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ON SYNANTETIC MINERALS

AND RELATED PHENOMENA

(REACTION RIMS, CORONA MINERALS, KELYPHITE, MYRMEKITE, &C.)

BY

J. J. SEDERHOLM

WITH 14 FIGURES IN THE TEXT AND 48 FIGURES ON 8 PLATES

HELSINGFORS

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PREFACE.

In several eruptive rocks minerals are common for which it is characteristical that they occur only where two definite minerals meet. I propose to call them *synantetic* minerals (from Gr. *συναντάω*, meet). The most well-known ones among them are those which form the coronas around the olivine of gabbros and diabases, and the intergrowth of plagioclase and »vermicular» quartz which I have called *myrmekite*,[1] occurring in granites and gneisses. About each of them an extensive literature has been written, but the ideas concerning their origin still widely differ. I have lately had occasion to study some very typical instances of such minerals, and have found new phenomena which certainly are of identical origin. As I think that they throw new light upon the origin of those minerals, whose study seems to give a clue to many of the metamorphic phenomena, I desire here to discuss also the question of their genesis.

As the literature covering these matters, containing many very interesting observations and theories, is greatly scattered, in consequence of which most petrologists will hardly find an opportunity to peruse it all, I have thought it advisable here to reprint or resume at length the most important parts of this earlier literature.

I am much indebted to Professor P. J. Holmquist, of Stockholm, who has kindly called my attention to some very interesting micro-structures, and placed at my disposal several photographs taken by him. Dr. A. Gavelin and Professor A. G. Högbom have, with great courtesy, lent to me thin sections belonging to the Geological Survey of Sweden and the Mineralogical Laboratory of the University of Upsala, and the former has also kindly assisted me in procuring an abstract from a pamphlet not accessible to me in Helsingfors.

[1]) I prefer to write *myrmekite*, as analogous to poikilite etc., instead of myrmecite, and hope that it does not seem a barbarism. Now when we begin to pronounce c in Latin words as k, it seems unnecessary to use Greek words in English in their latinized forms, written with c. In French also the form myrmekite has been used.

Dr. Pentti Eskola, Dr. Benj. Frosterus, Dr. V. Hackman, Mr. Aarne Laitakari, Dr. Eero Mäkinen and Mr. W. W. Wilkman have also furnished me with valuable micro-petrological evidence, for which I thank them all.

Where not otherwise mentioned, all micro-photographs have been taken, with great skill, by Mr. W. W. Wilkman. I cordially thank him for his very valuable astistance.

I desire also to express my thanks to Miss Charlotte Frietsch for the aid which she has rendered me in correcting my manuscript and proof-sheets.

PART. I. SYNANTETIC MINERALS IN BASIC ERUPTIVE ROCKS.

Some Typical Examples.

FORMATION OF BIOTITE AT THE BOUNDARY OF PLAGIOCLASE AND ORE IN DIABASES AND GABBROS.

One of the simplest cases is the formation of biotite around crystals of magnetite or ilmenite which is common in diabases and gabbros. It has already been described in 1876 from the hyperite of western Sweden by Törnebohm, who expresses no opinion as to the mode of its formation.

He makes the following statement (in translation):[1] »The *ilmenite*, which occasionally shows a very distinct rhomboëdral striation, is often surrounded by a zone of brown mica which again, when the rock is more changed, in its turn is surrounded by a zone of green hornblende similar to that around the olivine».

He also mentions that the biotite of the Åsby diabase »partly occurs as a narrow fringe surrounding the ilmenite» (l. c. p. 14).

Lacroix has described the same phenomenon (1889) in the gabbro from Pallet in France, where, as he mentions:[2]

»La magnetite est souvent entourée d'une zone de biotite qui est elle-même enveloppée par de l'amphibole brune» (cf. also p. 17).

[1] A. E. Törnebohm, Om Sveriges viktigare diabas- och gabbro-arter. K. Svenska Vet. Akad. Handl. Bd. 14, N:o 13. 1877, p. 38.

[2] A. Lacroix, Contributions à l'étude des gneiss à pyroxène et des roches à wernerite. Bull. de la Soc. Franc. de Minér. Tome XII. 1889, p. 230–246.

Bayley has also observed (1893) the same phenomenon in basic rocks from the Lake Superior region, and regards the biotite as a secondary mineral. He says:[1]

»Biotite is present in many sections of the gabbro, though not in all. It not only occurs in the neighborhood of magnetite, where this mineral is in contact with plagioclase, but it is sometimes found imbedded in the feldspar and augite, and at other times it forms a mosaic with decomposed diallage. In basal sections it is reddish brown, and in longitudinal sections is light yellow normal to the cleavage, and dark brownish-green, almost opaque, parallel to this structural feature. In all cases it is probably secondary, for, even when it apparently occurs alone a very close inspection of its sections will often reveal remnants of magnetite grains imbedded in it. This form of the mineral is evidently a reaction product between the magnetite and the plagioclase by which it is sourrounded».

Kemp has also studied (1894) the same phenomenon in the gabbros of Lake Champlain and makes the following statement:[2]

»Biotite, forming border scales on magnetite is a very common phenomenon in many rocks. Dr. Wadsworth (M. E. Wadsworth: Minn. Geol. Surv. Bull. 2, 1887, Plate VI, fig. 1) has figured it as secondary in a Minnesota gabbro, and thinks it due to the reaction between magnetite and feldspar. The writer has been previously inclined to regard it as original.»

In the olivine-diabase of the Åsby type, occurring on both sides of the Gulf of Bothnia, e. g. in the neighbourhood of Björneborg in Finland, the same phenomenon is observed in a very characteristical form, as has been mentioned by Törnebohm. The rock is a very typical ophitic diabase, consisting of idiomorphic crystals of oligoclase separated by allotriomorphic augite, olivine and ilmenite. The ilmenite is surrounded by a narrow rim of biotite flakes, seldom measuring more than 0.1 mm in breadth (fig. 1, plate I). In some instances it forms an even rim, in others the flakes project like protuberances to all sides. It is a strongly pleochroic biotite with a dark brownish red colour.

In most cases, however, the biotite does not form a continuous rim, but occurs only where the ilmenite is in direct contact with the plagioclase, not where it meets olivine or augite. It has thus the character of a »reaction rim». The ore has supplied iron, the

[1] W. S. Bayley, The Basic Massive Rocks of the Lake Superior Region. III. The Great Gabbro Mass of North-Eastern Minnesota. Journ. of Geol. Vol. I, p. 710.

[2] J. F. Kemp, Gabbros on the Western Shore of Lake Champlain. Bull. Geol. Soc. of America. Vol. 5, 1894, p. 220.

plagioclase silica, alumina and some alcali, while magnesia and probably some potash have been derived from other minerals.

This diabase is entirely devoid of any signs of regional metamorphism. It is the youngest of all eruptive rocks of southern Finland and has not taken part of any crustal movements later than its eruption.

The changes in the rock must be due to the influence of agencies which belonged to the same eruption. Now these olivine-diabases, especially on the opposite, Swedish shore of the Gulf of Bothnia, very often contain small quantities of rocks, rich in silica which constitute the last crystallization rest of the magma. These acid rocks consist mainly of micropegmatite, but also contain biotite and some hornblende, often forming needles which seem to have crystallized at a rather late period of the consolidation of the rock; besides this they contain ore for which the same seems to be true. Thus it is probable that the olivine diabase has been percolated by acid juices, possibly accompanied by gases.

