. In contrast to the gabbros, the granites have crystallised under still stronger equalisation-reactions between liquid and crystallised phases. No real ground-masses are formed, but the anorthite-richer granites show some indications of ground-masses (fig. 17, nos. 1 and 2).

In the hornblende-bearing porphyritic granite (1), there occur large and numerous microcline-perthite crystals and large sporadic plagioclases. The latter may be considered to constitute an earliest phase of phenocrysts. On account of the ability of the plagioclase to form relatively numerous centres of crystallisation, this characteristic texture becomes somewhat indistinct. The two-mica granite (2) shows a really obvious hiatus between the earlier crystallisation of the rectangular microcline-perthites and the later crystallisation of the even-grained base. In the latter there also occur small shapeless individuals of microcline as well as plagioclase grains. In view of these facts, we may state the crystallisation-lines of both these rocks to be opposed to each other. Thus the individualisation-boundary of the feldspars must lie between the feldspar-proportions of these rocks — which, as a matter of fact, is actually the case.

Though some theoretical compilations (cf. p. 104) assume an important displacement of this boundary towards the potash-feldspar corner in the diagram, the present rocks show that there are no displacements of the individualisation-boundary of the quartzy magmas compared with the boundary drawn by Johansson for the quartz-poor and quartz-free magmas.

Still more evidently is this fact illustrated by the analysed aplitic granite (no. 4 of the diagram of fig. 17). Though in this rock the microcline is shapeless, yet some plagioclase individuals show some indications of being idiomorphic, evidently the microcline began to crystallise before the plagioclase. A contrary assumption would have given the feldspars of the rock quite different proportions. Owing to a very early beginning of the crystallisation of the plagioclase, the feldspar-proportions of the rock would have entered the ternary area of mix-crystals on the Or-side of the diagram, and consequently a plagioclase-poor quartz-perthite granite would arise. Some figures will explain these circumstances. Supposing a plagioclase-quantity of 6.32 weight-percentage ($Ab_{85}\,An_{15}$) (about 20 % by weight of the whole quantity) should have been crystallised, the feldspar-proportions of the remaining magma would be $An_{2\cdot0}\,Or_{63\cdot0}\,Ab_{35\cdot0}$ This composition would certainly crystallise as a homogeneous potash-feldspar. A presumption that the area of mix-crystals had already been limited does not explain the dissimilar modal proportions of the rock; for, pre-supposing a so limited capability of forming mix-crystals as characteristic of the druse-feldspars, only about 40 % by weight of the total quantity of plagioclase would crystallise (13.72 % crystallised plagioclase gives the remaining magma the following proportions: $An_{1\cdot4}\,Or_{71\cdot0}\,Ab_{27\cdot6}$). Nor does this quantity show any similarity to the present quantity, 20.1 %.

Consequently, for this Or-rich rock also, the direction of crystallisation must be similar to the direction of the crystallisation of the porphyritic two-mica granite, and there are indeed no facts indicating a displacement of the individualisation-boundary as drawn by Johansson[1].

The diagram of fig. 18 illustrates the medium-grained granites. It is based upon a number of geometrical analyses. These granites show a more pronounced equilibrium between the different feldspars. Some zonary structures and also a slight indication of porphyritic structure are observed (1 and 2); however, the allotriomorphic texture is generally predominant.

The texture of the porphyritic granites is also pronounced, owing to the ability of the potash-feldspar to form only sparing centres of crystallisation compared to the plagioclases. A similar texture is also to be observed among the effusive rocks. In these rocks the orthoclase or sanidine individuals are usually larger and rarer than the phenocrysts of plagioclase. Among the present rocks, this difference of crystallisation-ability is especially marked in the hornblende-bearing granite. At the beginning of the crystallisation, large,

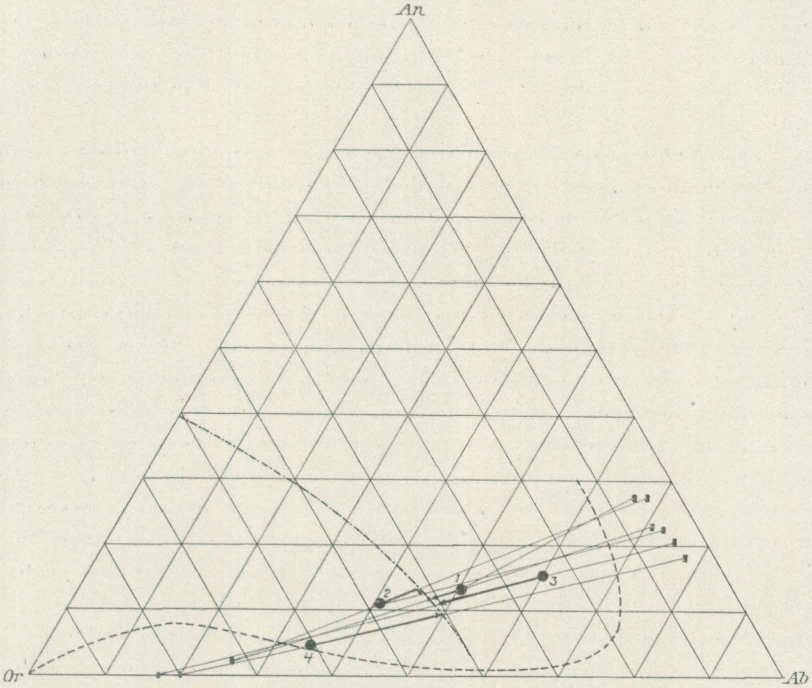

Fig. 18. Survey of the feldspar-crystallisation in the medium-grained granites. (As regards the dots, cf. fig. 17, p. 71.)

1. medium-grained granite from the north of Stavsjön.
2. » » » » » south of Bråten.
3. » » » » » east of Stavsjö Manor.
4. salic granite from the north of Lake Strålen.

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[1] The studies of J. H. L. Vogt have also led to a similar result. Über anchi-monomineralische und anchi-eutektische Eruptivgesteine, Videnskabs-Selskabets Skrifter, I. Math.-Naturv. Klasse, 1908, no. 10, pp. 50—100.

but rare, centres of plagioclase grew out. Later on, when the individualisation-boundary was reached, sparse centres of potash-feldspar and numerous centres of plagioclase were formed. No indications of differences in the rapidity of crystallisation can be observed, since there occur no ground-masses.

The rather porphyritically textured granites occurring as sporadic dikes round about Lakes Älgsjön and Åksjön (p. 62) are very interesting for this discussion. In these granites the microcline-perthites, as well as the occasional large plagioclases and the abundantly occurring quartz grains, acquire the character of real phenocrysts. This generation is distinctly bounded against a ground-mass, which contains a new generation of microcline-perthite, plagioclase, and quartz. Sometimes the large microcline-perthites are bordered by oligoclase-albite, in which case the rocks become similar to some rapakivi granites.

The author defers a more exhaustive discussion of the quartz-richer granites of the Graversfors types to the detailed description of the Graversfors mass. Now, summarising the feldspar-crystallisation of the granitic rocks, it need only be stated that especially the anorthite-richer granites — taking into consideration their textural habits — show similarities to the volcanic rocks. There cannot exist a real difference between the »eyes» of the porphyritic granites and the phenocrysts of similarly composed volcanic rocks. The beginning of the crystallisation-courses must have been analogous; the textural differences, however, are due to strong equalisation-reactions between the crystallised and liquid phases. As Johansson has shown, these reactions impede the advance of the remaining liquid to an eutectical quartz-alkalifeldspar composition. It need only be added that, to a large extent, especially the sparse primary crystallisation-centres of potash-feldspar must also be the centres of the later crystallisation-stages, and in this way the porphyritic structure of anorthite-richer granites must become more pronounced.

Among the femic minerals of the granites, only the biotite (and muscovite) seems notably to influence the crystallisation of the feldspars. Such an influence is to be studied in the analysed oligoclase-granite of the area. The plotting dot of that granite (An : Or : Ab = 19.7 : 20.5 : 59.8) falls within the area of two feldspars. However, the rock contains no free centres of potash-feldspar. This fact may be explained on the assumption that the biotite has taken up so much of the potash that the remaining magma could not reach the individualisation-boundary of the two feldspars, and consequently, during the course of crystallisation, the remaining liquid of the rocks has become very poor in potash. For several mica-richer granites, the mica-forming reactions must have a great influence upon the crystallisation of the feldspars.

The helsinkites. In the diagram of fig. 19 the calculated and the observed feldspar-proportions of the Stavsjö helsinkites (1 and A) and those of the analogous Finnish rocks, have been plotted[1] (2 and B helsinkite from Hogland [Suursaari], A. Laitakari; 3 and C medium-grained »natron-syenite» from

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[1] This diagram was drawn before the intermediate helsinkite from Aspetorp was analysed, and consequently its figures are not entered in the diagram.

Räsy, Oulainen, E. Mäkinen). The rather important anorthite-percentage calculated from the analyses was evidently broken up already in the magmatic stages of the rocks, to form epidote, and consequently the feldspar-proportions have been transferred to the Or-Ab-line of the diagram. The extremely limited ability of these rocks to form mix-crystals of feldspars (*e. g.* the very soda-rich »natron-syenite» from Oulainen contains two feldspars) shows that they must have crystallised at a low temperature, corresponding to that of the adularia-druses or ore-veins. The lowering of the temperature is evidently due to the high percentage of water in these magmas. The hydrohermal epidote and chlorite may also have influenced the crystallisation in a similar direction.

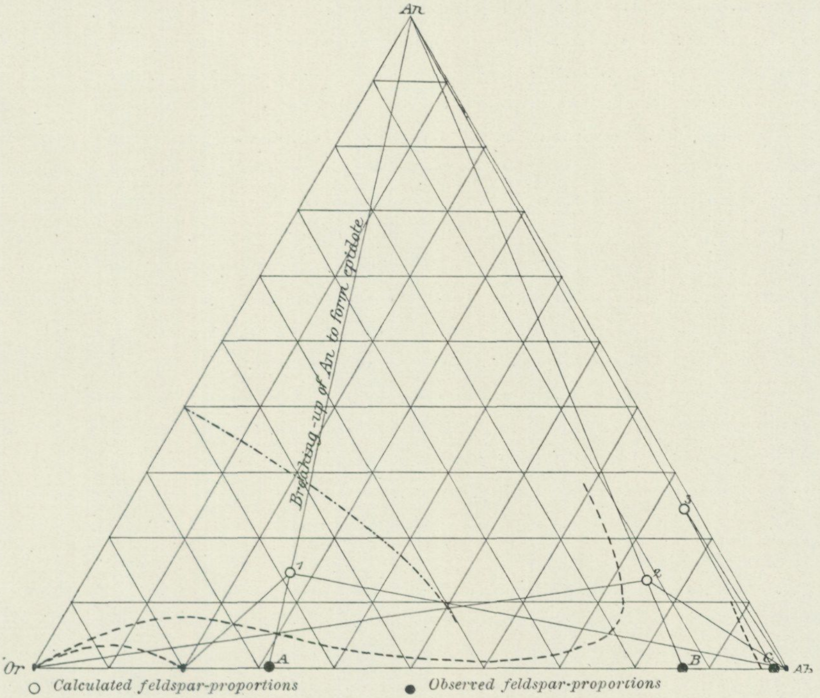

Fig. 19. The feldspar-crystallisation of the helsinkites.

A. Potash-helsinkite from Aspetorp, Stavsjö.
B. Helsinkite, Hogland (Suursaari).
C. Medium-grained soda-syenite, Oulainen.

Crystallisation of the Pyroxenes.

No standard method is available to get a graphic survey of the femic (and especially the metasilicatic) proportions of rocks. The first method to this end was suggested by W. Wahl[1]. In a triangle-projection Wahl expressed the molecular proportions of the metasilicatic MgO, CaO, and FeO, of diabases

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[1] Die Enstatitaugite, In. aug. Diss., Helsingfors 1906, pp. 51—62. Also in Tscherm. Min. u. Petr. Mittheil, 1907—08, p. 1.

and meteorites and their pyroxenes. For this purpose the Fe_2O_3-percentage of the pyroxene of the rock was re-calculated to FeO, a method of calculation whose uncertainty had already been pointed out by Wahl. Much more favourable, however, did the same calculations become, when the Fe_2O_3-percentage was not taken into account. Such a method was employed by Dr. H. E. Johansson for plotting diagrams of the pyroxenes and hornblendes. Those diagrams are not yet published, but Dr. Johansson has shown them to the present author. They were worked out before a similar diagram regarding the pyroxenes and some pyroxenitic rocks had been published by R. B. Sosman[1]. The latter worked out a statistical survey of pyroxenes and pyroxenites, whose sum of molecular-percentages for $MgO + CaO + FeO + SiO_2$ was greater than 94 % of the total molecular percentage of the mineral or rock in question. From this diagram, as well as from that of Johansson, an area between the $MgSiO_3$-$FeSiO_3$ series and the diopside-hedenbergite series was, as a matter of fact, found to contain no dots of pyroxenes, but, on the contrary, contained the dots of pyroxenites bearing two kinds of pyroxenes.

During several years the present author has been working on an extension of these calculation-methods, to get a comprehensive survey of the crystallisation-courses of the pyroxenes and pyroxene-bearing rocks. For the present only the Ca-Mg-Fe-pyroxenes have been considered.

In rocks whose femic silicates are completely dominated by abundant pyroxenes, the femic CaO (remaining after allotting CaO for anorthite, apatite, *etc.*), FeO (remaining after allotting FeO for magnetite, ilmenite, pyrite, *etc.*) and MgO, must express the metasilicatic proportions of the modal pyroxenes fairly exactly. The correctness of the relation between this »normative» and the modal proportions is naturally influenced by the percentages of magnetite and ilmenite, considering their oxide-components which enter into the pyroxenes, or form titaniferous magnetite. However, in plutonic rocks the predominant percentages of Fe_2O_3, and probably also the TiO_2, will enter into magnetite (cf. norm and mode of the analysed noritic gabbro, p. 19); and also in view of the high molecular weights and relatively unimportant occurrences of these oxides in the rocks, the miscalculation of the FeO-metasilicate will be unimportant when there occurs abundant FeO in the rock. In the same way the proportions of MgO : FeO will be very slightly influenced by small quantities of biotite. The quantitatively dominating formation of biotite seems partly to belong to a stage when the pyroxenes are already crystallised, with a composition regulated by the original metasilicatic proportions of the rock; and, on the other hand, the MgO-FeO-proportion of the biotite may be partly regulated by the pyroxenes already crystallised, which, through the resorbing influence of the remaining liquid magma, contribute to the forming of biotite. The CaO-concentration of the metasilicates is to some extent influenced by the percentage of anorthite broken up to supply $CaO . Al_2O_3 . SiO_2$ to the pyroxenes.

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[1] Minerals and Rocks of the Composition $MgSiO_3$-$FeSiO_3$, Journ. Wash. Acad. of Science, 1911, 1, p. 54. — Reviewed in H. Boeke, Grundlagen der physikalisch-chemischen Petrographie, Berlin, 1915, p. 186.

As regards the analysed noritic gabbro, this quantity has been approximately calculated from thorough quantitative studies of the plagioclases. The quantity is unimportant and no longer influences the calculation.

Starting from these data, the author (using the standard work of H. S. Washington on »Chemical Analyses of Igneous Rocks»[1], a work whose importance from a petrographical point of view cannot be over-estimated) has calculated the MgO : CaO : FeO proportions for all »superior» analyses of pyroxenites, gabbros, and diabases. After studies[2] of the literature available in the well-equipped library of Sveriges Geologiska Undersökning and other Swedish public libraries, information as to the pyroxenes occurring, has been assembled. The acceptable analyses have been plotted into a triangle-diagram (as regards the available molecular proportions of MgO, CaO, and FeO, re-calculated to represent a total of 100). The diagram (fig. 20) only refers to rocks with a high percentage of metasilicatic components, crystallised as pyroxenes. Small

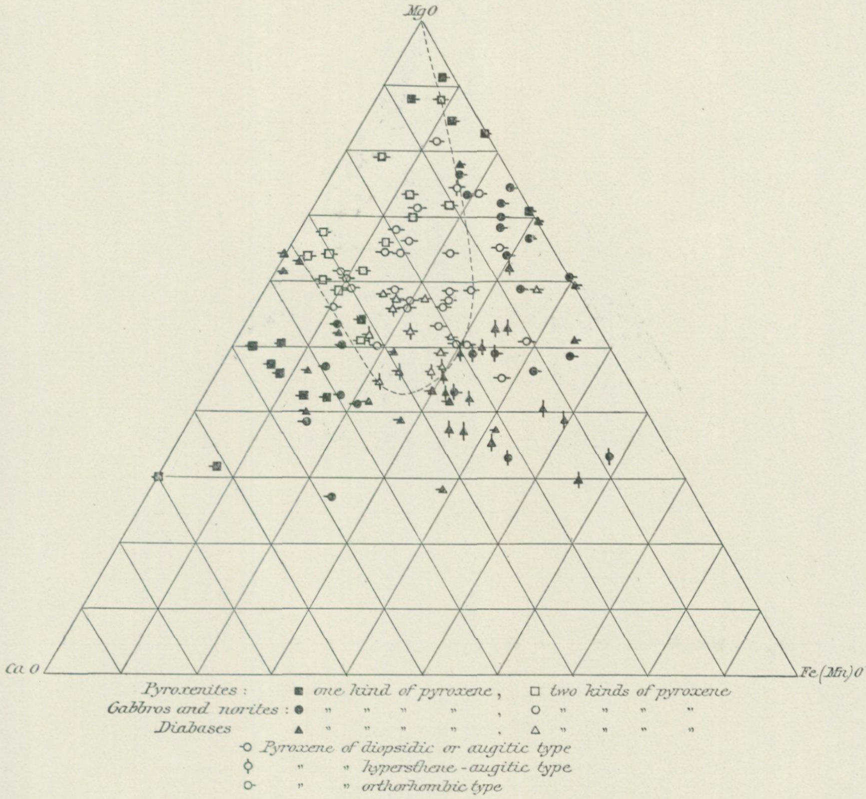

Fig. 20. Diagram showing the distribution of rocks containing one or two kinds of pyroxenes.

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[1] U. S. Geol. Surv., Prof. Pap., 99, 1917.

[2] Such an investigation shows that no great quantity of petrological information exists. Consequently, a great many superior analyses must be rejected, because we are given no, or very vague, descriptions of the mineralogical contents of the rocks analysed.

quantities of biotite do not perceptibly influence the pyroxene-proportions; on the contrary, all rocks containing considerable amounts of primary hornblende have been rejected.