This circumstance may also account for the formation of the biotite at the border between ore and plagioclase. It is a metamorphic product in so far as it has been formed as a crystalloblastic mineral in the plagioclase, after the consolidation of the magmatic rock constituents. But it is neither dynamometamorphic, nor formed by contact action, but might rather be termed »autometamorphic», because it has obviously originated in the continuation of the same processes that created the rock itself, or »autopneumatolytic» (Tronquoy), if gases have acted as mineralizers.

I have described in 1891 from the uralite-porphyrites of Kalvola in the Tammela region, east from Tavastehus in southern Finland, pseudomorphs after olivine, consisting of small flakes of biotite.[1] But later observations seem to indicate, that biotite, in most cases, is not directly substituted for olivine, although such a process is certainly possible. Generally, the course of the alteration seems to be of another kind: the olivine becomes filled with grains of ore which later on form the core for secondary biotite.

In the region just mentioned, metamorphic gabbros (or as I called them in my description of the map of the Tammela area, gabbro-diorites) are common in which biotite also occurs as a synantetic mineral. As I pointed out in this description (1890) »the biotite occurs in such of these gabbros, where the pyroxene has

[1] J. J. Sederholm, Studien über archäische Eruptivgesteine aus dem südwestlichen Finnland. Tschermaks Min. u. Petr. Mitth. XII, 1891, p. 106.

H. B. v. Foullon (Ueber Eruptivgesteine von Recoaro. Ibid. II, p. 481—484) already described much earlier the change of olivine into biotite.

been more or less completely changed into hornblende, everywhere in the proximity of the ore grains, or, where these have completely vanished, as small sparsely distributed heaps.» [1]

As a rule upon the examination of different metamorphic basic rocks, it is noticeable that biotite has very frequently been formed as a crystalloblastic constituent which replaces plagioclase where ore is adjacent.

FORMATION OF BIOTITE AS A REACTION RIM BETWEEN HYPERSTHENE, OR DIALLAGE, AND PLAGIOCLASE IN DIABASES &C.

In a thin section of an ophitic diabase from Tuulasoja in Merijärvi in north-western Finland to which Dr. Mäkinen has called my attention and which will be described by him in a future publication, there is a hypersthene which shows, when bordering on plagioclase (andesine with 38 % An) small flakes of biotite which seem to be arranged parallel whith the interpositions of the mineral and often slightly project from its margin (fig. 2, plate I), reminding one of the picks of a porcupine. In an anorthosite from Nurma in Jaala collected by Frosterus, to which I will return later on, at the northern boundary of the great area of rapakivi granite and anorthositic rocks in southern Finland, there is a diallage which contains similar flakes of biotite when bordering on plagioclase.

FORMATION OF BROWN OR DARK GREEN HORNBLENDE AROUND ORE IN GABBROS AND DIABASES.

In gabbros and diabases a brown hornblende often occurs which has almost the same colour and pleochroism as the »synantetic» biotite and which also sometimes forms narrow zones between ore and plagioclase, or between plagioclase and hypersthene, or augite, and also often occurs in the shape of small, irregular patches and specks. I have observed it, under similar circumstances, both in the basic rocks of north-western Finland, just referred to, (fig. 3, plate I) and in the diabases and gabbros of the Pellinge region. It is very difficult to determine whether it is to be regarded as secondary or primary. E. g. in the dolerite from Virskär in Pernå, which is astonishingly well preserved, although it is of high Archæan age, there occurs a brown hornblende which possesses the same orientation over extensive areas and includes sharply defined crystals of augite, as well as plagioclase, etc. This hornblende is very probably of primary origin. But there occurs also, in rocks from

[1] J. J. Sederholm, Beskrifning till kartbladet N:o 18, Tammela. Finlands Geol. Unders. N:o 18, 1890. p. 38.

the same locality, a brown hornblende which is more irregularly interspersed with the pyroxene, and appears to play the same rôle as the biotite of the same rock which is certainly secondary. The occurrence of the brown hornblende in narrow zones bordering ore also reminds one very much of the secondary minerals of synantetic origin.

Lacroix described an analogous amphibole in the gabbro from Ödegården in Norway with the following words: [1]

›*Amphibole brun rouge.* — Cette amphibole possède des teintes d'un pleochroïsme extrêmement voisines de celles de la biotite qu'elle accompagne toujours (Heias mine, Hitterö).

On observe:

n_g brun rouge, n_m brun jaunâtre, n_p jaune, $n_g > n_m > n_p$.

L'extinction dans g^1 (010) est d'environ 13°. La biréfringence maxima est: $n_g - n_p = 0.027$.›

In an olivine gabbro from Pallet in la Loire-Inférieure he has observed another similar case, and explicitly says that the amphibole is epigenetic:

›Deux sortes *d'amphibole* s'observent dans la roche.

La première est vert clair peu polychroïque. — —

La seconde est brune; elle épigénise le diallage. Sa couleur et son polychroïsme la font ressembler au premier abord à la biotite:

On observe: n_g brun rouge, n_m brun, n_p jaune clair, $n_g > n_m > n_p$.

L'extinction dans g^1 (100) est environ 17° . $n_g - n_p = 0.029$.»

Kemp has made (1894) observations of the occurrence of a brown hornblende, which is probably of a secondary origin, in the gabbros of Lake Champlain. [1]

»The other larger minerals are light green monoclinic pyroxene, hypersthene, grains of titaniferous magnetite, and occasionally, but not invariably, irregular crystals of olivine. Almost always around each of these are the most beautifully developed zones, which include, in one and another, brown hornblende, hypersthene, garnet, brown biotite and quartz. The simplest case is shown in figure 1. Around a crystal of pyroxene (Py) a zone of brown hornblende (H) in small individuals has gathered, preventing at most points the former from coming in contact with the feldspar which is decomposed. A few small garnets, marked G, appear. More complex than this is the case illustrated in figure 2. (fig. 1 in this memoir). Around a crystal of magnetite, undoubtedly tita-

[1] l. c. p. 230—231 and 243.

[2] l. c. p. 2 8—220.

niferous, have gathered first a rim of brown hornblende, next a zone of pink garnet, and then the feldspar, with its clear rims and clouded interior; but between the garnet and a hypersthene crystal that is marked Hy, there is a further zone of clear irregular bits of quartz. This series is oftentimes increased by the presence of brown biotite next the grain of ore. A most peculiar change appears in figure 3. The interior grain of magnetite is surrounded as usual by brown hornblende; then follow a clear streak of quartz and next the garnet; the last named is not, however, in irregular grains as before, but has worked into the labradorite, replacing its alternate lamellæ. This has been noticed on several slides, and

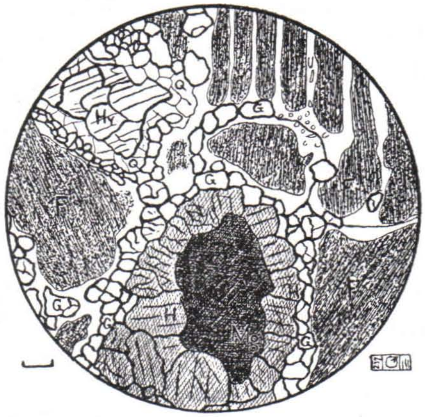

Fig. 1. (= fig. 2 in Kemps memoir). Thin section of gabbro from West Port, N. Y. Showing reaction rims of successive zones of brown hornblende (H), garnet (G), quartz (Q) around titaniferous magnetite (Mg) or hypersthene (Hy) and between them and labradorite (F). The outer portions of the labradorite are clear because of the absence of inclusions. The specimen was obtained from the hanging wall of Split Rock mine, West Port, NewYork.

gives a very peculiar effect. At times only a nest of brown hornblende fragments remains at the nucleus, the core mineral, if such there were, having been all absorbed. An additional mineral sometimes appears next the magnetite and is brown biotite, the succession outside of it then being as above. Zones or »crowns» or »aureoles», similar in all respects to these except as regards quartz, that have been noted by Lacroix in the reference above given and are pictured in the figure there cited. The closeness of the parallel will appear at once to any one who will compare it with figure 2 of this paper, but the replacement of alternate lamellæ of feldspar seems not to have been previously noted. These zones are regarded by the writer as secondary, at least in large part. The garnet certainly is, as shown by its relation to the feldspar. The quartz is doubtless residual silica from the excess left in the alteration to garnet of a more acidic mineral — the labradorite. Of the brown hornblende and biotite one can speak with less positiveness. The nests of the former without a core of magnetite lend weight to the view that they are secondary».

In the sequence of the same article, which I will quote later on, Kemp describes an occurrence of brown hornblende in strongly metamorphic portions of the same gabbro and says explicitly: »It would appear to be secondary».

Dr. Hezner regards the brown hornblende which occurs in the diallage-amphibolite from Schauenstein in Austria as secondary. It is irregularly interspersed amongst the diallage, sometimes arranged along the cleavage cracks of the pyroxene, and often wedging out.[1]

Loughlin has observed, (1912) in an olivine-gabbro from Preston, Connecticut, rims of brown hornblende around ilmenite and olivine. He remarks when describing a microphotograph, Plate XII, B, in his memoir: »The poikilitic character of ilmenite is especially well shown. Its contacts with adjacent and inclosed feldspar are marked by rims of brown hornblende. The olivine also has rims of brown hornblende along its contacts with feldspar. Within this rim is a third rim of magnetite. No diallage appears in the field.»

G. F. Williams has observed a dark-green hornblende in such a close proximity of grains of magnetite as to indicate an epigenetical connection:[3]

»The colour of this hornblende is invariably influenced by the proximity of a grain of magnetite. Here it becomes a much deeper green, showing that this mineral has contributed something to its composition, a fact which still further indicates its secondary nature. Magnetite grains are sometimes themselves fringed with a border of dark-green hornblende».

I have also observed the same phenomenon in some Fenno-Scandian rocks, e. g. in the syenitic and dioritic rocks from Rackberget and adjacent localities in Arvidsjaur in northern Sweden

[1] L. Hezner, Ein Beitrag zur Kenntnis der Eklogite und Amphibolite. Inaug.-Diss. Sep.-Abdr. aus Tschermaks Min. u. Petr. Mitt. XXII Bd. 1903, p. 60.

[2] G. F. Loughlin, The Gabbros and Associated Rocks at Preston, Connecticut. Bull. U. S. Geol. Survey, N:o 492, 1912, p. 100.

[3] G. H. Williams, The Gabbros and associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Md. Bull. U. S. Geol. Survey N:o 28, 1886, p. 42.

which rocks I have been able to study in thin sections, thanks to the courtesy of prof. A. G. Högbom in Upsala.

These rocks also contain the intergrowths of biotite and quartz which I will describe in the sequence as biotite-symplektites. They seem to have originated in many cases as crystalloblastic minerals, which crystallized, however, before the complete consolidation of the rock magma. Thus it is very difficult, even in these cases, to discriminate between primary and secondary phenomena. At least this hornblende seems not to have been formed during a period of metamorphism later than the consolidation of the rock.

FORMATION OF VIRIDITIC GREEN HORNBLENDE AT THE BOUNDARY OF OLIVINE AND PLAGIOCLASE IN A NON-METAMORPHIC OLIVINE-DIABASE.

In the olivine-diabase from the shores of the Gulf of Bothnia, mentioned in the beginning, there almost constantly appear fine threads of a green mineral, which certainly is hornblende, at places where olivine and plagioclase meet. Although it shows itself only in small quantities, the occurrence is of considerable interest because it is an initial of the same phenomen which we meet in a more developed form elsewhere, and also because the rock, as already mentioned, has not undergone any metamorphism at a time posterior to its eruption. The formation of viridite, as well, must either be regarded as belonging to the »autometamorphic» process mentioned above, or as being due to a purely »hydro-chemical» metamorphism caused by percolating waters.

ABSTRACT OF THE EARLIER LITERATURE CONCERNING CORONAS OF PYROXENE, AMPHIBOLE, GARNET, SPINEL, ETC., AROUND OLIVINE, BRONZITE AND HYPERSTHENE IN DIABASES AND GABBROS.

The mineral zones which occur around the olivine in gabbros and diabases and which have been called »coronas» or »couronnes» by various writers, also very often reveal peculiarities which place them in the same group with the synantetic minerals. The first writer who described these interesting structures was Törnebohm who studied them in the »hyperite» of Vermland, an ophitic hypersthene-bearing olivine-diabase or gabbro of very high Archæan age.

I will here quote Törnebohms original description in English translation: He says vith reference to the olivine:[1]

»At the metamorphism of the mineral (viz. olivine) new crystals originate almost exclusively at the borders of the mineral grains.

[1] l. c. p. 37—39.

These are then surrounded by a colourless border of radiately arranged minerals, on the outside of which there is, in every place where felspar is the adjacent mineral, another equally radiating border formed by a green fibrous, rather strongly pleochroic mineral, hornblende.

These zones of newly formed minerals have obviously originated through the reaction between plagioclase and olivine, the outer green zone having been formed at the expense of the plagioclase, the inner, light one, having replaced the olivine. This is proved by the fact, that these zones always occur where olivine and felspar are adjacent, but are lacking between olivine and augite. If a wedge of augite is interposed between olivine and felspar, the two zones diverge at this place; the light one continues for a while between the olivine and the augite, the green one continues in the same way for some time between the augite and the felspar, however both very soon wedge out.»

R. D. Irving mentions a similar observation by Julien who seems to have been the next, after Törnebohm, to study these phenomena: [1]

»In some of the very coarse-grained gabbros of Bad River, Wisconsin, as first shown by Julien, (Vol. III, Geology of Wisconsin, p. 235) the olivine shows a very interesting and unusual mode of change, namely into biotite, viridite, and talc, the two former replacing the interior of the olivine grain, the latter forming a sort of shell of minute flakes around the outer part of the grain. Particles may be seen in all stages of this change.»

Analyses which were made in order to show whether the zones were really reaction products intermediate in composition between the hypersthene and the felspar were not quite conclusive.»

Becke gave already in 1882 very detailed and exact descriptions of reaction rims around olivine in an olivine gabbro from the Forest Region of Lower Austria, which read as follows: [2]

»Der interessanteste Gemengtheil ist der Olivin. — — Häufig ist der Diallag mit dem Olivin in der Art verwachsen, dass der letztere den Kern, der erstere eine meist mehrfach unterbrochene Rinde darstellt.

Sehr eigenthümlich sind die Umwandlungserscheinungen, welche dieser Olivin darbietet. Alle Olivinkörner sind von einer millime-

[1] R. D. Irving, The Copper-bearing Rocks of Lake Superior. Mon. U. S. Geol. Survey, V. 1883, p. 38—39.

[2] F. Becke, Die Gneissformation des niederösterreichischen Waldviertels. Tschermaks Min. u. Petr. Mitth. Bd 4, 1882, p. 355—357.

terbreiten Rinde umgeben, die aus mehreren Schichten besteht und ein radialfaseriges Gefüge erkennen lässt. — —

Zunächst an dem unveränderten Kern von Olivin folgt eine Schichte aus einem farblosen, wasserhellen Mineral. Die Schichte besteht aus breiten, etwas unregelmässig gestalteten Stengeln, deren Grenzen aber erst im polarisirten Licht deutlicher hervortreten. An manchen Stellen zeigt diese Schichte auf grössere Strecken hin einheitliche Auslöschung. Die Auslöschung erfolgt unter schiefem Winkel zur Längsrichtung der Stengel. Messungen sind unmöglich, da orientirende Spaltrisse ebenso wie geradlinige Begrenzungen fehlen. Die Doppelbrechung ist ziemlich stark.