The diagram shows a very distinct area between the diopside-hedenbergite series and the magnesia-richer, lime-poor monoclinic and orthorhombic pyroxenes, indicating that the capability of forming mix-crystals is quite absent. Compared with this diagram, an analogous diagram of rock-pyroxenes[1] (calculated in a completely analogous way, consequently by allotting CaO for Al_2O_3

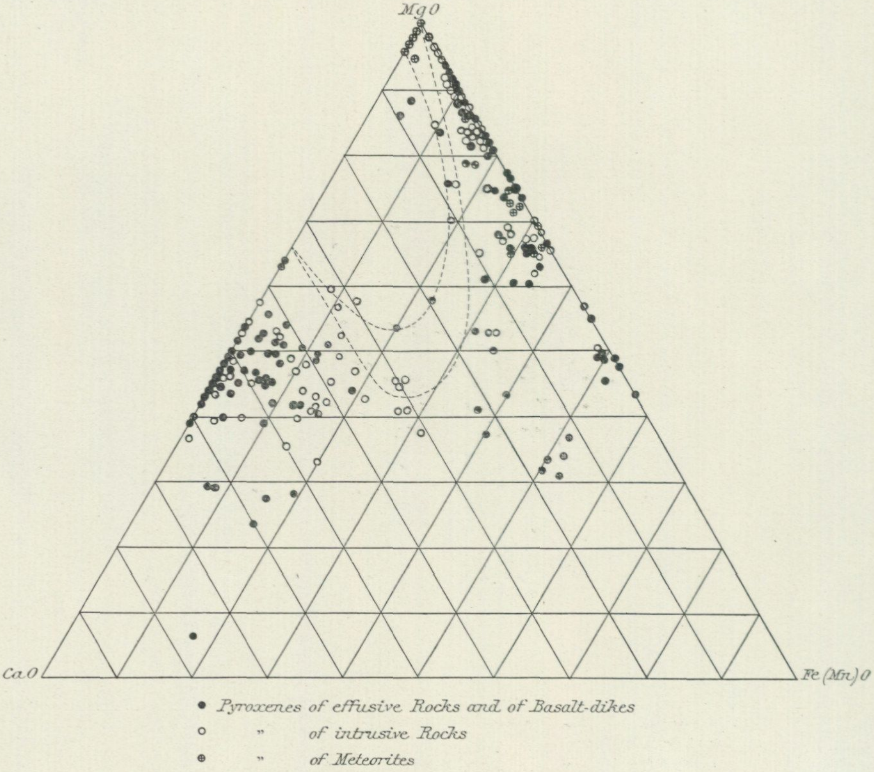

Fig. 21. Distribution of analysed pyroxenes. The calculation-method was the same as that for the rocks (fig. 20).

and FeO for Fe_2O_3, *etc.*) has been drawn (fig. 21). Also here (as found by Johansson and Sosman) a similar area of discontinuity is to be seen. The latter diagram naturally is only of comparative importance (cf. p. 80).

Compared to the elaborate study of N. L. Bowen[2] on synthetical pyroxenes of the diopside-clinoenstatite series, the diagrams show those pronounced differences which seem to exist in respect to the capacity to form mix-crystals between the natural and the synthetical pyroxenes. A more superficial glance

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[1] The Ternary System: Diopside-Forsterite-Silica, Am. Journ. of Science, 4th Ser., no. 38, p. 207, 1914.

[2] The analyses calculated were obtained from Hintze's «Handbuch der Mineralogie».

at the problem presented by these differences would perhaps suggest the explanation that clinoenstatite does not occur in tellurian rocks. However, it may be suggested that in these rocks the clinoenstatite may be replaced by the orthorhombic pyroxene enstatite, whose physical mode of occurrence would be quite different. But a glance at the distribution of the lime-poor, *monoclinic* pyroxenes (the enstatite, or better, hypersthene-augites) in the diagram, contradicts this explanation: between the magnesia-richer members of the hypersthene-augites and the common monoclinic series the same discontinuity exists. For instance, the enstatite-augite of Föglö (W. Wahl) gives the proportions MgO : CaO : FeO = 51.8 : 15.5 : 32.7, and consequently it lies on the right-hand side of the discontinuity-area. Several optical investigations have also proved this fact. For instance, the diabase from Richmond, Cape Colony, contains two independent pyroxenes, one with a large optic axial angle, and the other with a very small optic axial angle, which passes through 0°, and, in the nuclei of the mineral, shows a normal-symmetric position [⊥ (010)] of the optic axial angle plane (W. Wahl). Cohen[1] has published an analysis of the light-coloured pyroxene of the diabase from Richmond. Probably it may represent a mixture of both the independent pyroxenes. The proportions MgO : CaO : FeO of the analysis are 63.2 : 16.6 : 20.2, and from those we can at least presume the first crystallised pyroxene to have been rich in magnesia. Using the figures given by Wahl for the 2E of the pyroxene with small optic axial angles:

2E ‖ (010) maximum 31°,5
2E ⊥ (010) » 20°,5

and, reducing these values to obtain the approximate values of 2V (taking β to be the same as that of the well-known enstatite-augite from Föglö, 1 . 691), we may calculate:

2V ‖ (010) maximum approx. 18°
2V ⊥ (010) » » 12°

Substituting these values in the provisional optical determination-diagram for the pyroxenes (fig. 7, p. 29), we can at least state that the pyroxene has in part a similar composition to that of several orthorhombic pyroxenes.

Another similar case was described by H. Backlund[2]. In a diabase from Halleberg, Sweden, Backlund has found two kinds of pyroxenes (as also found by Merian and Hovey[3]). One lath-shaped pyroxene shows 2V = 15°,5 ⊥ (010); however, a symmetrical optic axial plane was also observed. The other pyroxene shows 2V = 57°, or less. Evidently, judging from the optical diagram on p. 29, we may at least state that those parts of the pyroxene [I] which present a normal-symmetric axial plane must have a composition such as is often found in orthorhombic pyroxenes. From Merian's analysis[4] of a mixture

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[1] E. Cohen, Neues Jahrb., Beil. B., 5, 1887, p. 235.

[2] Über einige Diabase aus arktischem Gebiet, Tscherm. Min. Petr. Mittheil., 26, 1907—08, p. 387.

[3] *Ibid.*, 13, 1893, p. 213.

[4] Neues Jahrb., Beil. B., 3, 1885, p. 289.

of the pyroxenes from Halleberg, the present author has re-calculated MgO : Cao : FeO = 49.7 : 19.7 : 30.6. From these proportions it is probable that the hypersthene-augite is rather rich in ferrous iron.

From these interesting facts — scanty though they are — it is evident that the appearance of lime-poor pyroxenes of rocks in monoclinic or orthorhombic habitus does not influence the capability of the pyroxenes to form mix-crystals. General experience also shows that the crystallisation of lime-poor orthorhombic or monoclinic pyroxenes, rich in magnesia, proceeds in the same manner, and at higher temperatures than in the case of those richer in ferrous iron or lime[1]. These latter pyroxenes, in zonary banded pyroxenes, represent the margins round nuclei of the magnesian pyroxenes. Consequently, as regards the crystallisation-temperature and the ability to form mix-crystals, general experience indicates that the question of the dimorphism of the lime-poor or lime-free magnesia-iron pyroxenes respectively is of no importance. These facts really tally remarkably well with the conclusions arrived at by Groth[2], Zambonini[3], and Michel[4], who explain the crystallographic relations between the monoclinic and orthorhombic Mg-Fe-pyroxenes as polysymmetric.

After this survey, some words may be added with reference to the determination-diagram on the pyroxenes (fig. 7, p. 29). For the diagrams discussed in this chapter, the calculation methods of the quantitative system have been employed (*i. e.* subtraction of CaO for anorthite, FeO for magnetite and ilmenite). If one tries to set up an optical determination-diagram for the pyroxenes, based upon the metasilicate-proportions so obtained, a completely confused picture results. If, on the other hand, the total amounts of constituent MgO, CaO, and FeO, are used, the accurate survey is obtained as shown in the diagram of fig. 7. From this circumstance we may draw the conclusion that the metasilicates cannot be considered to have combined with the sesquioxides to form constituent molecules, as »Tschermak's molecules», but may enter as crystal solution in the form of simple oxides (which have an unimportant influence upon the optical properties). This opinion has been vindicated by Rammelsberg, Zambonini, and Washington (cf. Winchell, Am. Journ. of Science, 5th Ser., 6, 1923, p. 513).

An approximate survey of the directions of crystallisation, in the case of the metasilicatic mixtures crystallising as pyroxenes, may be outlined as follows: Starting from Bowen's standard investigation on the system $MgSiO_3$-$CaMg(SiO_3)_2$ (clinoenstatite-diopside), we know that system to belong to Type 3 of Bakhuis Roozeboom[5]. Its liquidus has a flat minimum at about 82 % diopside: 18 % clinoenstatite. In order to discover whether this minimum has any influence upon the crystallisation-courses of the rock-pyroxenes, the author

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[1] Cf. N. L. Bowen, Am. Journ. of Science, 4th Ser., 1914, p. 256.

[2] P. Groth, Einleitung in die chemische Kristallographie, 1904, p. 7.

[3] F. Zambonini, Die morphotropischen Beziehungen zwischen Enstatit, Diopsid, Hedenbergit, Ägirin und Spodumen, Zeitschr. für Krystallographie, vol. 46, 1909, p. 1.

[4] H. Michel, Zur Kenntnis der Pyroxene der Meteoriten, Ann. d. k. k. Naturhist. Hofmuseums, 27, 1913, p. 106.

[5] H. W. Bakhuis Roozeboom, Erstarrungspunkte der Mischkrystalle zweier Stoffe, Zeitschrift für Physikalische Chemie, vol. 30, 1899, p. 385.

availed himself of the rather scanty material to be found in the petrological literature dealing with rapidly solidified pyroxene-bearing magmas, their phenocrysts, and their ground-masses (diagram of fig. 22).

The material is summarised in the following table:

Metasilicatic proportions of:	the rocks	the phenocrysts	the ground-masses
	MgO : CaO : FeO	MgO : CaO : FeO	MgO : CaO : Feo
1. Hypersthene-trachyte [1]	48.1 : 12.6 : 39.3	47.4 : 4.8 : 47.8	43.6 : 30.8 : 25.6
2. Augite-labradorite porphyrite [2] .	43.3 : 27.5 : 29.2	42.5 : 37.9 : 19.6	
3. Hypersthene-andesite [3]	54.8 : 15.7 : 29.5	67.0 : 5.5 : 27.5	
4. »Glassy rock» [4]	20.8 : 8.5 : 70.7	40.4 : 8.7 : 50.9	
5. Basanite (limburgitic) [5]	31.0 : 38.8 : 30.2	36.7 : 46.0 : 17.3	

For these calculations the total FeO-content of the rocks, as well as the minerals has been entered, without allotting FeO for Fe_2O_3 or TiO_2, since the magnetite is only partially crystallised, and also since the total FeO-percentage seems to have governed the FeO-percentage of the first crystallised phases (the phenocrysts).

From this diagram it is evident that a line can be drawn in the direction of the FeO-corner, representing the projection-points of the minima of pseudobinary diagrams, which can be cut out of the ternary diagram, and which intersect this line. Consequently, with the combination $[82\,(CaMgSi_2O_6)\,.\,18\,(MgSiO_3) + n\,(FeSiO_3)]$, the ternary liquidus surface must show a groove-shaped depression, whose dip in the direction towards the FeO-corner of the crystallisationdiagram may be expected, *a priori*, from general experience, which indicates that FeO-richer members of silicates crystallise at lower temperatures than MgO-richer members (as, for instance, the olivines).

It must be considered a remarkable fact that no replacement of the »minimum-composition» compared to that of the pure metasilicatic melts can be observed, even when a great number of other components enter in the system. This fact, deduced from statistics, shows a remarkable conformity with the crystallisation-history of the feldspars, *viz.* that the entering of other magma-forming components into pure feldspar-melts does not seem to exercise any noticeable influence on the situation of the individualisation-boundary nor on the composition of the ternary minimum. Indeed, it is these circumstances which permit us — from a schematical point of view — to consider the meta-

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[1] Hypersthene, Casa Tasso, Monte Amiata. J. F. Williams, Ueber den Monte Amiata in Toscana und seine Gesteine, Neues Jahrb., B. B., 5, p. 381.

[2] Augite, Atàtsch. J. Morozewicz, Die Eisenerzlagerstädten des Magnetberges im südlichen Ural und ihre Genesis, Tscherm. Min. Petr. Mitth., 23, p. 132. — The P_2O_5 and TiO_2 of the rock are not determined. Consequently, the Al_2O_3 may be too high, and CaO in the metasilicates too low.

[3] Hypersthene, Buffalo Peak. W. Cross, On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, U. S. Geol. Surv., Bull., 1, p. 26.

[4] »Augite», Beinn and Lochain, Pennygael, Mull, Scotland. Geol. Surv. Great. Brit., Summary Progress, 1913, p. 81. — The rock containing this interesting »augite» was recently described as an »inninmorite». »Tertiary and post-Tertiary Geology of Mull, Loch Aline and Oban», Mem. Geol. Surv., Scotland, 1924, pp. 282—84.

[5] Augite, Kilima Ndjaro. Gustav Becker, Zur Kenntnis der sesquioxyd- und titanhaltige Augite, In. diss., Erlangen, 1902.

silicate-components and the feldspar-components to be »independent» systems.

The facts here brought out, showing that, as regards their crystallisation-history, the natural pyroxenes show resemblances to the synthetical pyroxenes, must be of great importance. However, the differences in their ability to

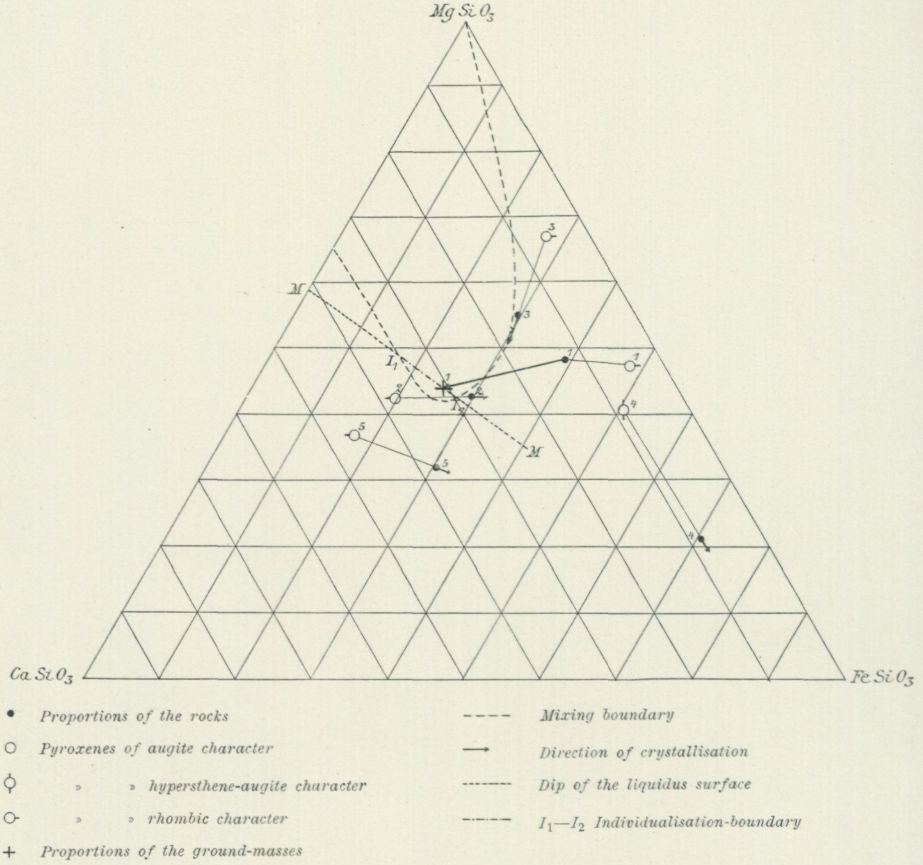

Fig. 22. Diagram illustrating the proportions of the first crystallised phases of rapidly cooled pyroxene-bearing magmas.

form mix-crystals is very striking. By making a comparison with the feldspar-minerals, whose ability to form ternary mix-crystals is evidently governed by the temperature-lowering ability of the other mineral-components present in the magmas, we may arrive at a possibly general explanation of the limitations to the forming of mix-crystals in natural minerals. A few analyses of pyroxenes, indeed, indicate that this ability is progressively limited. But we must remember that the existing analyses are not sufficiently reliable to enable us to judge this question finally and definitely. In plutonic rocks, however, an equilibrium-stage is reached, as shown by the diagram of fig. 24

(illustrated by the broken curve, which will fairly well express the general mix-crystal boundary for all pyroxene-bearing magmas).

On the other hand, we may discuss the differences between the synthetical and the natural pyroxenes from the point of view that the synthetical mix-crystals falling within the area of discontinuity may form metastable minerals. This supposed metastability must be caused by the rapidity of the crystallisation. However, in the case of very rapidly cooled rocks, as, *e. g.* the pyroxene andesites (whose metasilicatic proportions fall within the area of discontinuity), we always find two pyroxenes. This fact shows that there really exists an influence of the other mineral constituents upon the crystallisation-courses of the pyroxenes. But, regarding the pyroxenites, which contain almost exclusively pyroxene-forming oxides, it seems rather curious that two pyroxenes are formed. Indeed, there exists a pyroxenite which, according to F. C. Calkins[1], consists of lamellar intergrowths of diallage and enstatite. The minerals may probably have formed a homogeneous pyroxene, which, *after the crystallisation*, was broken up into normal pyroxenes. However, the paucity of such pyroxenites indicates that really very small quantities of other constituents may have a very strong influence on the crystallisation-history of the pyroxenes, *i. e.* on their crystallisation-temperatures.

If we consider together the investigations on the directions of crystallisation of metasilicatic substances and the statistics of the mix-crystal boundary for pyroxenes, we get a general view of the crystallisation-types of the Mg-Ca-Fe-pyroxenes (fig. 23).