Die nächste Schichte erscheint bräunlich gefärbt; sie besteht aus einem sehr fein radialfaserigen Mineral; gegen die vorige Schichte ist sie stets scharf abgegrenzt; die Grenze gegen die nächste ist minder scharf.

Die dritte Schichte macht den Eindruck körniger oder schuppiger Zusammensetzung, auch sie zeigt lebhafte Polarisation. In der Nachbarschaft der zweiten Schichte ist sie reich an Einschlüssen von starker Lichtbrechung, bald Körnchen, bald Nädelchen; diese scheinen demselben Mineral anzugehören, welches der zweiten Schichte die faserige Beschaffenheit verleiht. Gegen aussen verlieren sich die Einschlüsse mehr und mehr. Diese einschlussfreie Zone ist es, welche in der körnigen Schichte bei der Beobachtung mit schwacher Vergrösserung als heller Streif erscheint.

Weiter nach aussen wird das Gefüge lockerer; die Körner und Schuppen schliessen nicht mehr dicht aneinander und bilden ein lockeres, daher dunkler erscheinendes Haufwerk, von welchem aus sich Aggregate dieser Körnchen in die Sprünge und Zwischenräume der Feldspathe eindrängen. Die dritte schuppigkörnige Schichte hat eine blassgrüne Farbe. — —

Diese Umwandlung geht nur dort vor sich, wo der Olivin von Feldspath umgeben ist. Dort wo eine auch noch so dünne Lamelle von Diallag sich zwischen Olivin und Feldspath einschiebt, unterbleibt die Bildung dieser Umwandlungsproducte. Man sieht auch aus der mitgetheilten Zeichnung, dass der Feldspath gleichzeitig umgewandelt wird. Die ursprüngliche Grenze zwischen Feldspath und Olivin scheint zwischen den Schichten 1 und 2 zu liegen. Dafür spricht auch das Vorkommen von isolirten rundlichen Partien von dem Aussehen und der Structur der Schichte 2, umgeben von einem Kranze der Schichte 1, welche mitten im Olivin vorkommen. Sie sind auf kleine Einschlüsse von Feldspath im Olivin zu beziehen. Die Neubildungen sind daher auf eine gegenseitige Einwirkung der Silicate des Feldspathes und des Olivins zurückzuführen. Aus dem Olivin bildet sich unter Einfluss des Feldspathes das stengelige Mineral der ersten Schichte, aus dem Feldspath unter Einwirkung des Olivin das faserige und das körnigschuppige Mineral der zweiten und dritten Schichte.

Eine interessante Beziehung ergibt sich zwischen diesen Umwandlungs-Producten des Olivin in einem Feldspathgestein und den Pseudomorphosen nach Pyrop in dem Olivinfels von Steineck.

Beide Pseudomorphosen bestehen aus zwei scharf geschiedenen Zonen; einer grossstrahligen farblosen hellen, welche bei den Pyrop-Pseudomorphosen aus Hornblende und Bronzit besteht und aus einer anderen dunkleren Zone von mehr faserigem Gefüge, welche bei den Pyrop-Pseudomorphosen als ein Gemenge von einem farblosen Mineral (Hornblende ?) und einem braungefärbten Spinell erkannt wurde. Die Aehnlichkeit im Aussehen dieser inneren Zone der Granat-Pseudomorphosen mit den äusseren Schichten der Rinde der Olivinkerne ist ausserordentlich.

Will man die Parallele gelten lassen, so müsste die innere Zone in unserem Falle aus Hornblende oder Bronzit bestehen. Dass in der That Hornblende-Pseudomorphosen nach Olivin in den Gabbrogesteinen von Langenlois vorkommen, machen die folgenden Beobachtungen sehr wahrscheinlich.»

E. Svedmark communicated (1885) while describing gabbros and associated rocks from Rådmansö near Stockholm in middle Sweden, descriptions of coronas around olivine which I reprint in translation. Concerning the olivine-gabbro from Åkerö he says:[1]

»Around the olivine grains there always occurs a green rim consisting of slender leaves or fibres of hornblende. Between this rim and the olivine there is, further, a zone consisting of a light-brown or light-green fibrous mineral which seems to be actinolite, and next to the olivine, or in this zone of actinolite, there is a narrow zone of magnetite, which is interrupted in some places. Beside the olivine, there are also grains of diallage in the green hornblende zone, whereby it also frequently happens that a zone of the mineral interpreted as actinolite, and of magnetite, intervenes between the olivine and the diallage».

The olivine of the gabbro from the region which lies N.W. from Åkerö and that between this place and Stortorp is surrounded by similar coronas. Svedmark further remarks:

»The grains of diallage, the greatest part of which is uralitized, and which occur together with the olivine, are also in these

[1] E. Svedmark, Gabbron på Rådmansö och inom angränsande trakter af Roslagen. Geol. För. i Stockholm Förh. Bd. VII, 1885, p. 829.

groups separated from the olivine by a zone of actinolite».

Concerning the olivine-gabbro occurring N.W. from Vestanvik he, on the contrary, says:

»The zone of light amphibole next to olivine is often visible, but it is absent at the boundary between olivine and diallage, where a zone of serpentine regularly occurs.»

There are quite similar rims of amphibole around the olivine of other localities in the same region.

Svedmark also presents a good coloured picture of these coronas around olivine in a rock occurring between Edsvik and Vestanvik.

Geo. H. Williams described in 1886, with the following words, the reaction rims between olivine and felspar in gabbros from the neighbourhood of Baltimore.[1] »Wherever it comes in contact with the olivine, the peculiar reactionary rims of amphibole described by Törnebohm are finely developed. The interior zone of these rims next to the olivine is narrow, granular and almost colorless. Outside of this is a darker greenish portion, having a feathery appearance; this exterior zone projects in rounded tufts into the feldspar substance, at the expense of which it has apparently been formed.»

He also described and figured zones of hornblende surrounding hypersthene which have quite the same character as those surrounding the olivine:[2]

»The secondary nature of hornblende which accompanies the hypersthene is much more evident than of that occurring in connection with the diallage. This is always composed of two distinct zones, of which the inner one is made up of fine, colorless fibers, while the outer one is dark green in color, decidedly pleochroic, and comparatively compact in structure.»

The fibres or the interior colourless zone grade imperceptibly into the hypersthene. The needles are so fine that no decision based on crystal form could be arrived at with regard to their nature, but Williams thinks it highly probable that they are some form of hornblende.

»It is interesting to note that the process of alteration here described shows the closest analogy with that well known to take place around the olivine in many ancient massive rocks, although,

[1] l. c. p. 52.

[2] Geo. H. Williams, The peridotites of the »Cortlandt Series», on the Hudson River near Peekshill, N. Y. Amer. Journ. Sci. 3 ser. 1886. Vol. XXXI, p. 35—36.

so far as I know, it is here described for the first time in the case of the corresponding bisilicate, hypersthene».

According to Williams, »no essential difference could be observed between this change of the olivine and that exhibited by the hypersthene of the Baltimore gabbro,» but judging from his fig. 2, plate 1, which shows this phenomenon, it seems to be much less regular than the corona around olivine, and more like the rims formed in the uralitization of pyroxenes.

In the peridotites of the »Cortlandt Series» on the Hudson River Williams observed true reaction rims at the contacts of olivine and felspar which he describes as follows:

»Aside from the ordinary alteration of olivine to serpentine, which may be most instructively studied at every stage in the Cortlandt rocks, the most interesting phenomenon exhibited by this mineral is the beautiful development of reactionary rims or zones, wherever the olivine comes in contact with feldspar. This latter mineral is indeed no essential ingredient of the peridotites, but as already mentioned, they constantly show a tendency by its assumption to grade into olivine-gabbros and olivine-norites. Wherever olivine comes in contact with feldspar, no matter how fresh both of the minerals may be, there is always present between them a double zone, the inner portion, nearest the olivine, being composed of square grains of nearly colorless pyroxene and the outer one of tufts of radiating actinolite needles of a beautiful bluish-green color and strongly pleochroic.

— — So constant is the dependence of this zone upon the contact of the olivine and the feldspar, that it must be in some way due to a reaction between the substance of these two minerals, the resultant amphibole and pyroxene having an intermediate composition. So sharply defined, however, are the crystals of this zone against the perfectly fresh feldspar and olivine substance that it is difficult to conceive of any of them as produced after the rock had entirely solidified. They may have been formed by a reaction between these substances while at least one of them — the feldspar — was crystallizing, although in some cases the formation of the actinolite seems to have continued after this time. In any event, all traces of this border around the olivine disappears the instant this mineral comes in contact with any other constituent than the feldspar.»

We have further to note the description of similar things, in a Californian diabase, given by M. Schuster in 1887:[1]

[1] M. Schuster, Mikroskopische Beobachtungen an californischen Gesteinen. Neues Jahrb. für Min. Geol. u. Pal. V Beil.-Bd., 1887, p. 518.

»Sodann sind die eigenthümlichen Abgrenzungen und Umrandungen des Olivines gegenüber dem Feldspathe hervorzuheben. Der Olivin erscheint nämlich da wo seine Umrisse besser erhalten sind, mit einem Kranze eines pilitartigen, aus unvollkommenen fasrigen, keuligen bis spindelförmigen, im Ganzen zur Olivinoberfläche senkrecht gestellten Elementen bestehenden Gemenges umgeben. Dieses Aggregat, mit dem Habitus eines halb krystallin gewordenen Schmelzproductes, ist fast farblos (bis schwach grünlich), verhält sich bald isotrop, bald optisch activ mit Auslöschung schief zur Faserrichtung. Die Olivinkörner selbst sind da, wo sie von diesem Kranze, welcher dem angrenzenden, scheinbar völlig intacten Feldspathe eine Art mikroperthitisches Aussehen verlieht, nicht umschlossen werden, häufig in zahlreiche rundliche bis eckige Körner aufgelöst, die auch in dem benachbarten Feldspathe sich eingestreut finden. Diese Körner polarisiren zum Theile ganz wie der Olivin selbst, zum Theile verhalten sie sich wie Glas, zum Theile verhalten sie sich wie jenes Kranzmineral von dem früher die Rede war. Man hat es hier vermutlich einerseits mit einer theilweisen Einschmelzung des Olivins zur Zeit der Feldspathbildung, andererseits mit einer Wechselwirkung beider, die wohl einer anderen Zeit angehört, zu thun.

Wo Olivin, Augit und Feldspath zusammenstossen, erscheinen sie dank einer schmalen grünen Rand geschieden. Wie der Plagioklas durch seine Beziehungen zum Augit sich deutlich als die ältere Bildung erweist, so bleibt nach dem eben gesagten kein Zweifel, dass der Olivin den Plagioklas wieder an Alter übertrifft.»

Teall described in a Lizard gabbro zones of fibrous minerals surrounding olivine where it occurs in contact with felspar.[1] The inner one consists of a colourless fibrous mineral, which is probably anthophyllite, and the outer one of green actinolite. Sometimes the olivine is separated from unaltered plagioclase by a narrow zone of a compact mineral, having the pleochroism of a rhombic pyroxene.

Lacroix who has studied (1889) the metamorphism of gabbros and diabases perhaps more extensively and systematically than any other petrologist, has described a number of similar phenomena, in rocks occurring in different parts of the world.

In the gabbros from Pallet he has observed »couronnes» very similar to those described by Törnebohm and other petrologists quoted above:[2]

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[1] J. J. Harris Teall, British Petrography. London 1888, p. 176.

[2] l. c. p. 245—246.

»L'olivine est l'élément le plus ancien. Elle est rarement isolée dans la roche; presque toujours elle est entourée par une couronne à double zône semblable à celles qui ont été étudiées dans les gabbros de Norwège.

Cette couronne s'observe seulement entre l'olivine et le feldspath; lorsqu'un cristal d'olivine est inclus partiellement dans le diallage, la partie qui fait hernie dans le feldspath la possède seule (fig. 40).

La zône interne est incolore, fibreuse; les extinctions sont roulantes; on peut s'assurer cependant qu'elles sont peu obliques. Le minéral qui la constitue semble identique à celui des gabbros décrits par Törnebohm et par suite différent de ceux que j'ai étudiés à Ödegården. Dans quelques cas rares, j'ai pu voir cette zône centrale épigéniser d'une façon complète le cristal de péridot central, ce qui n'a jamais été observé à Ödegården (fig. 40.)

La zône externe est formée par de l'amphibole vert très clair. Cette dernière s'étale en éventail à la périphérie et dessine dans le labrador de gracieuses pegmatites.»

In the gabbros from Ödegården, Tvedestrand, Kragerö and Hitterö in Norway, Lacroix has observed »couronnes» of another character, containing also garnet:[1]

»Le fait intéressant à signaler dans ces roches consiste dans la variété des associations minéralogiques qui prennent naissance autour du péridot et des minerais, associations très analogues à celles qui ont été signalées par divers auteurs et qui méritent une discussion approfondie.

Le péridot et les minerais (ilménite, magnétite) antérieurs a tous les éléments de la roche, sont enclavés indistinctement par tous ceux-ci.

Lorsqu'ils sont enclavés par le diallage ou l'hyperstène, aucun phénomène particulier n'est à noter. Quand, au contraire, ils sont inclus dans les feldspaths, ils présentent les particularités suivantes:

Autour du péridot, on observe dans le cas plus général trois couronnes concentriques. La plus intérieure est formée par du pyroxène légèrement violacé et très peu polychroïque avec teintes verdâtres suivant n_g; ses propriétés optiques, signalées plus haut, sont celles du pyroxène normal; il ne renferme pas d'inclusions comme le diallage de la roche.

Sa position, par rapport au péridot, est quelconque; souvent son axe vertical est normal à la surface du péridot, mais souvent aussi il possède une orientation différente. La seconde couronne est

[1] l. c. p. 231—236.

constituée par l'amphibole vert bleuâtre décrite plus haut. Tantôt cette amphibole est fibreuse; tantôt, au contraire, elle forme de petits grains d'environ 0.10 mm. de largeur, ayant leur axe vertical dirigé normalement à la paroi du pyroxène sur laquelle elle repose; la ligne de séparation du pyroxène et de l'amphibole est en général très nette; il n'en est pas de même avec la zône la plus externe de la couronne qui est constituée par des grains de grenat.

Fréquemment, le grenat creusé de cavités arrondies en forme de crosse, dont l'allongement est dirigé vers l'intérieur de la couronne, forme des pegmatites avec de l'amphibole presque incolore; la grande abondance de ces pegmatites vermiculées donne parfois au grenat une apparence fibreuse.

Chacune de ces zônes, souvent très fines, peut atteindre 0.15 mm. d'épaisseur.

Il peut y avoir, en outre, entre le péridot et le pyroxène une couche de magnétite dendritique (Regårdsheien).