Starting from the supposition mentioned above, that the solutions of the area $(Di\text{-}Di_{60}\,He_{40})$ — $(En\text{-}Hy)$, crystallising from pure melts, may possess unlimited capability to form mix-crystals, and [with reference to the pseudo-binary sections $(Di\text{-}Di_{60}\,He_{40})$ — $(En\text{-}Hy)$] may belong to Roozeboom's Type 3, we are also able to consider the different parts of the area discussed, which come into existence when the forming of mix-crystals becomes limited. On the supposition that the presence of even small quantities of other constituents may be the cause of this limitation, it ought to be obvious that the original liquidus will become depressed until a temperature is reached at which an essential limitation of the capability to form mix-crystals supervenes. In a temperature-diagram the beginning of this limitation would probably be situated just beneath the liquidus of the pure melts[2].

Inside the area En-I-M the pyroxenes — as regards the pseudo-binary sections — will crystallise according to a curve which agrees with Roozeboom's Type 4. The whole area, excepting that inside the curve $En\text{-}I_1\text{-}I\text{-}A$, will generally belong to Type 3. However, the areas quite near to sections $I\text{-}I_1$ and $En\text{-}I_1$ may, under special cooling-conditions and owing to the composition of the first crystallised phase, assume the crystallisation-types of the neighbouring areas. A perfectly clear conception of these circumstances postulates a thorough

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[1] Un. California Publ., Bull. Dep. Geology, vol. 3, 1902—04, p. 119.

[2] For these results it is necessary to know the interesting deductions of F. A. H. Schreinemakers, published in Zeitschrift für physikalische Chemie, 50, 1905, pp. 169 *etc.*, and 51, 1905, pp. 547 *etc.*

knowledge of the directions of crystallisation under different conditions. Consequently, only the Types are sketched so far. With rapid cooling the area En-I-I_1 will belong to Type 5, and the groove-shaped depression of the liquidus changes its character into an individualisation-boundary or ternary crystallisation-curve between the lime-poor pyroxenes and the diopside-augite series. With slow cooling, however, the directions of crystallisation will show an obtuser dip to the M—-M_1 line, and consequently the upper part of the area En-I-I_1 will belong to Roozeboom's Type 4.

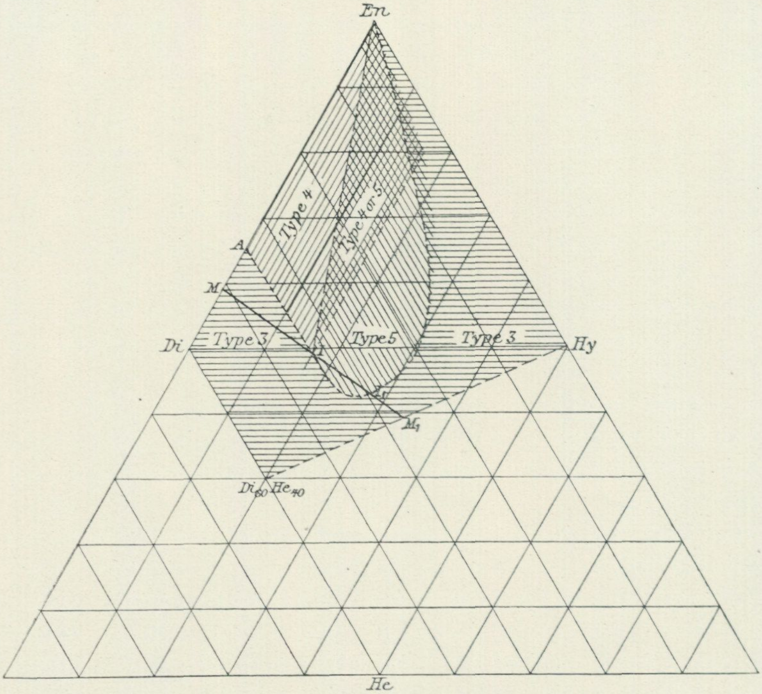

Fig. 23. Diagram giving a survey of the crystallisation of the common Mg-Ca-Fe-pyroxenes.

With very slow crystallisation, which postulates strong adjustments between crystallised and liquid phases by fractional resorption, the diagram becomes much simpler (fig. 24). In the discontinuity-area, only two types of crystallisation can be observed: Type 4 for the magnesia-richer magmas and Type 5 for those richer in ferrous iron. The pyroxenitic magmas will belong chiefly to Type 4; the noritic gabbros, on the other hand, to Type 5. Among the pyroxenites we may expect relatively lime-poor diopsides (chromic diopside). However, it seems to be possible that, during the latest stage of crystallisation, the ability to form mix-crystals has become still more limited. This limitation may probably transform the crystallisation-type of two-pyroxene pyroxenites into Type 5. More exhaustive chemical studies are needed on that subject. The other areas of the diagram (fig. 24) are characterised by only one kind of pyroxene, quite homogeneous. On the right-hand side of the diagram may obviously occur both monoclinic and orthorhombic pyroxenes. However, in accordance with the above-mentioned deductions, this co-appearance would be chiefly due to crystallographic circumstances. The diagram only deals with the occurrence, on the one hand, of lime-richer pyroxenes, and, on the other hand, of lime-poorer pyroxenes.

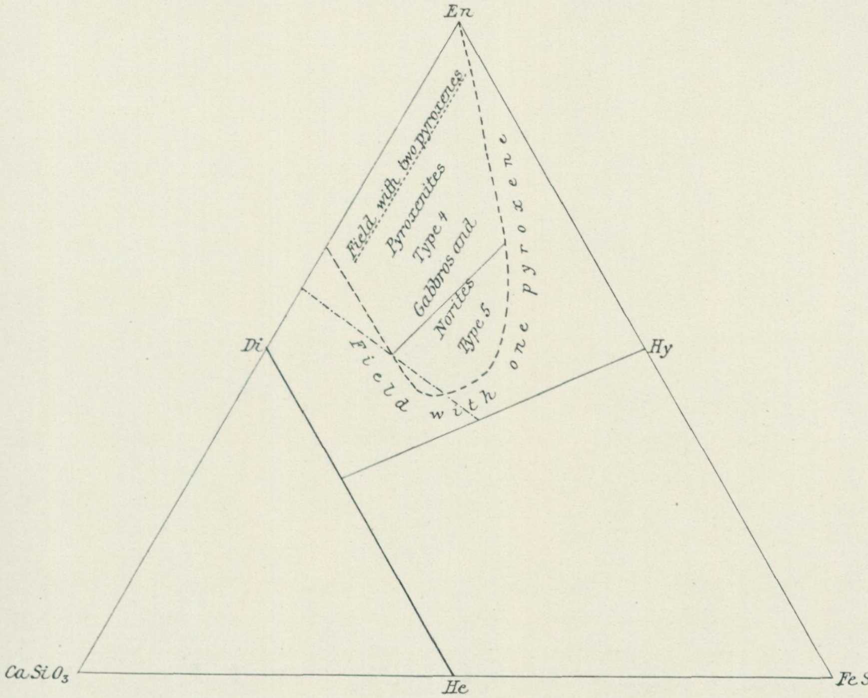

Fig. 24. Diagram showing the crystallisation-types of the pyroxenes of plutonic rocks.

We are now in a position to judge the crystallisation-courses of the present noritic gabbro.

The method of calculation just described gives the following figures:

Pyroxene-forming oxides (cf. p. 68)			Metasilicatic proportions
MgO	CaO [1]	FeO	MgO : CaO : FeO
209	88	88	54.4 : 22.8 : 22.8

Presuming that the hypersthene and hypersthene-augite are CaO-free Mg-Fe-minerals and assuming the MgO : FeO proportions of the hypersthene are analogous to those of the norite, we are able to calculate from the actual mineral-composition:

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[1] To the proportions of femic CaO (82) also 6 molecules of CaO from the feldspars have been added (cf. p. 69).

	A. Pyroxene-forming oxides			B. Metasilicatic proportions
	MgO	CaO	FeO	MgO : CaO : FeO
Hypersthene	176	0	72	71 : 0 : 29
Augite	33	88	16	24.1 : 64.3 : 11.6

The metasilicatic proportions of the augite resulting from such a calculation cannot correspond to the actual proportions of the present augite. The unusually high CaO-percentage, as calculated, would give a basaltic augite relatively rich in ferrous iron; the present mineral, on the contrary, is a green augite of diallage character. With regard to chemical composition, this pyroxene type varies within narrow limits, as shown in the diagram (fig. 5, p. 24), which presents a grouping of monoclinic augites and diopsidic augites from norites and closely related diabases. Consequently, as deduced from the microscopical investigations, the hypersthene must contain some lime.

A much more correct distribution of the metasilicatic proportions is obtained by starting from the composition of the diallage (cf. p. 20) of the norite from Gwynn's Fall, Baltimore, described by G. H. Williams. Entering the actual augite-percentage (p. 68) we get:

	Pyroxene-forming oxides			Metasilicatic proportions
	MgO	CaO	FeO	MgO : CaO : FeO
Diallage-like augite	72	69	24	43.5 : 41.8 : 14.7
Hypersthene + hypersthene-augite	137	19	64	62.2 : 8.6 : 29.2

The proportion of hypersthene + hypersthene-augite found from microscopical investigation may be roughly estimated at 50 % hypersthene and 50 % hypersthene-augite. Now we are able to proportionate the femic oxide-quantities in the following way (the hypersthene nuclei are considered as pure Mg-Fe-silicate):

	Pyroxene-forming oxides			Metasilicatic-proportions
	MgO	CaO	FeO	MgO : CaO : FeOo
Diallage-like augite	72	69	24 (A)	43.5 : 41.8 : 14.7
Hypersthene	88	0	36 (H)	71.0 : 0.0 : 29.0
Hypersthene-augite	49	19	28 (H—A)	51.0 : 19.8 : 29.2
Noritic gabbro	209	88	88 (N)	54.4 : 22.8 : 22.8

(N etc. are the letters entered on the diagram of fig. 25.)

Neglecting the biotite, we consequently get a survey of the crystallisation of the pyroxenes (diagram fig. 25).

The noritic gabbro belongs to an area characterised by Roozeboom's Type 5. During the separation of hypersthene-augite margins round the hypersthene centres first crystallised, the line of crystallisation continuously approaches the individualisation-boundary, and then an independent augitic pyroxene begins to crystallise, at the same time as the hypersthene-augitic margins become completely separated. Some parts of the hypersthene seem subsequently to have been separated into purer hypersthene and monoclinic pyroxene, an

»*entmischung*» which is structurally quite similar to the perthite-separation of the feldspars. This separation will probably continuously overtake the pyroxenes at temperatures lower than their crystallisation-temperature, possibly even during the later stages of the crystallisation of the magma containing them. This structure has already been described by Henderson[1], Wahl, and Vogt.

As regards the crystallisation of the pyroxenes in the other rock-types of the area studied, unfortunately the author cannot submit chemical analyses.

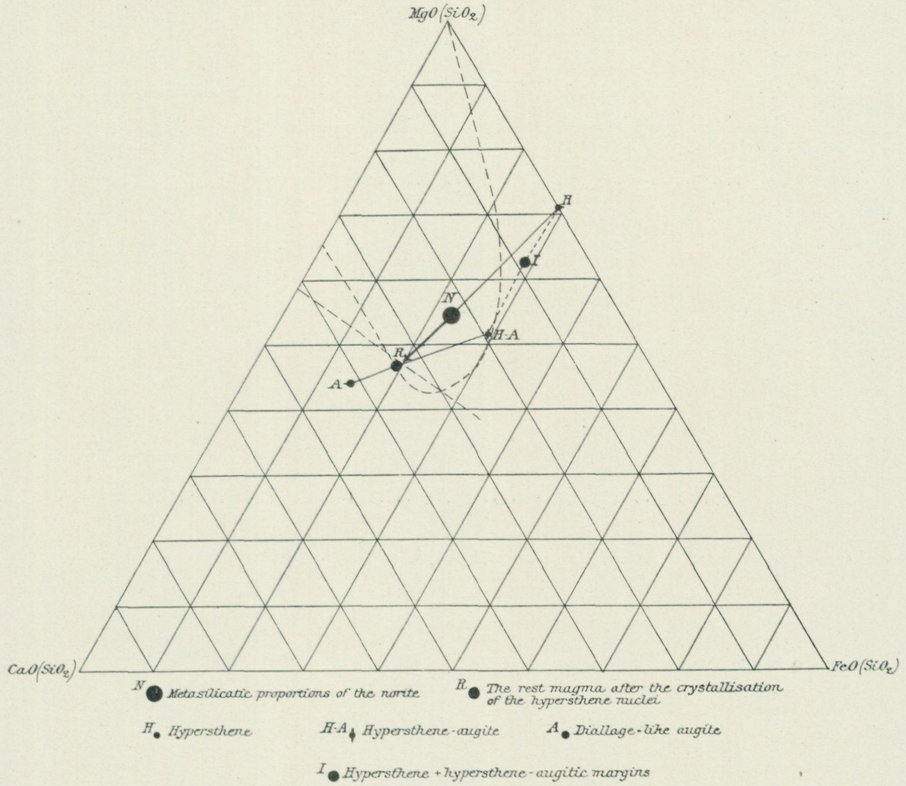

Fig. 25. A survey of the pyroxene-crystallisation of the noritic gabbro.

The hypersthene-augites of the quartz-diorites will evidently belong to the pyroxenes whose composition lies near the depression of the liquidus surface of the ternary pyroxene-mixtures. Consequently, they will represent the latest stage of the crystallisation of the pyroxenes in question. However, no earlier crystallised pyroxene phase occurs. Possibly such a phase may have existed, subsequently altered to other ferro-magnesian components (hornblende or biotite); or it is probable that its *rôle* may have been assumed by them during the crystallisation-courses of the magma in question.

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[1] *Op. cit.* (*vide* p. 34).

Now, considering the interesting cummingtonite-bearing gabbro from Skärgölen pool, it is evident from the optical properties of the hypersthene-augite present that this began to crystallise as a mineral quite rich in ferro-magnesia ($2V = 0°$) and continuously became Ca-richer ($2V = 34°$). These facts completely accord with the general results established above as to the crystallising of the pyroxenes. Concerning the crystallisation-type, this hypersthene-augite belongs to an area of the character of Type 3. Consequently we may state that this type extends also over areas of the pyroxene-diagram not dealt with in the above general discussion.

The above-mentioned results regarding the crystallisation-courses of the pyroxenes partly accord with the results reached by Vogt[1] and also discussed by Wahl[2]. Vogt has done most to demonstrate that the magnesia-rich members of the enstatite-diopside series belong to Roozeboom's Type 4. As regards the natural minerals, this ingenious conception of Vogt's must be right. Wahl, who was working more especially with pyroxenes richer in ferrous iron, has proposed Types 4 or 5, and quite rightly so. Further, Bowen has found Type 3, and it is partly his elaborate study that has made it possible for the author to reach his present results. Finally, we can state that the crystallisation-courses in nature are very complicated, but, on the other hand, they really show some accordance with the synthetical investigations.

CHAPTER 4.

The Differentiation of the Rock-Sequence.

The plutonic series described in this work form a genetically associated sequence of rocks belonging to a type quite common in the Archean of Southern Sweden.

In consequence of the very complex composition of the igneous rocks and their tendency to crystallise into very complicated mixtures of minerals, the discussion of the character of their differentiation is naturally removed into the border-land between petrology and physical chemistry. In the field, we are able to understand the age-relations between the various differentiates, and therefrom we may draw general conclusions. However, the questions »Why?» and »How?» as regards differentiation belong to physical chemistry. The experiments aiming at synthesising minerals and rocks still deal with such elementary combinations and such simple systems that only in rare cases do they afford interpretations and conclusions of general import to the extre-

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[1] J. H. L. Vogt, Die Silikatschmelzlösungen mit besonderer Rücksicht auf die Mineralbildung und die Schmelzpunkt-Erniederung, Videnskabs-Selskabets Skrifter, Math.-Naturv. Klasse, 1904, no. 1, pp. 105—109.

Physikalische-chemische Gesetze der Krystallisationsfolge in Eruptivgesteinen, Tscherm. Min. und Petr. Mitth., 24, 1905—06, p. 486.

The Physical Chemistry of the Crystallisation and Magmatic Differentiation of Igneous Rocks. Journal of Geology, 29, 1921, p. 519.

[2] *Op. cit.*, p. 135.

mely complicated systems of rock-components and their crystallisation-courses. In many cases, however, a combination of mineralogical syntheses with statistics of the composition of the natural minerals, seems to open possibilities for interpretations of more general import. In order to make the statistics surveyable, we must resort to graphical methods of illustration, dealing with different systems of mutually related components. However, if we neglect the mutual relations between these different systems, false conclusions may creep in.

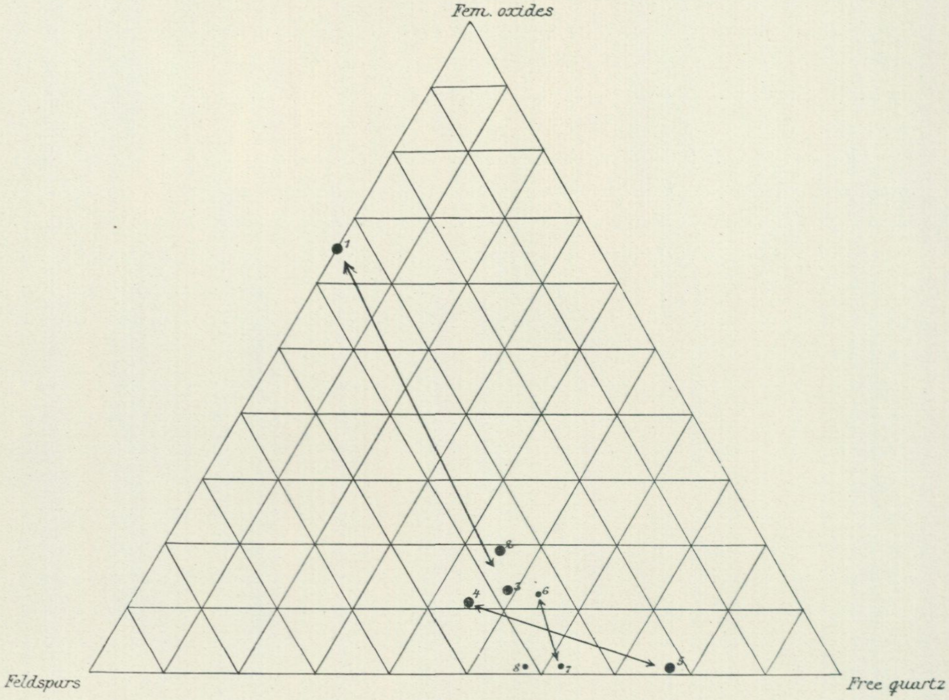
Certainly the differentiation problems must, to a much higher degree than hitherto, be subjected to the sharp control of graphical statistics. Conceptions based on ambiguous field observations and general physico-chemical discussions, whose basis is uncertain, cannot reach the heart of the differentiation problems. Nor can the automatic averaging of analyses-groups regarding quite different rocks (as, *e. g.* diabases and gabbros) to »average-magmas» lead to satisfactory results.