Les norites de l'Heias mine, près Tvedestrand, et d'Hitterö, nous ont offert une variété curieuse de ces couronnes; la zône intérieure est formée non plus par du pyroxène monoclinique, mais par de l'hypersthène; la zône d'amphibole est très large et remplie d'une quantité considérable de grains arrondis de spinelle vert émeraude. Ils sont très rares dans l'olivine et l'hypersthène toujours en gros grains; ils sont localisés dans l'amphibole et le feldspath. Dans le premier de ces deux minéraux, ils affectent souvent des formes de crosses et produisent des sortes de pegmatites. Au milieu du second, ils forment les fines inclusions microscopiques signalées plus haut.

Il est à remarquer que ces inclusions disposées suivant l'axe vertical du feldspath se continuent dans l'amphibole en restant orientées comme dans le feldspath voisin; ces inclusions ne franchissent pas la zône d'hypersthène (fig. 37).

Cette même roche est riche en amphibole brune et en biotite; on y trouve rarement du rutile.

Ces auréoles autour de péridot ne se produisent qu'au contact de ce minéral et du feldspath, lorsqu'un cristal de péridot est enclavé en partie dans un pyroxène et en partie dans un feldspath; cette dernière portion seule possède une auréole (fig. 40).

Assez souvent (Ödegården, Kragerö), autour d'un fragment d'ilménite, on observe une couronne de biotite, entourée d'une zône d'amphibole brune et parfois de grenat. Ce fait fréquent dans les gabbros du Pallet (Loire-Inférieure) est représenté dans la fig. 36.

Dans d'autres cas, autour d'un noyau formé de grains de pyroxène, englobés parfois par une masse stalactiforme d'ilménite, on rencontre les trois zônes signalées plus haut de pyroxène, amphibole verte, grenat (fig. 36).

Dans quelques cas plus rares, la biotite se trouve soit au centre, mélangée au pyroxène et à l'ilménite, soit à la périphérie associée au grenat en délicates associations pegmatoïdes. Ajoutons que dans quelques cas plus rares encore, la couronne de grenat, au lieu d'être continue, est constituée par de petits grains arrondis de grenat situés à une petite distance les uns des autres. On trouve ainsi plusieurs couronnes alternatives de grenat et de pyroxène grenu.

En résumé, la plus grande variété existe dans la composition de ces couronnes et dans les dimensions respectives des éléments minéralogiques qui les composent. — —

Dans les roches que nous étudions, il semble difficile d'admettre que le grenat soit exclusivement formé au contact du gneiss amphibolique. En effet, dans presque tous les échantillons que nous avons recueillis en divers points du gisement, dans les roches les plus intactes, nous l'avons retrouvé accompagnant de l'olivine sans aucune altération, tandis, qu'au contraire, nous le voyons disparaître dans les roches qu'il nous reste à décrire: les gabbros et norites grenus qui se chargent de hornblende et établissent le passage insensible au gneiss amphibolique.

Bayley gave (1892) very important communications regarding similar phenomena in a Minnesota gabbro:[1]

»In one-third of the section of this rock studied, the olivine grains, where they would otherwise come in contact with plagioclase, are kept from doing so by a finely fibrous growth» of a mineral which »in some places polarizes with bright colors, and in others with the bluish-gray tint of thin felspar. — — It is also found around decomposed biotite — — and around grains of magnetite.

A close inspection of the sections often reveals the presence of an intermediate zone between the fibrous one and the mineral surrounded by it. This is very narrow and consists of a highly refractive substance with strong double refraction — —. Every gradation can be traced between wide enveloping mantles of diallage and thin seams with all the characteristics of the immediate zone. Moreover, it is frequently noticed that the narrow rim widens out and expands into large wedge-shaped plates of whose diallagic nature there can be no doubt.

[1] W. S. Bayley, A Fibrous Intergrowth of Augite and Plagioclase, resembling a Reaction Rim, in a Minnesota Gabbro. Amer. Journ. Sci. 3d Ser. Vol. XLIII. 1892, p. 516—520.

— — Since the narrow zones between the fibrous envelope and the surrounded minerals are similar in every respect to these narrow rims of pyroxene, it is safe to assume that the former, like the latter, are composed of diallage.

— — It is sometimes found in the midst of feldspar as little granophyre-like bunches, not associated with any iron-bearing mineral whatsoever. It is thus quite evident that the fibrous growth is not a reaction rim between diallage and plagioclase, and since it occurs indiscriminately around so many different minerals that it is not a reaction rim at all.»

One of the constituents of the intergrowth is undoubtedly plagioclase, while the other one »is occasionally in such coarse fibres that its augitic character cannot be questioned.» It sometimes occurs as pseudopodia-like tongues which seem to be prolongations of the diallage, although »it is true that there is no absolute proof that the highly refractive substance of the fine fibrous intergrowths is identical with the material of the coarse prolongations just mentioned — —.

We may safely infer, therefore, that the fibrous intergrowth which so closely resembles a reaction rim between olivine and plagioclase, but which is surely not such, is merely a granophyric aggregate of plagioclase and pyroxene.» [1]

In another petrological paper Bayley gives the following descriptions of the phenomena in question: [1]

»The pyroxene occurs either in the interstices between the labradorite grains, or as narrow rims around the olivine, forming a mantle that surrounds these and separates them from the feldspar.

In some sections every grain of olivine is thus separated from plagioclase, (Fig. 1) while in other sections, where this is not the case, the diallage is in too small a quantity to serve this purpose. Narrow rims of this mineral also exist around magnetite and biotite. They occur between these two minerals and olivine and a fibrous growth that surrounds them, especially the olivine, in a manner resembling a reaction rim. — —

The relation existing between the olivine and the diallage is the most interesting of the phenomena presented by the rock. It has already been stated that but very few olivine-grains are in direct contact with feldspar. Around nearly all are narrow rims of pyroxene. At first glance these appear to be a sort of reaction rim

[1] W. S. Bayley, The Basic Massive Rocks of the Lake Superior Region. III. The great Gabbro Mass of North-Eastern Minnesota. Journ. of Geol. I, 1893, p. 702—708.

between the two minerals, but a more careful study of the sections disposes of this assumption, for the surrounding rim frequently broadens out and merges into the well defined diallage plate (Fig. 3). In consequence of the occurrence of the olivine and augite in the manner described sections of the rock exhibit a kind of concentric structure, with the rounded olivine grains surrounded by a zone of diallage, and imbedded in a mass of plagioclase. Perhaps the most perfect exhibition of this association of the three minerals is shown in the section of rock N:o 1103 from the Cloquet River, where the augite is in such large quantity as to completely envelop the olivine (see Fig. 1).

When the pyroxene is in smaller quantity the rim is much narrower, and in many cases is in its turn separated from the plagioclase by a fibrous growth between the last named mineral and itself. This fibrous growth imitates in great perfection many of the reaction rims described by various investigators as existing between olivine and plagioclase in many basic rocks. It usually consists of very fine fibres extending perpendicularly from the bounding surfaces of the diallage rim, or when this is lacking, from the peripheries of the olivine grains. In a few instances the fibres form radial groups, centering at points on the exterior of the surrounded mineral. The growth is especially noticeable in the vicinity of the olivine, but it is occasionally also found bordering magnetite grains (Fig. 4) and flakes of biotite. The fact that the fibres are not confined to the borders of olivine, but are found as well around magnetite, biotite and outside of the diallage rims around olivine grains, is presumptive evidence that the growth is not of reactionary origin.