Much more certain results were gained by previous generations of petrologists, who, first acquiring a thorough knowledge of the rock-minerals and component-groups, tried to understand the problems of crystallisation and differentiation. Even though earlier generations had to work with very inferior technical resources, their results have scarcely been carried any further, in spite of present technical progress. To give only a couple of instances, almost all the existing analyses of pyroxenes are about forty years old, and scarcely any investigations into the glass-basis of rocks have been made since Lagorio's time.

As a foundation for graphical statistics on rock-analyses, the methods of calculating the »norms» of the »Quantitative System» are almost preferable, on account of their uniformity. However, to obtain a comprehensive survey of the calculation-material is hardly possible. Therefore a selection and graphical study of different systems of components is necessary. In this respect the feldspar-triangle is the clearest; but, on the other hand, the triangle-projection of the MgO : CaO : FeO may also be equally necessary. In this triangle, the metasilicatic and orthosilicatic proportions respectively can be surveyed, independently of their mode of appearance in the many species of the femic minerals. In projecting the salic proportions, the free quartz must be taken into consideration. When entering the free quartz in the feldspar-diagram, however, we get a prism-diagram or a tetrahedron-diagram, which can only with difficulty be projected on a plane. An introductory survey of the essential components of a rock may be suitably obtained by projecting feldspars: free quartz: femic oxides in a triangle-diagram. In the calculation, the accessories ilmenite, magnetite, apatite, *etc.*, are subtracted, in conformity with the calculation-method for the norm.

Such an introductory diagram (molecular percentage) of the analysed rocks of the Stavsjö area is given in fig. 26 (here also an old analysis of the reddish Graversfors granite has been entered, in order to illustrate the quartz-rich granites).

The diagram shows the chief lines of the differentiation-courses, *viz.* the separation of a normatively quartz-free gabbro from, on the one hand, a series of quartz-poor granites and quartz-diorites, and, on the other hand, the evident separation of these latter from the quartz-rich granites.



Large circles: leading types.
Small circles: unimportant differentiates.

Fig. 26. Diagram of the Stavsjö rocks, showing proportions of the femic oxides, feldspars, and quartz.

Projection-figures.	Free quartz :	feldspars :	femic oxides
Noritic gabbro (1)	0	34.7	65.3
Quartz-diorite (2)	44.6	36.9	18.5
Hornblende-bearing granite[1] (3)	49.3	40.5	10.2
Mica-bearing porphyritic granite (4)	44.4	45.0	10.6
Reddish Graversfors granite (5)	77.9	21.5	0.6
Oligoclase granite (6)	53.5	34.2	12.3
Aplitic granite (7)	61.3	37.2	1.5
Quartz-feldspar nodule (8)	57.2	41.8	1.0

Fig. 27 illustrates the feldspar-proportions of the plutonic sequence. In this diagram also the re-calculated proportions from the geometrical analyses have been entered.

The diagram shows a very characteristic distribution of the dots. The noritic gabbro and the quartz-diorites prove to be richer in anorthite. The granites fall into two series, the coarser granites and the medium-grained granites. The two sequences evidently differ in their percentage of anorthite. A clearly distinguished group is formed by the unimportant soda-rich granites.

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[1] In the diagram this dot is slightly misplaced.

The differentiation of the femic silicates is illustrated in a diagram (fig. 28). In this only the leading types have been entered; the remaining analyses (except those of the helsinkites) correspond to the leading types. However, their percentage of femic minerals is so unimportant that they are not discussed. The distribution within the MgO : CaO : FeO triangle is very characteristic. All quartziferous rocks approach the MgO-FeO-line, showing the most characteristic distinction between gabbros and granitic rocks. The differentiation-type, pyroxene-bearing gabbro to biotite-granite, finds in this way its most evident graphical mode of expression. The occurrence of hornblende is due to very unimportant traces of metasilicatic CaO (3), or it is quite independent of such

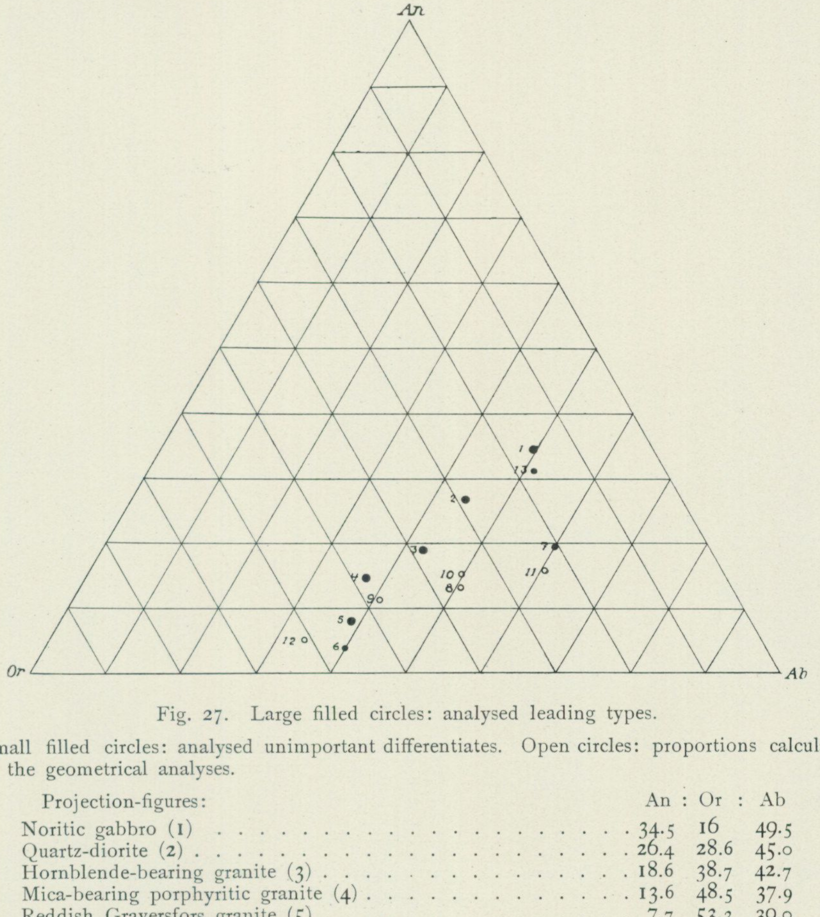

Fig. 27. Large filled circles: analysed leading types.

Small filled circles: analysed unimportant differentiates. Open circles: proportions calculated from the geometrical analyses.

Projection-figures:	An	Or	Ab
Noritic gabbro (1)	34.5	16	49.5
Quartz-diorite (2)	26.4	28.6	45.0
Hornblende-bearing granite (3)	18.6	38.7	42.7
Mica-bearing porphyritic granite (4)	13.6	48.5	37.9
Reddish Graversfors granite (5)	7.7	53.3	39.0
Aplitic granite (6)	2.7	57.3	40.0
Oligoclase granite (7)	19.7	20.5	59.8
Medium-grained granite (N. of Lake Stavsjön), (8)	13.0	35.3	51.7
Medium-grained granite (S. of Bråten), (9)	11.0	48.0	41.0
Medium-grained granite (N.E. of Lake Holmsjön), (10)	14.2	34.0	51.8
Medium-grained granite (E. of Stavsjö), (11)	15.7	24.1	60.2
Medium-grained granite (N.W. of Lake Strålen), (12)	5.0	60.8	34.2
Quartz-feldspar nodule from quartz-diorite (13)	31.4	17.5	51.1

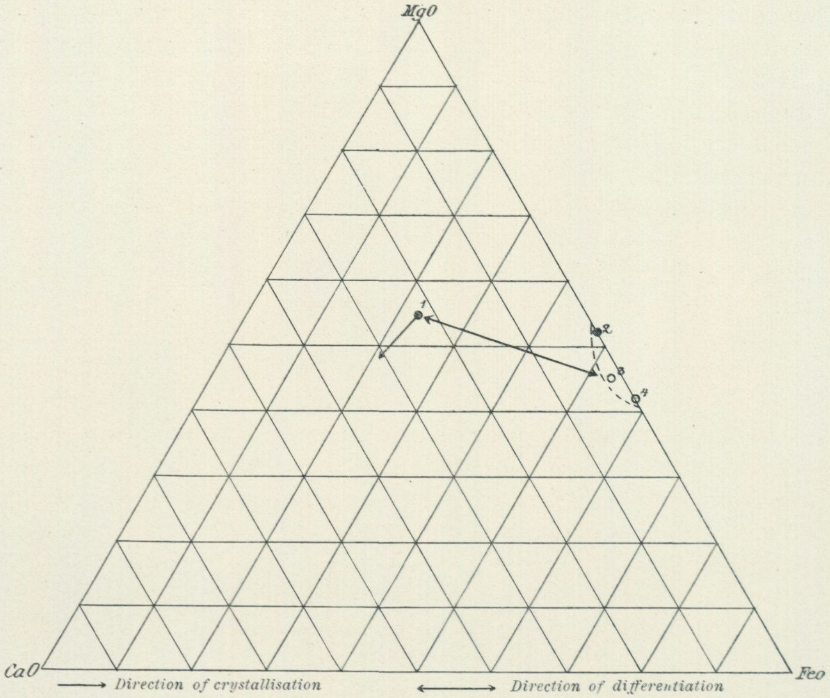

Fig. 28. Diagram showing the distribution of femic silicates in the Stavsjö rocks. The arrows indicate the remarkable differences between the directions of crystallisation and differentiation of the gabbros.

Projection-figures:	MgO	: CaO	: FeO
Noritic gabbro (1)	55.1	21.6	23.3
Quartz-diorite (2)	52.7	0.0	47.3
Hornblende-bearing granite (3)	44.6	1.5	53.9
Mica-bearing porphyritic granite (4)	42.0	0.0	58.0

traces (2). In the latter case, the metasilicatic CaO must be formed through a breaking-up of anorthite.

Discussion on the Differentiation from the Point of View of Fractional Crystallisation.

Taking the calculations just described as the basis of further discussions, we are on fairly safe ground. We will begin by discussing the sequence of differentiation from the point of view of the hypothesis of fractional crystallisation.

This hypothesis was not long ago accepted and carried further by N. L. Bowen[1], who has dealt with the elaborate sequence of synthetical systems of minerals investigated in the Geophysical Laboratory of the Carnegie Institution,

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[1] The Later Stages of the Evolution of the Igneous Rocks, Journ. of Geol., 23, 1915, supplement.

Washington. Further worked up by V. Goldschmidt[1], the hypothesis has since made victorious progress among petrologists, and it has recently been adopted by J. H. L. Vogt[2]. Among Swedish petrologists, N. Sundius[3] has tried to explain the differentiation of the Swedish Archean intrusive-formations as caused by fractional crystallisation. Also P. Geijer[4] has claimed to have found that fractional crystallisation, considered as the dominant factor of differentiation, gives a satisfactory explanation of the differentiation-problems of the igneous rocks of Jotnian and sub-Jotnian age.

Following the differentiation-scheme drawn up by Bowen, we shall now consider the differentiation-courses from the point of view of the course of crystallisation of the various rock-species. It is to be noticed that the present rocks cover the greater part of Bowen's scheme. Adopting Bowen's view, it seems to be quite evident that the present noritic gabbro will be the parent magma of the whole series. We may state it to be an approximate »basaltic» magma, which, in relation to its surrounding rocks, seems to occur as an early solidified differentiate. Though it is not directly attached to the contacts of the pre-existing rocks, it may, however, represent a »roof-differentiate» of the plutonic area.

Pre-supposing such a condition of the noritic gabbro, it evidently may represent the early crystallised parental magma, according to the views of R. A. Daly[5] and Bowen[6].

As a result of thorough investigations, the analysed norite is found to be quite representative of the whole area occupied by this rock-species.

Though the noritic gabbro is shown to have been subject to rather strong equalisation-reactions between the crystallised and liquid phases during the course of crystallisation, we may presume that such inter-actions did not occur in the deeper-lying parts of the magma, where the earliest crystallised minerals have settled down under the influence of gravitative differerentiation.

Case I. The settled minerals belong to the modal constituents of the noritic gabbro.

Excluding the first crystallised phase, an amount of 124 molecules of MgO + + FeO have to be subtracted from the whole MgO + FeO content to form hypersthene (cf. p. 86), and 55 molecules of CaO + Na_2O content to form labradorite (p. 68). As regards its metasilicatic proportions, the remaining magma has now obtained a much lime-richer composition, and simultaneously the feldspar-proportions in the diagram have changed to a composition usually characterising the medium-grained granites. However, since in the normative composition of the rock, there is already a deficiency of the silica necessary to

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[1] Stammestypen der Eruptivgesteine, Videnskaps-Selskapets Skrifter, Math.-Naturv. Klasse, Christiania, 1922, no. 10.

[2] Die physikalish-chemischen Gesetze der magmatischen Differentiation, *ibid.*, 1923, no. 17.

[3] Några frågor rörande våra arkäiska intrusivformationer i mellersta och södra Sverige, G. F. F., vol. 43, 1921, p. 580.

[4] Problems suggested by the Igneous Rocks of Jotnian and sub-Jotnian Age, G. F. F., vol. 44, 1922, p. 429.

[5] Igneous Rocks and Their Origin, pp. 244 and 246.

[6] *Op. cit.*, p. 13.

form metasilicates, the proportions of SiO_2 will be lowered when we subtract hypersthene and labradorite. Now the proportions of free quartz: femic oxides: feldspars are equivalent to 0 : 66.7 : 33.3. The original proportions of the rock were 0 : 65.3 : 34.7. Consequently, the presumption that the hypersthene kernels have settled would involve the result that the magma became richer in orthosilicates, and in a similar way the presumption that the labradorite had settled would involve the result that the remaining magma became richer in femic minerals. Now, when we find that similar calculations based upon the actual crystallisation-courses cannot explain the differentiation-courses, we must rely entirely on theoretical calculations; and we may assume that different femic oxide-quantities have crystallised as olivine, which has separated under the influence of gravitation. The hypothesis that the femic oxides separated as spinels may be ignored in the case of gabbros and basic rocks containing FeO, and, according to Loewinson-Lessing[1], spinels never occur in the rapidly solidified members of these magmas, the basalts. Consequently, in this discussion the spinels have been ignored.

Case II. Half the molecules of MgO + FeO may have been separated as olivine; plagioclase-kernels as labradorite. Thus it may be presumed that an olivine rich in magnesia would separate, roughly as $(Mg_2\,SioO_4)_{80}\,(Fe_2\,SiO_4)_{20}$. After subtracting, we get the following proportions for the remaining magma:

$$\mathrm{MgO : CaO : FeO} = 39.2 : 35.6 : 25.2$$
$$\mathrm{An : Or : Ab} = 25.0 : 25.0 : 50.0.$$

Free quartz : femic oxides : feldspars = 10.0 : 57.9 : 32.1.

These positions of the projection-loci in the different diagrams show no correspondence with the real directions of differentiation. First and foremost, this becomes evident from the femic diagram, in which the remaining magma, during the settling-out of olivine-crystals, moves perpendicular to the direction of differentiation. In this calculation it has still been presumed that labradorite would be the earliest plagioclase; the presumption that a more basic plagioclase had crystallised would necessarily give the crystallisation-line of the ternary feldspar-solution such a steep direction towards the Ab-Or-line of the diagram that the remaining magma would never assume positions occupied by the salic differentiates.

No similar calculations can show a supposed consanguinity between the noritic gabbro and the granite-series, and consequently there only remains one mode of calculation, *viz.* to consider the different salic rocks which may be re-calculated from the analyses of the noritic gabbro. In this case also the femic remainder may be considered.

The starting-point for such a calculation is the amount of potash in the salic differentiate, to which the molecular quantities of the other oxides must be proportioned. For this calculation, the whole amount of potash in the norite is supposed to be taken up by the salic rock thus subtracted. The cal-

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[1] The Problem of the Anorthosites and Other Monomineral Igneous Rocks, Journal of Geology, vol. 31, 1923, p. 94.

culations refer to the molecular proportions of the noritic gabbro. The norms of the two parts of the noritic gabbro thus obtained are also given, in order to get a comparison between the compositions of the two artificial magma components, and more particularly of the normative minerals of the basic derivatives.

Such calculations are worked out for three leading types, the quartz-diorite, the hornblende-bearing granite, and the reddish Graversfors granite.

1. Quartz-diorite, calculated from the noritic gabbro (cf. tables 1 and 3, pp. 19 and 36).

Molecular proportions.

	Quartz-diorite	Remainder of the norite
SiO_2	498	380
TiO_2	13.6	0.4
Al_2O_3	72	63
Fe_2O_3	3.4	8.6
FeO	43	70
MnO	1	0
MgO	29	180
CaO	36	122
Na_2O	25	25
K_2O	16	0
P_2O_5	2	0

Norms.

Sal: Q	8.34	Fem: $MgSiO_3$	2.90	Sal: Ab	1.83	Fem: Di	18.81
Or	8.90	$FeSiO_3$	3.43	An	10.56	Ol	12.34
Ab	13.90	Mt	0.70	Ne	6.11	Mt	2.00
An	8.06	Il	2.13	Σ Sal	18.50	Il	0.10
Σ Sal	39.20	Ap	0.67			Σ Fem	33.25
		Σ Fem	9.83				

Sal + Fem = 49.03

Sal + Fem 51.75
Quantitative system: Rossweinose

2. Hornblende-bearing granite, calculated from the noritic gabbro (cf. tables 1 and 10, pp. 19 and 51).

Molecular proportions

	Hornblende-bearing granite	Remainder of the norite
SiO_2	355	523
TiO_2	5	11
Al_2O_3	49	86
Fe_2O_3	2.6	9.4
FeO	19	94
MnO	0.3	0.7
MgO	10	199
CaO	19	139
Na_2O	17	33
K_2O	16	0
P_2O_5	1	1

Norms.

Sal: Q	6.30	Fem: $MgSiO_3$	1.00	Sal: Ab	11.79	Fem: Di	18.67
Or	8.90	$FeSiO_3$	1.53	An	14.73	Ol	14.90
Ab	8.91	Mt	0.60	Ne	2.98	Mt	2.18
An	4.45	Il	0.76	Σ Sal	29.50	Il	1.67
Σ Sal	28.56	Ap	0.34			Ap	0.34
		Σ Fem	4.23			Σ Fem	37.76

Sal + Fem 32.79

Sal + Fem = 67.26
Quantitative system: Ornose.

3. Reddish Graversfors granite, calculated from the noritic gabbro (cf. tables 1 and 17, pp. 19 and 60).

Molecular proportions.

	Reddish Graversfors granite.	Remainder of the norite.
SiO_2	395	483
TiO_2	1.7	12.3
Al_2O_3	37.7	97.3
Fe_2O_3	1.8	10.2
FeO	2.7	110.3
MnO	0.3	0.7
MgO	1.2	207.8
CaO	4.6	153.4
Na_2O	12	38
K_2O	16	0
P_2O_5	0	2

Norms.

Sal: Q	13.02	Fem: $MgSiO_3$	0.12	Sal: Ab	1.31	Fem: Di	19.62
Or	8.90	Mt	0.23	An	16.40	Ol	16.68
Ab	6.29	Il	0.26	Ne	10.08	Mt	2.37
An	1.28	Hm	0.11	Σ Sal	27.79	Il	1.87
C	0.51	Σ Fem	0.72			Ap	0.67
Σ Sal	30.00					Σ Fem	41.21

Sal + Fem = 69.00.
Quantitative system: Bekinkinose.

From these calculations it is evident that the norite is capable of producing about 50 % by weight of quartz-diorite, and about 30 % by weight of granite. However, it is to be remarked that the Stavsjö norite is unusually rich in potash in contrast to typical gabbros. These percentages will become about 25 and 15 if the potash-content is taken at half the amount actually present in the norite.

The different derivatives of the noritic gabbro represent rocks very rich in orthosilicates. Though the norms, indeed, enter into the »quantitative system» in the groups »Bekinkinose» and »Ornose», *etc.*, we cannot expect the normative minerals. Evidently the condition for fractional crystallisation must be that the MgO + FeO in the femic crystallisation-phase crystallised as orthosilicates, and also that CaO and Na_2O were capable of crystallising as silicates poorer in silica than pyroxene or albite. The silicates poor in silica which can take up MgO and FeO can only be olivine or biotite. The rapid settling-out of small quantities of olivine would give the remaining magma a composition so rich in silica[1] that CaO and Na_2O could not crystallise as silica-poorer silicates than pyroxene and albite. And, naturally, it would be diopsidic pyroxene, and not Ca-orthosilicate, that would crystallise out. Consequently, the whole of the MgO + FeO cannot be taken up by olivine, and thus the formation of such mixtures of minerals as those just calculated is out of the question. Hence, finally, we may state that the crystallisation of the norite cannot give remaining magma-solutions so rich in silica as quartz-diorites and granites.

However, it may seem remarkable that no olivine occurs in the the norite. A basalt with such a composition would certainly contain olivine. An explanation of this fact has already been suggested (p. 69), *viz.* that during a very early stage of crystallisation MgO + FeO entered into the biotite formed in small quantities as reaction rims between kernels of magnetite and the norite-solution. In such reactions small amounts of normative silica must be set free. These amounts, however, were sufficient to impede the crystallisation of olivine. Probably such reactions occurred, and probably the early formation of small amounts of biotite may explain the frequent loss of olivine in gabbros and norites whose norms include this mineral.

From these facts we might possibly expect that biotite settled out from the noritic gabbro at an early stage of its crystallisation. However, a settling-out of biotite from a basic magma robs the magma of its potash-percentage and must render the remaining magma richer in soda, quite contrary to the usual course of differentiation. In granites very rich in biotite such an increase of soda, during the completion of the crystallisation process, really seems to result (cf. p. 74).

From these arguments it seems impossible to consider the noritic gabbro to have been the parental magma of the present plutonic series. Between the gabbro and the acid series a real chemical discontinuity exists, chiefly expressed by the differences in the quartz-percentage[2], and so also between the quartz-diorites and the gabbros.

Now we shall discuss the salic rocks from the point of view of fractional crystallisation. According to the feldspar-diagram (fig. 27), the different types simply seem to derive from each other only as a result of a successive

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[1] When the magma-solution has reached a composition containing small quantities of free silica, the crystallising of pyroxene may be expected, according to Bowen's diagram (Forsterite-Diopside-Silica). This diagram indicates that there must exist a limit to the formation of olivine (rich in MgO) also in nature, governed by the percentage of silica. Cf. Am. Journ. Science, vol. 38, 1914, p. 217 (the diagram).

[2] This fact is pointed out by H. E. Johansson, Die eisenerzführende Formation von Grängesberg, G. F. F., vol. 32, part I, 1910, p. 382.

settling-out and gravitative sinking of plagioclase. And, on the other hand, the femic proportions (fig. 28) show a quite uniform composition, only differing in the total quantities, and consequently we may expect that a successive settling-out of femic minerals would give the different types of rocks. The courses of differentiation may be sketched in the following calculations, in which — in conformity with the above calculations — the entire percentage of potash is supposed to be left in the remaining solutions. In the case of the calculation of the reddish Graversfors granite from the rock most nearly related to it, the porphyritic mica-bearing granite, the calculation must be somewhat different, on account of the important quartz-percentage of the former. Therefore the calculation must start from the quartz-percentage of the latter. All the quartz is supposed to remain in solution, and from its quantity the other minerals are proportioned. In this case we must start from the norm of the two-mica granite.

1. Hornblende-bearing granite, calculated from the quartz-diorite (cf. tables 3 and 10, pp. 36 and 51).

Molecular proportions.

Hornblende-bearing granite.		Remainder of the quartz-diorite	Norm.	
SiO_2	731	296	Q	4.20
TiO_2	14	14	Ab	8.38
Al_2O_3	101	47	An	7.78
Fe_2O_3	5	2	C	0.31
FeO	40	49	Σ sal	20.67
MnO	1	1	$MgSiO_3$	4.00
MgO	20	40	$FeSiO_3$	4.49
CaO	39	35	Mt	0.46
Na_2O	36	16	Il	2.13
K_2O	33	0	Ap	0.67
P_2O_5	2	2	Σ fem	11.75

Sal + Fem = 32.42

Quantitative system: Bandose

2. Two-mica granite, calculated from the hornblende-bearing granite.

Molecular proportions.

Two-mica granite (p. 59)		Remainder of the hornblende-bearing granite	Norm.	
SiO_2	823	261	Q	7.38
TiO_2	6	10	Ab	8.38
Al_2O_3	130	20	An	1.11
Fe_2O_3	6	2	Σ sal	16.87
FeO	39	20	$CaSiO_3$	1.97
MnO	1	0	$MgSiO_3$	0.90
MgO	20	9	$FeSiO_3$	1.06
CaO	30	28	Mt	0.46
Na_2O	38	16	Il	1.52
K_2O	49	0	Ap	0.67
P_2O_5	1	2	Σ fem	6.58

Sal + Fem = 23.45

Quantitative system: Unnamed.

Reddish Graversfors granite, calculated from the two-mica granite.

Norms

Norm of two-mica granite		Reddish Graversfors granite (p. 60)		Remainder of the two-mica granite	
Q	15.66	Q	15.66	Or	25.0
Or	35.58	Or	10.60	Ab	18.9
Ab	26.20	Ab	7.31	An	8.5
An	10.01	An	1.51	C	1.2
C	1.94	C	0.69	Σ sal	53.6
Σ sal	89.39	Σ sal	35.77	$MgSiO_3$	2.45
$MgSiO_3$	2.60	$MgSiO_3$	0.15	$FeSiO_3$	4.62
$FeSiO_3$	4.62	Mt	0.34	Mt	1.52
Mt	1.86	Il	0.33	Il	0.89
Il	1.22	Hm (not calc.)		Ap	0.34
Ap	0.34	(Σ fem	0.82)	Σ fem	9.82
Σ fem	10.64			*Quantitative system*: Monzonose.	

From these calculations, a very odd picture of the crystallisation-courses would arise, *e. g.* the potash-richer granites would derive from the more basic quartz-diorite through the loss of important quantities of quartz. The youngest and most quartzy differentiates would arise through an extremely heavy loss of potash-feldspar. Sometimes a quite basic plagioclase, and sometimes an extremely acid one, would separate as a result of fractional crystallisation.

Such calculations for the present and other areas lead (though we very well know the sequence of the crystallisation for the supposed fractional crystallisation) to groupings of minerals and crystallisation-courses which do not exist in nature. Indeed, every petrologist ought to make calculations on fractional crystallisation, and then this hypothesis as to differentiation would not seem so self-evident as it is always claimed to be by its apostles. With regard to the presumption recently[1] appended to the hypothesis, *viz.* that the settling minerals would re-melt at deeper levels and then again begin a new magmatic life, with repeated crystallisation, gravitative fractionation, and »squeezing-out», we may indeed expect very extraordinary products of crystallisation, *i. e.* rocks! In the present area, with its well-differentiated and uniform rocks, nothing resembling such products is found!

Before the author enters upon the consideration of the differentiation-problems arising out of his studies of the present plutonic series, some weighty facts opposed to the hypothesis of fractional crystallisation must be brought forward.

1. *Basaltic or gabbroic magmas cannot be parental magmas for granites.* The dominant importance always attached to the »basaltic» and gabbroic magmas in the problems of differentiation, will first of all be due to their enormous extension, only equalled by that of the granites[2]. Starting from this fact,

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[1] A. Vogt, Videnskapsselskapets Skrifter, 1923, no. 17.

[2] R. A. Daly, Igneous Rocks and Their Origin, pp. 42 *etc.*

Daly questions their character of parental magmas to some basic rock-groups, and, following Loewinson-Lessing, he assumes that their ability extensively to assimilate acid material may result in magma-mixtures, which later on may separate into intermediate and acid rocks. With logical consistency, Bowen, the most extreme supporter of the fractional crystallisation doctrine, accepts the »basaltic» magma as the parental magma also of the acid rocks, assuming that assimilation cannot play at all such an important *rôle* as is maintained by Loewinson-Lessing and Daly. Against this assumption as to the character of the basalts, Daly[1] and Loewinson-Lessing[2] have put forward convincing critical arguments. From these criticisms it is evident that the crystallisation of a basaltic magma cannot enrich the remaining solutions with silica to the extent necessary to give them the quartz-percentages of granites. The lack of phenomena which may be explained as due to fractional crystallisation in most of the basalt-sills and diabase-sills or basalt-flows, and the lack of an ultra-femic phase, in differentiated sills and laccolithes — conditioned by the theory —, contradict the hypothesis. However, it must stand or fall with the presumption that the basaltic magma is the parental magma of all rocks. Otherwise the hypothesis cannot explain the usual basic borders towards the *upper* contacts of the intrusive bodies (such borders are very usual in the Archean of Southern Sweden; cf. also the whole series described by Daly), or the very usual appearance of basic rocks, intruded immediately before the advance of the comagmatic salic rocks belonging to the same intrusion-family and orogenesis — a sequence in the Archean of Fenno-Scandia best illustrated by the sub-Jotnian eruptive-family, which appears earliest as an extensive formation of diabases, followed by the rapakivi granites.

To these grave objections against the view that the basaltic magma is a parental magma may be added some physico-chemical objections. —The settling-out of olivine in basaltic-gabbroic magmas certainly leads to an enrichment of SiO_2 in the magma-solution, but also femic CaO and FeO must be enriched. Simultaneously, the feldspar-proportions change to a composition characteristic of granodiorites or granites.

The crystallisation leads to an enrichment of femic CaO in the salic solution. On the contrary, the differentiation in the present area (and overwhelmingly in all rocks belonging to the subalkaline clans) transfer all, or almost all, the femic lime to the gabbroic or basaltic rocks. The proportions MgO : FeO of the intermediate and salic rocks do not correspond (fig. 28, p. 92) to the proportions in the final stages of the pyroxene-crystallisation. The enrichment of femic CaO necessitated by the hypothesis of fractional crystallisation would lead to crystallisation of diopsidic pyroxenes or extremely lime-rich (basaltic) hornblendes in the granodiorites and granites rich in anorthite. However, such an enrichment does not occur in nature. A survey[3] of the analyses of the gra-

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[1] R. A. Daly, Genesis of the Alkaline Rocks, Journal of Geology, vol. 26, 1918, p. 97.

[2] F. L.-Lessing, The Problem of the Anorthosites and Other Monomineral Igneous Rocks, Journal of Geology, vol. 31, 1923, p. 89.

[3] This is obtained from Washington, Chemical Analyses of Igneous Rocks. Only superior analyses with P_2O_5, TiO_2, Fe_2O_3 and FeO determinations have been employed.

nites and granodiorites of the world collected by Washington, shows that about 75 % lack femic lime; the others show a distribution by no means corresponding to such a distribution in the MgO : CaO : FeO diagram as might be expected from a consideration of the crystallisation of the pyroxenes (an aggregation round the projection of the deepest parts of the ternary liquidus surface of the pyroxenes, *vide* p. 82). In itself, the essential occurrence of hornblende in the intermediate rocks indicates the femic CaO to have decreased; and the small amounts of hornblende present do not prove the occurrence of femic CaO, which, for the formation of hornblende, has, in many cases, been obtained from anorthite broken up during the crystallisation-courses. However, it may be presumed that all the pyroxenes crystallised before the plagioclase, and that they also settled before the magma obtained the feldspar-proportions characterising the diorites or granites. In order to meet such an objection, we must again discuss the crystallisation of the pyroxenes, this time in the basaltic magmas.

As already observed, the crystallisation of the pyroxenes in the usual two-pyroxene norites, and also in olivine-gabbros, proceeds during important equalisation-reactions; and, as shown by Vogt[1], the MgO : FeO ratios for the different pyroxenes of the rock in question have become almost equal. Thus, no movement of the remaining solution along the groove of the liquidus surface arises. Consequently, the pyroxenes crystallised before the acid (andesine) plagioclase, and in this way the characteristic »granular» gabbro-texture would arise. The equalisation-reactions show that the gabbro-borders of the granite massives cannot be apprehended as rapidly solidified contact-phases. This fact is also illustrated by the equalisation-reactions which have affected the feldspars. Why were not these gabbros converted by fractional crystallisation? Sufficient time and suitable differences in the specific gravities of the minerals and the liquid phase were not lacking.

On the other hand, regarding the crystallisation-courses of typical basaltic, rapidly solidified rocks, we may find that in these a magnesia-rich olivine or Mg-Fe-pyroxene is the first crystallised phase, and consequently the remaining solution will be more enriched in femic CaO, and especially in FeO, than would be the case in the slowly crystallising magmas. The pyroxene crystallising later would, consequently, obtain a more FeO-rich composition, and in this case it would crystallise later than even rather acid plagioclase (later than andesine). In this manner arises the extraordinarily characteristic ophitic texture[2]. The typically ophitic diabases, basalts, or dolerites, cannot give rise to quartzy differentiates through fractional crystallisation. However, it may be presumed that through »squeezing-out» of the remaining, still uncrystallised, magma-solution rich in pyroxene-molecules, there would be

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[1] J. H. L. Vogt, The Physical Chemistry of the Crystallisation and Magmatic Differentiation of Igneous Rocks, Journal of Geology, 29, 1921, p. 532.

[2] These facts, telling against the dogmatic sequence of crystallisation advocated by Rosenbusch, were brought forward long ago by Loewinson-Lessing.

F. L.-Lessing, Studien über die Eruptivgesteine, Congrès Géologique International 7-me Session, 1897, Mem. no. XIII, p. 322 (130).

formed a pyroxenitic magma, separating from an anorthositic crystallised phase — a very comfortable explanation of the anorthosites (on the presumption of fractional crystallisation) which has already been discussed by others. The pyroxenites in this case would be composed of augites rich in ferrous iron. However, pyroxenites of such a type are not found, as shown by the diagram of fig. 20, which contains all the pyroxenitic rocks from Washington's collection of analyses (1917). The diagram shows that only iron-poor pyroxenites occur in nature.

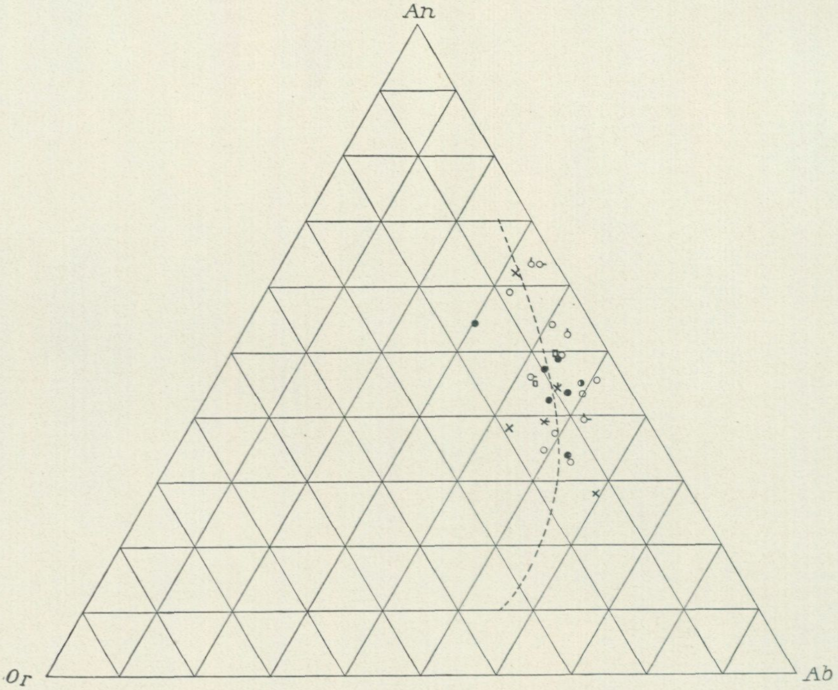

Fig. 29. Diagram showing the distribution of those plateau basalts dealt with by H. S. Washington. The symbols are the same as those of fig. 30.
The broken line indicates the ternary mixing-boundary of the feldspars.

Before leaving the interesting »parental» basalt-magma, the leading chemical character of the basalts may be discussed. We may start from the very interesting study recently published by H. S. Washington[1], who, in his paper on the plateau basalts, has given a quantitative account of the chemical character of these dominating basic rocks. From the chemical point of view, the mean of the basalts found by Washington is essentially different from the »average-basalt» of Daly.

For the discussion of differentiation, Washington's new material is of the greatest importance. By projecting the analyses in the MgO : CaO : FeO and An : Or : Ab triangles, very elucidative results may be obtained (figs. 29 and 30).