Between crossed nicols portions of the fibrous zone polarize brilliantly, while other portions have the pale blue tint of thin feldspar. Under very high powers the individual fibres are discovered to be discontinuous. They branch, fork and bend in a fantastic manner, and sometimes stop abruptly, while new fibres begin their courses some distance beyond and continue to the edge of the rim. It is impossible to determine the character of the fibres in the first rims, but in those in which the structure is coarser, it is learned that two components are present. One is possessed of a high index of refraction, and strong double refraction, and this appears to be continuous with the diallage of the narrow zones interposed between the fibrous growth and the surrounded olivine. The other component penetrates between the pyroxene fibres, and has clubshaped ends. Occasionally the twinning bars of plagioclase may be detected in it, and hence it is assumed to be a tricline feldspar. The fibrous rim is thus an intergrowth of plagioclase and augite, both of which minerals are normal constituents of the gabbro. In the fibrous rims they have evidently crystallized contemporaneously, whereas in the main body of the rock the main portion of the diallage proceded the plagioclase in its separation from the magma. There is no necessity for regarding the intergrowths as in any way connected with reactionary processes, while there is abundant reason for believing them to be due solely to the tendency of simultaneously crystallizing minerals to mutually interpenetrate each other. This tendency is well recognized as existing to a marked degree between quartz and orthoclase, whereby granophyre is formed, and to a less extent between various other minerals. Micropegmatitic intergrowths between hornblende and feldspar, for instance, have been described by Lévy, Camerlander and Lacroix, between hornblende and quartz by Kalkowsky, between garnet and feldspar by Becke, and between garnets and quartz by Lacroix, between diopside and quartz by Lévy, and between various monoclinic pyroxenes and plagioclase by Becke, Camerlander, Lacroix and Lévy. In the Minnesota rock the diallage in many instances sends out tongue-like processes that penetrate far into the plagioclase in which the pyroxene is imbedded (see Fig. 5), so there can be no doubt that the conditions were favourable to the formation of intergrowths between these two minerals during the period when they were separating from the rock magma. The only essential differences between the fibrous intergrowths and that illustrated in this figure are, first, the finer structure of the former, and second, its occurrence around the older components of the rock. Neither of these differences is important, however. Only the second needs a moment's consideration.

The position of the fibrous growth around the olivine and other minerals is due not necessarily to the fondness of the intergrowth for this place, but simply to the fact that the diallage, during the earlier stages of its growth, fastened itself to the solid particles in its vicinity and coated them with an envelope of its material. Continuing its growth it formed the encircling rims of this material that are so characteristic of many specimens of the gabbro, and, when the feldspar began to separate it formed with this the granophyric intergrowth. Since the position of the diallage had already become fixed, the intergrowth naturally was compelled to occupy a place just without this and around the minerals which the diallage had already partially or entirely encircled. Though a fibrous intergrowth of pyroxene and plagioclase with the aspect of a reaction rim surrounding the older minerals of a rock is a rare phenomenon, it is not a unique one, for Camerlander, in 1887, described a similar intergrowth of these two minerals around the garnets of a contact rock from Prachatitz, in the Bohemian Forest, and mentioned that it strongly resembled the kelyphite rims around garnets in serpentine».

In his important studies on the anorthosites of the Upper Laurentian in the Province of Quebec in Canada, Adams has also devoted, since 1882, considerable attention to the mineral zones occurring at the boundaries of olivine and plagioclase, and gave in 1893 his opinion regarding their genesis: [1]

Bei der Untersuchung von Dünnschliffen unter dem Mikroskop sieht man Olivin und Feldspath und um den ersteren herum die erwähnten Zonen. Einige wenige Körner von Hornblende, Ilmenit und Pyrit sind ebenfalls gewöhnlich vorhanden. Der Plagioklas ist wie der Olivin ganz frisch und enthält keine Zersetzungsprodukte — — Wir haben es also mit Bytownit zu thun. Er ist fast schwarz, da er voll ist von den oben beschriebenen winzigen Einschlüssen. Während man anderswo am Anorthosit des Gebietes die kataklastische Structur vorzüglich beobachten kann, bemerkt man hier kaum ein Anzeichen von Druck. — — Überdies sind es zwölf Meilen bis zum nächstgelegenen Contact mit dem umgebenden Gneiss. Die Zonen um den Olivin herum sind sehr breit und vorzüglich entwickelt. Der Olivin zeigt selten angenäherte Krystallformen, er kommt entweder in einzelnen Individuen oder in Aggregaten vor, die dann grössere Körner bilden. Der Olivin krystallisierte vor dem Plagioklas aus und wurde von diesem eingeschlossen. Trotz der Untersuchung einer beträchtlichen Zahl von Dünnschliffen wurden die beiden Mineralien niemals direct in Berührung gefunden, vielmehr ist jedes Olivinkorn unabänderlich von einer doppelten Zone anderer Silicate vollständig umhüllt und hierdurch von Plagioklas geschieden.

Die erste Zone um den Olivin ist ganz oder nahezu farblos, zeigt aber oft einen ganz schwachen Pleochroismus zwischen grünen und rothen Farben. Sie wird von vielen kleinen Individuen gebildet, welche fest mit einander verwachsen und rechtwinkelig zur Oberfläche des Olivin stark verlängert sind. Oft zeigt sie die beiden aufeinander senkrechten Schaaren von Spaltrissen, die für den Pyroxen charakteristisch sind. — —

[1] F. D. Adams, Über das Norian oder Ober-Laurentian von Canada. N. Jahrb. für Min. 1893. Beil.-Bd. VIII, p. 466—470. Cf. Ann. Rep. Canad. Geol. Survey. Appendix 1882.

Da die Individuen so klein sind und die Spaltbarkeit sehr unvollkommen ist, so stösst man auf grosse Schwierigkeiten, wenn man den Charakter als Pyroxen genau feststellen will. Indessen finden sich an Handstücken aus anderen Theilen des Gebietes ähnliche Zonen, in denen diese Krystalle der inneren Zone in grösserem Massstabe ausgebildet sind. Hier kann man parallele Auslöschung, Trichroismus in rothen, grünen und gelblichen Farben constatiren, und auch die anderen optischen Eigenschaften der rhombischen Pyroxene, welche in den Anorthositen von diesen wie von anderen Gebieten auftreten.

Die äussere, d. h. die an den Plagioklas grenzende Zone besteht aus einem hellgrünen Aktinolith in sehr dünnen nadelförmigen Krystallen, welche einen Rand um den Pyroxen bilden und von ihm aus strahlenförmig in den Feldspath hineinragen. Diese Zone ist beträchtlich breiter als die des Pyroxen und die Aktinolith-Individuen stehen immer senkrecht auf der Oberfläche der letzteren. Das Mineral ist häufig in der Nähe des Pyroxen dichter als weiter nach aussen.