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[1] Deccan Traps and Other Plateau Basalts, Bull. of Geol. Soc. of Am., vol. 33, pp. 765—803.

In the feldspar-triangle most of the plateau basalts fall into the one-feldspar area — usually a labradorite or labradorite-bytownite rather poor in potash-feldspar. Thus, for the most part, no independent orthoclase can be expected — nor, as a rule, does such occur in plateau basalts. The »femic» triangle, on the other hand, shows a very distinct distribution of the dots along the projection of the deepest groove of the liquidus of the ternary pyroxene solutions (cf. fig. 23, p. 84). This distribution directly suggests the essential mineralogical discoveries made by Backlund[1], Holmes[2], Merwin[3], and Washington, *viz.* the hypersthene-augitic character of the pyroxenes occurring in the plateau basalts (»hedenbergitic enstatite-augite», according to Washington). Owing

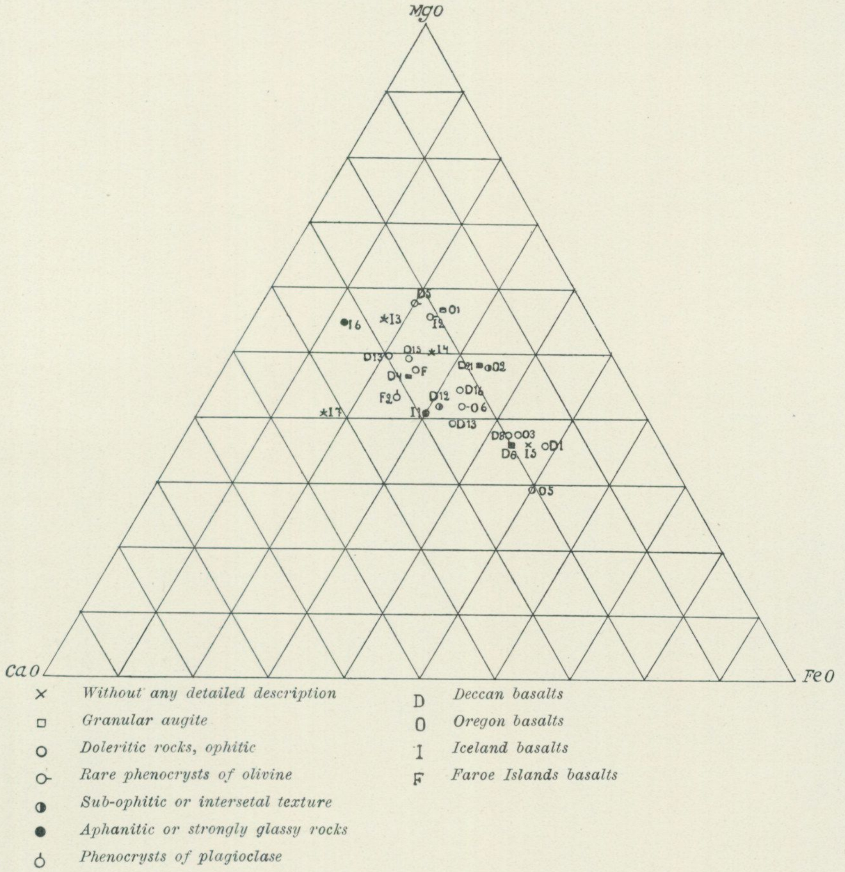

Fig. 30. Diagram illustrating the metasilicatic proportions of those plateau basalts dealt with by Washington.

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[1] H. Backlund, *op. cit.* (*vide* p. 79), and «On the Eastern Part of the Arctic Basalt Plateau», Acta Academiae Aboensis, Mathematica et Physica, I, Åbo, 1920.

[2] A. Holmes, The Basaltic Rocks of the Arctic Region, Mineralogical Magazine, no. 18, 1916—19.

[3] *Vide* Washington, *op. cit.*

to their richness in ferrous iron, these pyroxenes usually crystallise as ophitic interstitials, even later than the more acid plagioclases, or they become enriched in the interstitial glass-basis of the rocks. (These facts undoubtedly support the scheme drawn up by the present author regarding the crystallisation-courses of the pyroxenes). A more important deviation from the general position of the femic proportions favours the crystallising of olivine (no. D 5 in the diagram, fig. 30). Otherwise, an unimportant deviation from the deepest parts of the liquidus surface of the pyroxenes seems to favour the crystallisation of a pyroxene having the same femic proportions as the rock, without any previous crystallisation of phenocrysts rich in magnesia or ferrous iron.

The chief result of this discussion is: That the plateau basalts cannot give rise to the multitude of rocks which have been supposed to originate from the »basaltic parental magma». However, the plateau basalts undoubtedly constitute the overwhelming majority of all basalts, and therefore we may lay stress upon *their* inability to give rise to all other rocks through crystallisation. Indeed, the plateau basalts seem to represent a pole of differentiation, and they cannot further differentiate. Their origin must be entirely magmatic; they originate neither through a crowding of crystals nor by complicated re-melting processes of the crystals.

Consequently a new »parental» magma would be necessary for the fractional crystallisation hypothesis to be tenable.

2. *The potash-rich granites cannot be explained on the hypothesis of fractional crystallisation.* The important studies of J. H. L. Vogt and H. E. Johansson upon the individualisation-boundary of the ternary feldspar-solutions (figs. 16—19, p. 70) and its transition into a ternary minimum (H. E. Johansson[1]) or binary eutecticum (Vogt[2]), with the composition Or_2Ab_{3+An} (J.) or $Ab_3\,Or_2$ (V.), show remarkable agreement regarding the situation of the individualisation-boundary. The same scientists show a similar agreement as regards their statistical calculations concerning the ternary eutecticum of quartz and alkalifeldspars, which retains the same proportions of the feldspars and was calculated by Johansson to be,

$$1\,(Or_2Ab_{3\,+\,An}) \cdot 2\,SiO_2.$$

This granite-eutectic composition is represented in nature by the obsidians, which in their lack of phenocrysts indicate an eutectical composition (as shown by Johansson and later on discussed by Vogt). These considerations show that we have a thorough knowledge of the crystallisation-courses also in the case of acid magmas. We may presume that the remaining solutions of crystallising magmas tend to reach the individualisation-boundary and the ternary (or binary) minimum.

As well from the anchi-eutectical as from the fractional crystallisation

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[1] Om fältspaternas sammansättning och bildningsbetingelser, G. F. F., vol. 27, pp. 342—43. From these developments Johansson has evidently found that the binary crystallisation-curve of the alkalifeldspars belongs to Roozeboom's Type 3.

[2] Über anchi-monomineralische und anchi-eutektische Eruptivgesteine, pp. 84—85.

conceptions of differentiation, a grouping of the acid rocks (the granites) along the individualisation-boundary, or at the minimum mentioned, must be expected. However, such a grouping is not found, and, as pointed out by Vogt, we find a great number of granites which, as regards both the feldspars and quartz, have passed the individualisation-boundaries.

Among the Kolmården granites, all the coarse quartzy granites, and a great number of the medium-grained granites — indeed, the majority of all granites — contain a rather high percentage of potash. Their plotted points in the feldspar diagram are situated rather far from the individualisation-boundary towards the Or-corner. Manifestly these rocks cannot be explained as crystallised residual solutions from originally soda-rich and lime-rich magmas, which, owing to a continuous settling-out and gravitative sinking of plagioclase, have obtained a percentage of potash-feldspar not allowed by the laws of crystallisation. As previously maintained (p. 72), the potash-rich magmas commence their crystallisation with potash-feldspar, not with plagioclase. Consequently, the Or-richer granites cannot yet be explained on the hypothesis of fractional crystallisation. The striking distribution of potash-rich granites in, *e. g.* the Fenno-Scandia Archean, however, indicates that these must be regarded as quite normal phases of — in a word — every series of more acid rocks.

3. *The equalisation-reactions during the crystallisation of plutonic rocks.* The important equalisation-reactions between solid and liquid phases in plutonic rocks indicate that the crystallisation-courses proceeded very slowly. All calculations as to the rate of diffusion of magma-heat point to this, as do also observations on recent extrusives. In view of the fact that zonary banding also occurs to some extent in intrusive rocks, we may state that the equalisation-reactions pass on extremely slowly.

As shown above, the textural appearance and mineral-contents of every rock largely depend on the specific chemical proportions of its original magma, and these proportions must have existed during an extremely long crystallisation-period. It is obvious that, if favourable conditions for gravitative differentiation prevailed during this period, a real stratification of the minerals according to their specific gravities would have resulted. However, there is nothing to indicate such stratification in the huge existing granite areas. Magnetite (sp. gr. 5.20) is as characteristic of basic rocks as of acid granites. Hypersthene (sp. gr. about 3.40) occurs as well in gabbros as in Or-rich granites, and so also does hornblende. The settling due to gravitation would, under such circumstances, only affect the plagioclases, and consequently completely control a mineral group with specific gravities ranging from 2.76 (An) to 2.62 (Ab); otherwise it would show the most confusing inconsistencies. Naturally a hypothesis based upon so many contradictions and ignoring so many facts from field observations and physical chemistry, cannot in the long run be dogmatically maintained, nor can it promote a solution of the differentiation problems. The simplicity of the hypothesis is deceptively pleasing, but on further consideration, this simplicity proves illusory, and the differentiation problem — the key-problem of petrology — threatens to be submerged in a confusion of ideas. The dogmatic support given to the hypothesis, however, has been fortunate, for it has called forth sharp criticism, in the first place from Daly and Loewinson-Lessing. Also the contribution of F. F. Grout[1] has been very valuable as showing the chemical discontinuity between the gabbros and »red rocks» of the classical Duluth-series. By means of statistics, graphically and logically expressed, Grout has explained this discontinuity as due to limited miscibility in liquid phases. He also discusses the impossibility of solving this problem on the hypothesis of fractional crystallisation. One good feature of the persistent holding forth of the hypothesis of fractional crystallisation has been that it constituted a search for *one single* mode of solution. The criticisms have shown, too, that previously an exaggerated value was attached to the hypothesis, and that crystallisation in magmas may take place in solutions so viscous that the influence of gravitation on the crystallised phases is negligeable.

Liquation as the Chief Cause of the Differentiation of the Rocks Described.

From the considerations quoted above, the author has been led to the conclusion that limited miscibility — liquation — caused the differentiation of the present rocks.

As starting-points for a discussion of the differentiation-courses were taken the diagrams (figs. 26—28, pp. 90—92) already entered. To these a new diagram is added, showing the chief distribution of the rocks as found by experience[2]. The analysed and calculated rocks represent the leading types of the area, and this distribution has been expressed by an aggregation of dots round the dots given by analyses (fig. 31). Transition-types also have been projected; and their unimportant occurrences are expressed by a thinning of the dots. In the field the rare occurrence of transition-types is much more evident; *i. e.* there occur very unimportant transitions, and between the two-mica granite and the very quartzy Graversfors granites only some few granite dikes of transition-type were observed.

The interpretation of this diagram requires a grouping of the rocks from a geognostical point of view. Though the boundaries are generally indistinct and characterised by transition-types, we may, broadly speaking, observe the following division, in which the grouping between I and II marks a rather evident hiatus in age.

I A. Medium-grained granites, followed by aplitic and salic granites, and partly directly connected with group I B.

I B. Norite—quartz-diorites—quartz-syenite—hornblende-bearing granite: an intimately associated sequence of rocks, among which the hornblende-bearing granite, in places, shows direct connections with group II.

II. Coarse granites: porphyritic two-mica granite and very quartzy coarse

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[1] A Type of Igneous Differentiation, Journal of Geology, 26, 1918, pp. 626—658.

[2] This method was employed by H. E. Johansson, G. F. F., vol. 32, I, p. 379.

granites (Graversfors granites), which are connected by transition-types with one another and, as already mentioned, are sometimes allied to I B, but also cut the whole group I.

I A. The series of medium-grained granites differs from the other groups in its evidently lower percentage of anorthite; however, in the distribution in the feldspar-diagram it appears parallel to these groups. Regionally there is a fairly distinct distribution of two indistinctly porphyritic types with small (1 to 2 cm. long) crystals of microcline-perthite in a medium-grained matrix. Their corresponding types among the An-richer granites are the hornblende-bearing granites and the coarse two-mica granites. The percentages of the different feldspars are also analogous to those of these types. However, the hornblende is replaced by small amounts of muscovite. In the potash-richer, medium-grained granite this mineral becomes more common, and to this type the aplitic and medium-grained salic granites are connected by means of unimportant transition-zones. These two groups are more quartzy; the salic granites often very quartzy with indistinctly individualised quartz (»crystal-granites»), sometimes dark, as in the case of the rapakivi granites. These salic granites evidently form a parallel to the coarse quartzy granites. An isolated occurrence of soda-rich granite also indicates a differentiation parallel

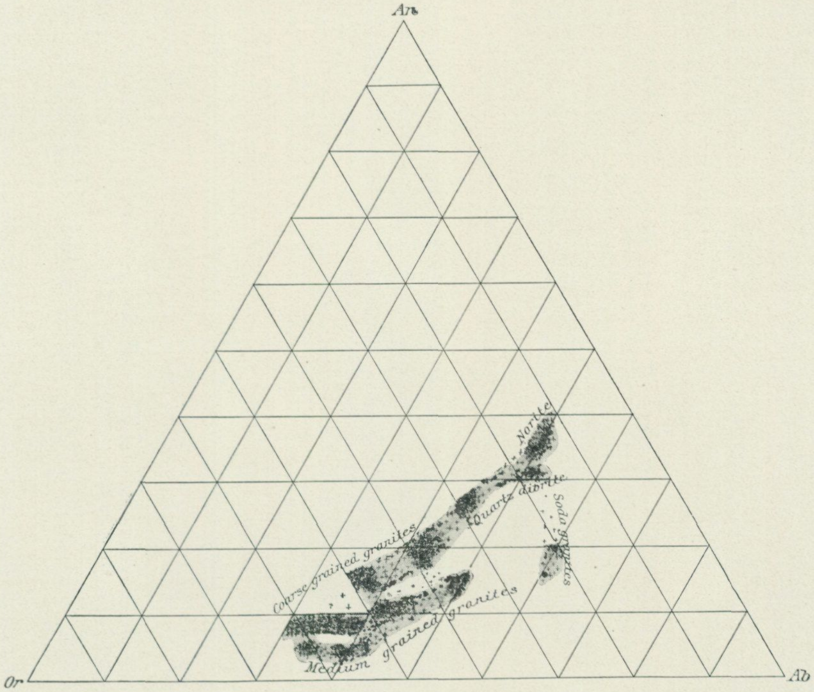

Fig. 31. Diagram showing the approximate feldspar-proportions of the rocks of the Stavsjö area. The dots indicate the analysed types.

to that observed in the boundary-zone of the hornblende-bearing granite towards the aplitic granite S. W. of Aspetorp (p. 45). A quantitatively very unimportant parallel to the noritic gabbro may be represented by the cummingtonite-bearing gabbro E. of Skärgölen.

In the Stavsjö area we can get a rather clear idea of the following sequence of differentiation, which is very characteristic of Southern Sweden: norite—[quartz-diorite—quartz-syenite (granodiorite)]—hornblende-bearing granite (Filipstad granite). The starting-point is found in the transition-rocks between the norite and the quartz-diorites (p. 32), *which — through their heterogeneous structure, characterised by noritic segregations in a granodiorite matrix — may be interpreted as magmas interrupted by crystallisation during their differentiation-stage.* The complex nodules of quartz and feldspars occurring in the quartz-diorites may also be considered as a distinct rock-phase. There seems to be no possibility of explaining them from the point of view of fractional crystallisation. On the contrary, owing to their similarity to, or almost exact identity with, the feldspar-proportions of the norite, they evidently illustrate how the complex magmas of the diorites strive, through the separation of such an An-rich soda-granite phase, to remove the composition of their salic component into a composition of equilibrium, which is characterised by hornblende-bearing granites and quartz-syenites. The fact that the soda-rich and lime-rich differentiation-pole of the feldspars associates, on the one hand, with a femic complex of the magma, and, on the other hand, with quartz, may imply that — with the prevailing concentration conditions of femic components and free silica — the feldspar-contents of the parental magma of the quartz-diorites and the noritic gabbro were distributed between two distinct magmas, owing to limited miscibility. The composition of this instable parental magma may be supposed to represent the arithmetical mean between the quantitatively predominant rocks in this sequence of differentiation, *viz.* the hornblende-bearing granite and the norite. Such a magma may be approximately classified as an andesitic magma.

It is remarkable that the area in the feldspar-triangle occupied by the inhomogeneous diorites and the hypothetical andesitic magma seems to form a continuation, towards the anorthite-richer fields of the triangle, of the remarkable area of discontinuity found by H. E. Johansson[1] to separate the soda-rich granites from the normal intermediate granites. This discontinuity has also been discussed previously by P. J. Holmquist (*vide* Johansson). Under abyssic conditions, complex solutions falling within these areas are particularly subject to differentiation, which renders a study of the areas of great importance.

A very interesting parallel to the type of differentiation mentioned was found by A. Gavelin[2]. At the boundaries of gabbro-intrusives against older salic granites, Gavelin has studied a series of re-melted and syntectic rock-

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[1] Harald Johansson, Till frågan om de mellansvenska järnmalmernas bildningssätt, G. F. F., vol. 29, 1907, p. 149.

[2] Om relationerna mellan graniterna, grönstenarna och kvartsit-leptitserien inom Loftahammarområdet, S. G. U., Ser. C, no. 224, 1910, pp. 44—86.

phases. Some unchanged re-melting products are found, but sometimes also syntectic mixtures of magmas were formed, which later on had differentiated into varying intermediate rocks, constituting transitions to the gabbro. In the dioritic transition-types close to the gabbro occur sparse nodules exactly similar to those found in the Stavsjö diorites. Gavelin has given a detailed description of them and considers them to represent »micro-pegmatitic» intergrowths between plagioclase and quartz. Evidently the separation of these nodules corresponds directly to the differentiation-type already mentioned. Through the assimilation of salic materials, the feldspar-composition of the gabbros in question was removed into the mentioned area of discontinuity, and consequently the syntectic mixture breaks up into two magma-phases, one intermediate and one gabbroic. However, the intermediate phase seems to have preserved too much of the gabbroic phase, and consequently it strives to correct its feldspar-proportions by ejecting a plagioclase-quartz complex — the nodules. Simultaneously, the intermediate phase tends to a quartz-monzonitic composition.

Sometimes the differentiation in group I B is characterised by the separation out of a soda-granite phase of the same type as that observed among the medium-grained granites. This differentiation-type is observed in the boundary-zone of the hornblende-bearing granite S. W. of Aspetorp (p. 45). Locally here a separation between an oligoclase-granite and an aplite rich in potash occurs. The mean composition of these small differentiates (analyses p. 44 and p. 45) falls within the area of discontinuity discussed by Johansson, and certainly we may suggest that the differentiating influence of this area of discontinuity has made itself felt here.

II. In parts the rocks belonging to this group form a geognostical sequence, constituting the youngest rocks of the area. Between the two chief types of the group, the porphyritic two-mica granite and the quartzy Graversfors granites, there occurs an almost distinct discontinuity in chemical composition, *viz.* the great difference in their quartz-percentage. Another distinct difference is often striking, *viz.* the frequently quite important percentage of hornblende in the quartzy granites. As an example, the small part of the Graversfors granite occurring in the western part of the area mapped is rather rich in hornblende.

Grouping the main divisions above considered, we get the following survey:

Group I A

(Hornblende-bearing gabbro) (Skärgölen)	Medium-grained biotite-granite	Medium-grained two-mica granite	Aplite; salic granites
Noritic gabbro, inhomogeneous quartz-diorite, quartz-diorites (granodioritic)	Hornblende-bearing granite	Porphyritic two-mica granite	Coarse quartzy granites

Group I B

Group II

As mentioned, Group I B offers a starting-point for the whole discussion of the differentiation. There we have found a supposed breaking-up of an »andesitic» magma into noritic gabbro and hornblende-bearing granite, with quantitatively unimportant transition-forms, showing a tendency to further differentiation. Among the medium-grained granites a correspondence is observed, *viz.* the small area of hornblende-bearing gabbro of Skärgölen. Parallel to this more basic phase of the differentiation, also, a group of salic magma-components occurs in groups I A and II, showing a separation into two-mica granites and strongly quartzy granites.

Thus, from a purely empirical point of view, there arises the possibility of recognising in the general differentiation separate differentiation-courses of two magma-phases, one »andesitic» and one salic (granitic). In the former group, chiefly the acider pole occurs (the hornblende-bearing granites of group I B and the biotite-bearing granites of group I A), while the basic pole, the gabbros, presents unimportant extension. The chemical studies on the composition of the »parental» magma of this group indicate that the magmas of gabbro and intermediate granite were mixed in about equal proportions, and consequently it seems probable that the separation of the gabbro-phase was generally completed before the magmas assumed their existing situations as crystallised phases. These suggestions indicate that the differentiation did not pass on *in situ*. On the other hand, however, we may imagine that the differentiation was not completed at the deeper stages, and that this course was finished *in situ*.

A survey of the age-relations of the different rocks of the sequences seems, in view of the interpretation suggested for the differentiation-courses, to lead to contradictions. On the one hand, there occurs a completed series of differentiated medium-grained granites (group I A), evidently low in anorthite, and on the other hand, there occurs a following sequence of anorthite-richer granites, containing greater admixtures of gabbros, and followed by potash-richer granites (group II), analogous to acider members of the earlier sequence. However, there are no contradictions when we suggest that the courses of intrusion and differentiation were subject to recurrence. The intrusion of the area begins with differentiated An-poorer granite-magmas, which were partly solidified before the advance of a similar, but later differentiated, new sequence of An-richer magmas. Generally the two series followed so closely on one another that perfect transitions between them occur. Again the salic members of the An-richer series followed the hornblende-granites so closely that complete transitions are observed also here. However, between these youngest rocks and the medium-grained series a distinct hiatus was found. Contemporaneously with the ceasing of the intrusion-courses, the orogenetic movements began to die down, and also the cooling of the Archean as a whole became more rapid, and consequently the latest magma-intrusions, appearing as dikes, were cooled more rapidly. These circumstances are more exhaustively discussed below (p. 115).

The remarkable difference in the percentage of anorthite to some extent indicates a real contrast between group I A and group I B + II (as a whole complex). From the point of view of differentiation, we may also lay stress upon this contrast. Indeed, this difference indicates that differentiation-groups I A and I B + II originated from magmas as groups characterised by chemical differences. Logically, we may suggest these chemical differences to have been concentrated *in different parental magmas*, one following on the other. We may suggest that, owing to successive intrusion, these hypothetical parental magmas tended at first, in deeper situations, to distribute silica and femic components over different magmas, which were later separately broken up into magmas fixed by crystallisation. Probably the differentiation proceeded in deeper situations, and the magmas forming the present rocks were intruded as inhomogeneous mixtures.

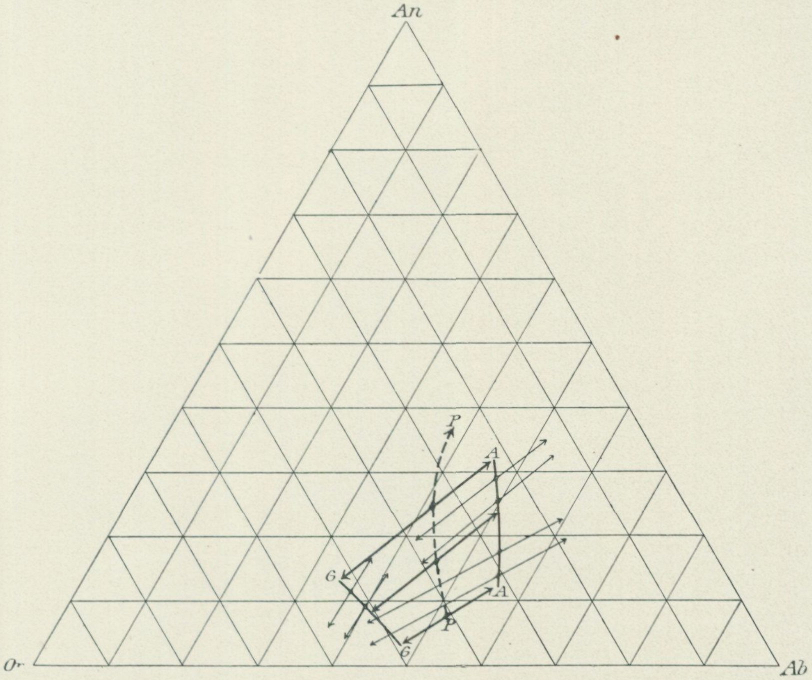

Fig. 32. Diagram illustrating the supposed evolution of the differentiation here considered. P—P marks the increase of An in the parental magmas continuously invaded. A—A and G—G mark the evolution of the first formed particular magmas, whose breaking-up is indicated by the thin arrows.

Now we will discuss the differences between these hypothetical magmas. On the one hand, we may imagine these differences to have been primary and caused by the increasing richness of femic components (with these components we may, in this case, include the anorthite) in the deeper situated and subsequently advancing magmas; or, on the other hand, we may suppose these differences to have been caused by courses passing on during the evolution of the magmatic cycle.

With regard to the first supposition, the intrusion-courses may be illustrated by a scheme comprising the feldspar-proportions, like fig. 32.

On the other hand, the poverty of the basic magmas in the plutonic series is rather striking. Indeed, we may suggest that the basic magmas, basaltic or gabbroic, and not the femic minerals, settled under the influence of »the gravitative control over the differentiation»[1]. However, we may suppose that in deeper parts of the earth's crust the sinking magmas would again become perfectly miscible with the undifferentiated »parental» magma, and consequently the magma would become more basic. Also we may imagine the first differentiated phase to have been more basic than that which separated later. To illustrate these suggestions, fig. 33 may be drawn. In this diagram P_1 represents the supposed parental magma. It was broken up into A_1 and G_1, each of which broke up into separate magmas. A_1 was differentiated into B (gabbro-magma) and granites richer in plagioclase than the particular magmas of G_1. In deeper situations the sinking magma B was dissolved in P_1, which consequently grew more basic, P_2. When intruded, this complex magma broke up into A_2 and G_2, and later on A_2 broke up into N (noritic gabbro) and hornblende-

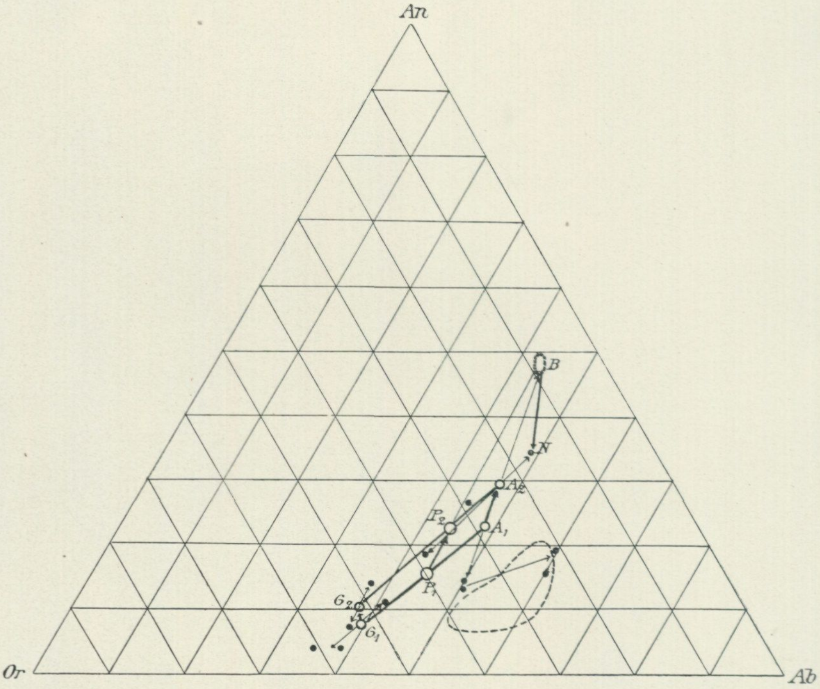

Fig. 33. Diagram illustrating the second supposition as to the differentiation of the Stavsjö rocks. The broken curve indicates the area of discontinuity for granites as found by Johansson. As regards the lettering, cf. the text. The dots indicate the analysed rocks.

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[1] Cf. Daly, Igneous Rocks and Their Origin, pp. 229—46.

bearing granite, G_2 formed quartzy granites and coarse two-mica granite. — The continuous evolution of the magmas may be suggested by the arrows in fig. 33.

However, the latter part of this discussion is based upon the supposition that, during the magmatic cycle, the basic pole of differentiation became continuously poorer in anorthite. This supposition may, indeed, afford an explanation of the present sequences, and there are also general indications of such an evolution of the basic rocks. It is to be pointed out that the noritic gabbros (with two pyroxenes) generally seem to contain lower percentages of anorthite than the basalts and diabases. Noritic gabbros probably represent the most common types of gabbros associated with the more basic granites of Fenno-Scandia. On the contrary, the more acid granites are accompanied by diabases, as, *e. g.* the salic rapakivi granites, which have generally been found to be hypabyssic. As regards the differences in the differentiation diabase ⟷ salic granite and norite ⟷ basic granite, it seems rather probable that the first type of differentiation may represent the introductory type of a magmatic cycle; the second type, on the other hand, may represent the succeeding type of evidently abyssal character. From the suggestions outlined in the diagram of fig. 33, the cessation of the magmatic evolution must result in intrusions continuously richer in basic differentiates.

Naturally, discussions as to the evolution of the magmas must be hypothetical. The author has introduced them only in order to point out that every petrologist must consider such problems. Indeed, it would be an excellent thing if every petrologist who intimately knows his field, thanks to thorough investigations, would express his own opinion on similar problems which arise. Surveys and compilations made by individual petrologists cannot make adequate use of the abundant and varying material.

A very interesting parallel to the suggested increase in the percentage of anorthite during magmatic evolution has been adduced by H. Backlund, who carried out exhaustive investigations upon the subject of the percentage of anorthite in the rocks of the præandine and andine cycles in South Mendoza, in the Cordillera of South America. With this work Backlund[1] has evidently raised an interesting problem of petrology, and further investigations would certainly support his conclusions. The present author has encountered this problem independently in his work on the small area here considered.

The above general aspect of the differentiation presents points of contact with the leading views supported by Loewinson-Lessing[2] and Daly[3].

In the case of the area described, the author hypothecates a previous occurrence of a basic magma (not basaltic, but andesitic) and a granitic magma, which each broke up into separate magmas. This view seems to some extent to correspond to the hypothesis of the occurrence of two primary magmas (Loe-

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[1] Der magmatische Anteil der Cordillera von Süd-Mendoza, Acta Academiae Aboensis, Mathemathica et Physica, II, Åbo, 1923, pp. 259—280.

[2] F. Loewinson-Lessing, The Fundamental Problems of Petrogenesis, or the Origin of Igneous Rocks, Geol. Magazine, Dec. V, vol. VIII, 1911.

[3] Igneous Rocks and Their Origin, New-York, 1914.

winson-Lessing) which were intruded as inhomogeneous mixtures, and subsequently differentiated. However, the chemical characteristics of the different groups of rocks in the present area indicate that such characteristics were originally concentrated in homogeneous parental magmas.

The general view of Daly, at least upon the normal magmatic evolution, postulates an extraordinarily active assimilation of the invaded rocks. However, Daly[1] also evidently lays stress upon the fact that the pre-Cambrian granites probably originated from intermediate parental magmas, whose basic (basaltic) pole disappears under the influence of gravitative differentiation. Our general knowledge of the pre-Cambrian igneous rocks compared to younger intrusions, however, indicates no differences between them. Therefore, on the one hand, the assumption of primary intermediate parental magmas for the pre-Cambrian rocks, and, on the other hand, the assumption of primary *basaltic* parental magmas (changing into intermediate magmas through the action of assimilation) for the post-Cambrian rocks, seems to involve inconsistencies. The latter view also postulates an evolution from basic to acider groups of intrusion during the magmatic cycle. In the account of the sequences given in this chapter, we have found an opposite evolution. Indeed, it proves very difficult to explain this fact on the assimilation-hypothesis. But assuming that the quantitatively predominant assimilation took place chiefly in the deepest parts of earth's crust, at the boundaries between the crust and the deeper-situated magmas, the assimilation-hypothesis seems more tenable. However, in this case the »syntectic» magmas change to the »parental» magmas, which latter are properly dealt with in a consideration of the crystallised differentiates[2].

CHAPTER 5.

The Position of the Plutonic Series.

The area invaded by the plutonic series belongs to the areas of veined gneisses characterising the coast region of South-Eastern Sweden. Independently of the supracrustal or infracrustal origin of the older rocks, they were stamped by a uniform metamorphism which is characterised, in the first place, by the separation of pegmatitic veins in the very inhomogeneous gneisses. According to the petrologists who have worked in these areas, the courses of metamorphism were completed by partial re-melting of the rocks, and thus the pegmatitic products have originated[3]. Regarding the age of this »palingenetic» metamorphism, it is generally stated to have arisen during the later stages of

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[1] Genesis of the Alkaline Rocks, Journal of Geology, 1918, p. 120.

[2] Cf. Loewinson-Lessing, *op. cit.*

[3] P. J. Holmquist, Om pegmatitpalingenes och ptygmatisk veckning, G. F. F., vol. 42, p. 191. Axel Gavelin, Återblick på uppfattningarna om mellersta och södra Sveriges urberg *etc.*, G. F. F., vol. 43, pp. 210—11.
B. Asklund, Några urbergstektoniska problem från Östergötland, G. F. F., vol. 43, p. 609.

the Archean (cf. also foot-notes 1 and 2). In the south-eastern parts of the province of Östergötland, which are strongly characterised by the courses of the palingenetic regional metamorphism, a series of granites (»Filipstad granites») occur, in which the textures seem to have been subject to strong deformation during the crystallisation-courses. It is obvious that these magmatic deformations were due to the same metamorphism that was attacking the older Archean.

The correspondence between the regional-metamorphic development in these more southern areas and that of the present area of Kolmården is complete. Also at Kolmården evidently the similar and contemporaneous intrusions of gabbros and granites invaded the older Archean during strong orogenetic movements, which arranged the plutonic series in the prevailing folding and deformation-structures. The mainly vertical dip of the foliation and the moderate or flat dip of the linear structure[3], caused by regional stress and obtaining the same direction as in the more southern areas mentioned (S. E.—E. S. E.), also enhance the similarities between them. These deformation-structures also strike the plutonic series at Kolmården, but, in contrast to the southern areas, the youngest Kolmården granites are almost free from regional-metamorphic influences and generally show a distinctly cutting character. This is also marked by the occurrence of sharp cutting dikes of the youngest granites.

Consequently, the area shows that contemporaneously with the evolution of the magmatic cycle, there occurred an evolution of orogenesis. Though the concordance between the boundaries of the plutonic series and the directions of the foliated pre-existing rocks is often very well developed, there is no doubt that the plutonic series is completely discordant against the gneisses. However, during the commencing invasion of the plutonic rocks, especially when the medium-grained granites were intruded, the cutting contacts became insignificant, on account of the strong orogenetic movements and the palingenetic courses. The movements ceased contemporaneously with the intrusions of the youngest members of the cycle and the continuous cooling of the partly re-melted leptite gneisses, and consequently the final intrusions cut the vein-structure of the leptite gneisses and were partly intruded along the larger cracks, which may be considered the final effect of the orogenetic pressure on the older rocks, now again solidified and brittle.

The investigations hitherto made in the Stavsjö area have not led to any definite opinion on the plutonic area as a tectonic body. It obtains the massive form, which is very characteristic in these areas of Sweden. Along the boundaries against the leptite gneisses, the younger rocks dip towards the latter,

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[1] N. Sundius, Åtvidabergstraktens geologi och malmfyndigheter, (p. 83: survey of A. Gavelin's opinions on the geology of the north-eastern parts of the province of Småland), S. G. U., Ser. C., no. 306.

[2] A. Gavelin's unpublished investigations to sheet »Waldemarsvik», and B. Asklund och R. Sandegren, Beskrivning till kartbladet Torönsborg, S. G. U., Ser. Aa, no. 153.

[3] Cf. the literature quoted, p. 114, and also A. Gavelin, Beskrivning till kartbladet Loftahammar, S. G. U., Ser. Aa, no. 127, p. 65, and P. J. Holmquist, Stockholmstraktens berggrundstektonik, G. F. F., vol. 43, 1921, p. 229.

which consequently may form the upper parts of the area. On the other hand, the pronounced and uniform pitch of the linear structure and of the sparse flat-lying inclusions of leptites (*e. g.* N. of Lake Björnsjön) indicate a rather flat arrangement or stratification of the differentiates dipping towards S. E. This tectonical arrangement of the magmatic rocks, which is really also very characteristic of the coast regions of the provinces of Södermanland and Östergötland, and which in several cases has led to interpretations which explain the intrusive bodies as laccolithes or phacolithes[1], makes the writer hesitate to interpret the plutonic area as a batholithic intrusion. However, this question cannot yet be adequately considered. As regards the concentrated situation of the relatively younger sequence in the south-eastern part of the area mapped, it seems probable that the substratum of this part once formed an intrusion root.

In the survey of the earlier geological investigations in the Stavsjö area (p. 8), the conclusions of A. E. Törnebohm concerning the age of the plutonic series were reviewed. For a clear understanding of these conceptions, a short review of the questions of the age of the granites of Southern Sweden may be added here. Törnebohm divided the Archean granites of Sweden into four groups: »urgranites» (primitive granites), and granites of first, second, and third groups. The urgranites were considered by Törnebohm to be more directly connected with the gneisses, the oldest rocks of the Archean. The first group included chiefly the granites of the province of Uppland; to this group the two-mica granite of the Stavsjö area was added. This first group and also the other groups were considered to be younger than the porphyry-leptite formation, the supracrustal formation of the Archean.

Later on P. J. Holmquist[2] divided the Archean granites into three groups: 1) gneiss-granites 2) Archean massive granites and 3) »cutting» granites (»durchbrechende Granite»). The division of the gneiss-granites is geognostical and chiefly refers to the parallel-texture of the rocks. According to Holmquist, this group may also contain younger granites of 2) or 3); the division could not, however, be exactly carried out from the available investigations (1906). Certainly this question still remains for large areas of Sweden. Holmquist's group 2 included mainly Törnebohm's groups 1 and 2; the »cutting» granites represent Törnebohm's group 3. Later on this group was named »serarchean» granites by A. G. Högbom[3], and now this term is generally adopted.

Before and since Holmquist's division, A. Gavelin[4] offered evidence in

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[1] H. E. Johansson, Om Tunabergs kopparmalmsfält, S. G. U., Ser. C, no. 221, p. 5.
B. Asklund och R. Sandegren, Beskrivning till kartbladet Torönsborg, S. G. U., Ser. Aa, no. 153, p. 43.
Regarding the term »phacolith» or »phacolite», cf. A. Harker, The Natural History of Igneous Rocks, 1909, p. 78.

[2] Studien über die Granite von Schweden, Bull. Geol. Inst. of Upsala, VII, pp. 77 *etc.*

[3] Precambrian Geology of Sweden, Bull. Geol. Inst. of Upsala, X, p. 25.

[4] S. G. U., Ser. Aa, no. 127, and »Om relationerna mellan graniterna, grönstenarna *etc.*», S. G. U., Ser. C, no. 224.

support of a granite-formation, the Loftahammar gneiss-granites, which are older than the usual granites of the province of Småland. The latter district especially contains a great part of the Archean massive granites. Gavelin's division (gneiss-granites, Filipstad-Småland granites) was later on verified and was generally followed in surveys in Northern Småland and Östergötland.

Subsequently (1921), N. Sundius[1] proposed this more local division to be applicable to all the intrusive formations of Southern and Central Sweden. To that end, Sundius included the »urgranites» and Törnebohm's group I (as Törnebohm had also done originally) in one group, »urgranites» or gneiss-granites. Törnebohm's groups 2 and 3 Sundius included in a second group, which was named »the younger stoping granites». This opinion was advanced because »no adequate reasons have been given which justify the separation of a younger Serarchean group, considered as a unit of time; there is great probability that such does not exist»[2]. Previously Sundius[3] had already been disposed to consider the younger Archean granites of the Grythytte field as »Serarchean» granites. This opinion was disproved by Gavelin[4], who still found reasons to distinguish a Serarchean group from the Filipstad-Småland granites.

In a preliminary paper on the subject of the division and the tectonical features of the Archean of Northern and Eastern Östergötland, the present author maintained that two great granite groups may be distinguished in those areas. The name »Filipstad granites» was still preserved in conformity with Törnebohm's previous grouping in Western Östergötland. This author had demonstrated that the younger granites of these areas seemed to be directly connected with the original Filipstad granites of the classical Archean in the western part of the mining districts of Bergslagen. With regard to the Serarchean group, from a tectonical point of view the author considered that it might be genetically connected with the Filipstad granites. In the course of the investigations here described this opinion proved to be correct. As already stated, the two-mica granite, the youngest member of the plutonic sequence, is closely connected with the Serarchean granites of Southern Södermanland (Tunaberg; Sheet »Tärna»). However, among the relatively older granites there occur typical Filipstad granites — the hornblende-bearing granites. Consequently, the area presents the rare occurrence of a direct geognostical connection between the two groups.

From these field experiences it would seem that the distinguishing of Filipstad-Småland granites from the Serarchean granites lacks justification. However, this is not the case. Certainly the genetical connections are quite clear, and consequently a collective name may seem defensible. Instead of the »younger stoping granites», as proposed by Sundius, the writer would suggest »younger

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[1] Några frågor rörande våra arkäiska intrusivformationer i mellersta och södra Sverige, G. F F., vol. 43, 1921, p. 548.

[2] *Op. cit.*, p. 552.

[3] N. Sundius, Grythyttefältets geologi, Preliminärt meddelande, G. F. F., vol. 38, 1916, p. 287, and N. Sundius, Grythyttefältets geologi, S. G. U., Ser. C, no. 312, p. 334 (summary).

[4] G. F. F., vol. 43, 1921, p. 320 (remarks on a lecture by N. Sundius on »The Geology of the Neighbourhood of Åtvidaberg»).

massive granites», after Holmquist, because their batholithic manner of intrusion is not yet proved, and several observations already speak against this presumed character. The »Serarchean» granites are to be distinguished as the youngest members of this group, and consequently the name »younger massive granites» should in general be attached to the Filipstad-Småland granite series. In the author's opinion, the arguments for a preservation of the Serarchean group are the following:

1) These granites are distinctly younger than the younger tectonical and structural lines of the Archean. First of all, the granites cut the palingenetic vein-structures, generally in contrast to the Filipstad granites. The discordant character of the latter is often indistinct, owing to their intrusion during a period of extremely pronounced deformation, probably partly contemporaneous with the palingenetic period of the older gneisses.

2) The Serarchean granites of the provinces of Östergötland and Södermanland show such a characteristic petrological and chemical composition (first of all in their richness in potash) that, also from this point of view, they would easily be distinguished from the other younger granites.

Consequently, the author must disagree with the opinion of Sundius that, *e. g.* the »Stockholm granites» may represent »very superficially cut or satellithic parts of greater granite masses invisible in the present surface, and with a more basic and plagioclase-rich composition, to judge from the normal differentiation-scheme»[1]. On the contrary, the present investigations indicate that the normal, potash-rich Serarchean granites may be sequented by unusually quartzy granites, which approach to the »simple perthite-quartz-granites»[2]. Thus, the Graversfors granites may also be connected with the Serarchean granites, an opinion already vindicated by J. J. Sederholm[3].

This fact makes it probable that also some salic Småland granites, and especially the perthite-quartz granites, are to be associated with the Serarchean group — a circumstance, indeed, indicated by their frequently decided contacts against the other Småland granites.

From a geognostical point of view, a division of the »younger massive granites» within the areas only slightly affected by the younger Archean regional metamorphism, will certainly be difficult and often impossible. However, there are no reasons to neglect the relative age of the Serarchean granites in the areas where they (followed by a very characteristic group of pegmatites) unmistakably form the youngest intrusives of the Archean and are partly intruded along fault lines, which characterise the final movements in the ancient Archean. On the other hand, the Serarchean granites really also form gentle contacts against the other younger massive granites. However, these facts show us that the intrusion-history of granites covers inconceivably long periods of time.

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[1] G. F. F., vol. 43, p. 566.

[2] Cf. Holmquist, Bull. Geol. Inst. of Upsala, vol. VII, p. 85. Evidently there are only small differences in the percentage of anorthite between the two-feldspar-bearing Graversfors granites and the real perthite-quartz granites. The result of these differences may be explained by fig. 17, p. 71: the Graversfors granites are somewhat richer in An, and consequently they must have crystallised with two feldspars.

[3] Ladogium redivivum, G. F. F., vol. 38, 1916, p. 32.

Concluding Remarks.

In this work the author has given a description of a series of very typical subalkaline rocks belonging to the younger Archean granites of Southern Sweden. The reason why especially the Stavsjö area aroused his interest was that here there appeared a concentrated occurrence of a series of different rocks in a rather small area. Besides this, the co-appearance of Serarchean and Filipstad granites enhances the petrological value of the area discussed.

From the descriptive part of the work have been selected a range of facts for consideration from a theoretical point of view. In order to illustrate the theoretical investigations, the author has employed a number of graphical methods, some of which have already been employed by other authors, and some of which are introduced and discussed by the present author. The graphical method in petrology has been relied on more and more, but by degrees a confusion of systems seems to have arisen. Therefore it seems necessary to employ only methods which illustrate the natural, and especially the mineralogical characteristics of rocks. For this purpose the calculation method of the quantitative system really presents the most favourable basis, and, although at a casual glance the system seems to give rise to a confusion of odd names, it provides, indeed, a fairly natural basis for classification. Certainly the results obtained from a study of the pyroxenes offer much of value for a further division of the class »Salfemane», with reference to its femic minerals, which have not hitherto been considered from such a point of view as is here adopted.

*

As regards the aspects of the crystallisation-history of the pyroxenes, the author believes he has reached useful results. Naturally, these results must for the present be considered as provisional, but further investigations based upon them will probably promote our knowledge of the interesting basic rocks.

The author has ventured to publish his results in the hope that other petrologists may advance new aspects of the interesting subject, for it is a matter of fact that one single petrologist cannot have cognisance of nor obtain access to the abundant material necessary for a comprehensive consideration of such a wide question of petrology. Especially this circumstance stands in the way of the efforts to acquire a knowledge of the optical properties of the pyroxenes in their relation to the chemical composition — though the natural material for such studies certainly does exist.

*

Some chapters of this work contain criticisms of the hypothesis on differentiation which is perhaps the leading one at present. The author was led by his investigations to adopt a divergent view upon this subject, and he has taken up and further considered some older views which are at present under-estimated or entirely neglected. Originally he was inclined to uphold the fractional crystallisation hypothesis, but theoretical investigations induced him to adopt quite a different attitude.

*

It is true that several interesting problems presented by the area have not been sufficiently considered. In certain cases, however, the author has left problems untouched because he did not feel in a position to submit opinions which were sufficiently clear and succint. For example, he has for the present left out of consideration the very interesting differentiation-problem of the helsinkites, as our existing knowledge of these very interesting rocks is too imperfect to permit a clear conception of their differentiation-history. However, we can already consider them to be a distinctly defined series of rocks which will be quite common in the Archean.

For the present, also, the author has omitted a description of the very sparse occurrences of pegmatite dikes which occur in the neighbourhood of the area mapped. They belong to the same type and age as the granite-pegmatites of the Marmorbruket field, and therefore it seems more appropriate to defer any description of them until a more regional description of the Stavsjö Sheet is attempted. In the region now mapped a more extensive occurrence of a quartz-pegmatite, surrounded by muscovite-bearing graphic pegmatite, has been observed about 600 m. to the west of Björndalen farm. N. E. of Engelsholm there also occurs a dike of very coarse pegmatite. It is rich in muscovite and often obtains a graphic texture.

*

Though the author originally intended to include a survey of the numerous investigations regarding the younger massive granites of Southern Sweden and Finland, in the light of the points of view here presented, he postpones such a survey, since the information available is in many respects too ambiguous. However, there are many very valuable indications given for such a survey, especially in the investigations on the Småland Archean. Among these works in particular those published by N. O. Holst, E. Svedmark, H. Hedström, and A. Gavelin, are to be mentioned. Among the Finnish investigations, those of J. J. Sederholm, P. Eskola, E. Mäkinen, V. Hackman, and H. Väyrynen, include a number of suggestions for such a survey. But a comprehensive general review of the younger massive granites from the points of view brought out in the present paper, postulates series of analyses from well-defined and well-bounded minor areas, which the petrologists can deal with exhaustively, considering all the various rock species occurring. Existing analyses, however, generally comprise sporadic and occasional analyses, often worked out without reference to their genetical importance. It is also to be regretted that there are so few analyses of basic rocks available. In any further works on the differentiation-history of the granites, greater interest must be attached to their companions — the basic rocks. It is therefore that the present author has taken special interest in the basic rocks of the Stavsjö area.

*

As regards the orthography of this paper, it need only be mentioned that the author has employed the spelling »feldspar» (Swedish »fältspat») in consideration of the interesting facts regarding the origin of this name presented by Dr. N. Zenzén, whose studies will shortly be published.

Correction to the Map.

The situation of the small farm called Smedsbygget has been somewhat misplaced on the map (Plate I). It lies about 150 m. to the south-east of the position indicated on the map, which actually is occupied by the deserted homestead called Bergsäter.

In order to indicate the helsinkites and aplites occurring to the south of Aspetorp, the author has marked their boundaries by a broken line, though there are no distinct contacts against the surrounding rocks. A distinguishing colour was given to the »Helsinkite» after the legend of the map had been drawn, and therefore the colour rectangle was inserted beneath that for the »Noritic gabbro».

Corrigenda.

p. 11, line 8 from bottom, *for* two-mica-granite *read* two-mica granite
p. 18, first paragraph, *for* optic angle *read* optic axial angle
p. 66, note, *for* chow *read* show
p. 75, line 6 from bottom, *for* hydrohermal *read* hydrothermal
p. 81, line 13 from bottom, *for* crystallisationdiagram *read* crystallisation-diagram
p. 94, line 19 from top, *for* Mg_2SioO_4 *read* Mg_2SiO_4

In the Tables 11—13, pp. 52—54, the An-percentage of the microcline-perthites was somewhat over-estimated (cf. p. 53). In the diagram on p. 73 the proportions of the microcline-perthites have been more correctly indicated (Or_{72} Ab_{26} An_2).

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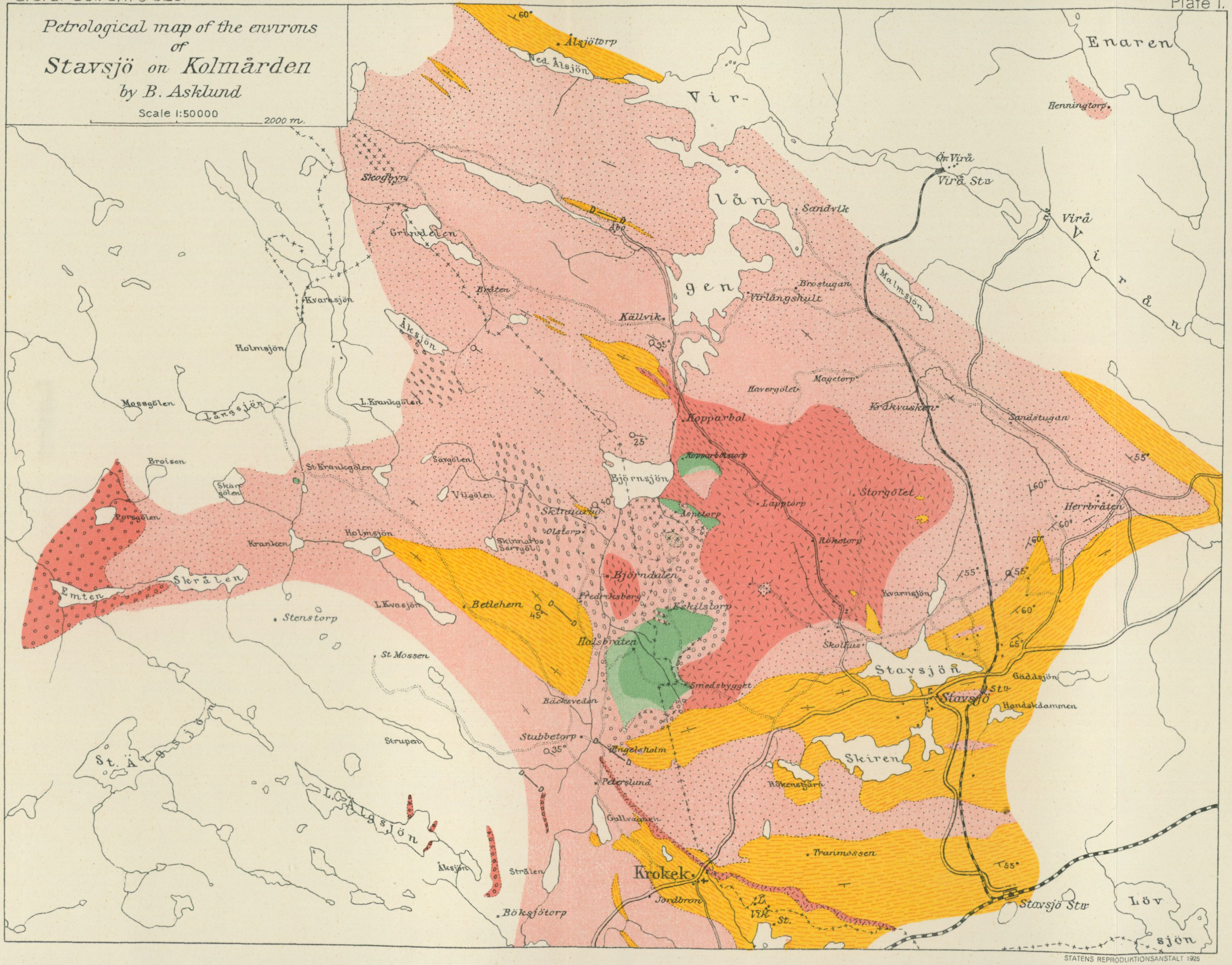
Petrological map of the environs of Stavsjö on Kolmården

by B. Asklund

Scale 1:50000



Legend

- ▨ Coarse, quartzy granite ("Graversfors granite")
- ▨ Coarse, muscovite-bearing granite; d:o with fluidal structure
- 🟥 Aplitic, salic granite
- ▨ Medium-grained granite, partly foliated or schistose
- ▨ Hornblende-bearing, coarse granite; d:o foliated
- ▨ Quartz-syenitic granite
- 🟩 Quartz-diorite
- 🟩 Noritic gabbro
- ▨ Helsinkite
- 🟧 Veined leptite-gneisses

- + dip approximately vertical
- ⊥ " steep
- ⊥ " moderate
- 40° " strike and dip of linear structure

Rock-boundaries are marked only when there is a distinct contact

- o—o Dikes of diabase

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