In einem Handstück von der Nordküste des Sees Kenogami ist die Hornblende der äusseren Zone voll von kleinen Spinell-Einschlüssen. Diese haben eine tiefgraue Farbe, sind isotrop, stark lichtbrechend, ohne Spaltbarkeit. Sie treten am meisten an den dem Pyroxen näheren Stellen der Hornblendezone auf. Bisweilen trifft man sie in Form von Körnern, gewöhnlich aber in sonderbaren, gekrümmten, garbenartigen Gebilden, gerade wie sie in feinkörnigen Pegmatiten oder Granophyren der Quarz zeigt. Diese sind innerhalb der Hornblendekrystalle, oder zwischen denselben, in der Richtung senkreckt zur Oberfläche der inneren Pyroxenzone angeordnet. Oft findet man diesen Spinell in der Hornblende in Linien parallel zu den Prismenflächen, wobei einige kleinere Individuen sich dann gabelförmig theilen, in der Weise, dass die Zinken der Gabel den beiden prismatischen Spaltbarkeiten parallel laufen. — —

Der Olivin und die Mineralien, welche die Zonen um ihn bilden, sind vollständig verschieden orientiert; die Breite der Zonen, wie man sie in den Dünnschliffen beobachtet, steht in keiner bestimmten Beziehung zu der Grösse der Olivinkörner, zumal da diese sich mit der Richtung, in welcher der Krystall getroffen wurde, stark ändert. Die Zonen sind offenbar durch die gegenseitige Einwirkung des Kalksilicatmolecüls des Plagioklases und des basischen Magnesia-Eisen-Silicats des Olivin entstanden. Daher findet man hier Silicate von mittlerer Zusammensetzung und zwar am Olivin ein saureres Magnesia-Eisen-Silicat, an welches sich an der Seite des Plagioklases ein saures Kalk-Magnesia-Silicat anschliesst. Die Begrenzungen der ursprünglichen Olivinkörner sind jedenfalls die scharfen Linien, welche den rhombischen Pyroxen von der Hornblende trennen, und die letztere ist zweifellos in den Plagioklas hineingewachsen; andererseits kann man vielfach beobachten, wie der Augit von dieser Begrenzungslinie aus in den Olivin hineingewachsen ist, besonders da, wo der übrig gebliebene Olivin die Form eines schmalen, keilartigen Korns hat, welches in einen Strich ausläuft, an dem sich von beiden Seiten her die Pyroxenindividuen treffen.

Man hat die Meinung geäussert, dass diese Zonen durch die dynamischen Kräfte, welche auf das Gestein wirkten, hervorgebracht sind. Anderswo mag es so sein, in unserem Districte giebt es keine Thatsache, die für diese Annahme spräche.

Sie sind nämlich gut ausgebildet auch da, wo das Gestein, wie oben gesagt, ganz massig ist, und keine Thatsache sich angeben lässt, die auf dynamische Wirkungen hinwiese. Ebenso gut entwickelt finden sie sich auch an anderen Punkten des Anorthitgebietes, wo man ebenfalls keine Spur von dynamischen Wirkungen bemerken kann. Gewiss, man trifft sie auch an einigen Stellen in unserem District zusammen mit kataklastischer Structur, aber das ist ja selbstverständlich, wenn die Zonen schon vor dem Eintritt der Structur vorhanden waren. Ein einziger Fall, wo sie auftreten, ohne dass Druckphänomene zu bemerken wären, hat mehr Beweiskraft als hunderte, wo zugleich deutliche Anzeichen von Druck sich finden, da dieser ja immer später eingetreten sein kann. Auch ein Grenzphänomen sind sie nicht, denn sie finden sich überall um den Olivin, wo er nur im Gestein auftritt. — — Es scheint demnach, als ob ihr Ursprung in der Einwirkung des Plagioklas-Magmas auf den Olivin vor der völligen Erstarrung zu suchen ist. Die sogenannten »Opacit-Ränder», welche man in so vielen Eruptivgesteinen um Hornblende und Biotit bemerkt, sind offenbar einigermaassen analoge Erscheinungen. — —

Adams has also observed coronas of garnet around ore, or pyroxene, in places where they come in contact with plagioclase:[1]

»Granat kommt nicht als Gemengtheil des normalen Anorthosit vor, findet sich aber häufig in der Nähe des Contactes mit dem Gneiss der Umgebung. Er hat eine rosenrothe Farbe, und man bemerkt ihn unter dem Mikroskop in kleinen unregelmässigen Massen, welche häufig mit den Eisenerzkörnern vermengt sind, oder diese ganz umschlissen. Er ist isotrop, gewöhnlich klar und ohne

[1] l. c. p. 447.

Einschlüsse. In den Schliffen der eisenerzreichen Varietät des Anorthosit vom Bezirk Wexford, Range 1, Lot 7 (und den anderen oben angeführten Fundorten) findet man einen blassrosafarbigen Granat, welcher einen schmalen Gürtel von gleichmässiger Breite um jedes Korn von Eisenerz oder Pyroxen da bildet, wo dieses sonst mit dem Plagioklas zusammenstossen würde. Zwischen Pyroxen und Eisenerz ist hingegen gar kein Granat. Er ist völlig isotrop und ist vom Eisenerz oder Pyroxen aus in den Feldspath hineingewachsen, gegen welchen er sich scharf krystallographisch abgrenzt. Diese Zonen von Granat sind analog den Zonen von Aktinolith und Hypersthen um den Olivin des Anorthosit vom Saguenay-Fluss, von denen weiter unten [1] die Rede sein wird, welche auch bei Olivingabbros von vielen andern Fundorten beschrieben sind.»

In the gabbro from Indiantown near St. John, New Brunswick, Matthew has observed reaction rims which he describes (1893) in the following way: [2]

Reaction rims. A very marked character in the thin sections is the invariable presence of reaction rims, surrounding the olivine crystals where they come in contact with the feldspar. These are composed of two zones:

1. The inner zone is very narrow, composed of a series of small highly refracting grains with green and pink pleochroism, and is continuous with the larger grains of hypersthene.

2. A zone of fine radiating needles of a faint green color and pleochroism which seem to be uralitic amphibole. The outer part of this zone is filled with minute vermicular grains of a very high refracting, deep green non-pleochroic mineral, probably spinel, as it is similar in color and refracting to the larger spinel grains, and, when coarse enough, which is not unusual, appears isotropic under crossed nicols.

The hypersthene zone is often wanting; the spinel is variable in amount and often disappears. But the actinolite seems to be very constant. The outer zone often surrounds the large hypersthene grains, and sometimes, also the monoclinic pyroxene. Its actinolite cannot be distinguished in appearance from the same mineral occurring as an undoubted secondary product, replacing the dark silicates and also in part the feldspar of the rock. Further, as spinel is abundant in the dioritic rock to which much of the gabbro has been altered, and is comparatively rare in the freshest gabbro, and

[1] quoted above.

[2] W. D. Matthew, The Intrusive Rocks near St. John, New Brunswick. Trans. N. Y. Acad. Science. XIII, 1894, p. 198, 201.

associated always with the actinolite, it is probably mostly, if not all, secondary, and that of the reaction rims has presumably the same origin. The actinolite rim follows the outline of the olivine, often running up into cracks traversing the mineral, where the hypersthene zone is not seen. Small plates and needles of magnetite, very like the secondary magnetite between the alteration cracks in the olivine, occur commonly between the actinolite fibres, their shape being conditioned by that of the interspace which they fill. The spinel granules are separated from the feldspar by a sharp line; on the other side they usually become gradually less numerous till they disappear. The evidence seems strongly in favor of the secondary nature of the outer zone, and I believe that in the case of the St. John gabbros, at least, it is formed by the same influences that caused the uralitization of the rock. Supposing those conditions to be present which favor the formation of uralitic hornblende, it would form first and most easily on the contact of a magnesia-iron silicate with a lime-alumina silicate, because here all the materials necessary to make an average amphibole would be furnished with a minimum of transportation. In a less basic rock the diallage might be of the required composition, and thus be uralitized before any reaction rims formed; but in the St. John gabbro, apparently, this was not so. In the formation of the uralite, the surplus magnesia and iron from the olivine and hypersthene would combine with the surplus alumina from the feldspar to make spinel, the position of the spinel being perhaps determined by the relative solubility of its acid and base, the more soluble magnesia and iron being more easily transported.

With regard to the inner zone, I have seen no evidence that it is secondary; on the contrary its continuity with the large hypersthene grains, its refusal to follow the outer zone into secondary cracks, and its fresh and granular character, lead one to believe that like most other occurrences of hypersthene it is an original mineral, which collected around the olivine crystals on account of their attractive influence, partly chemical, partly physical, on the molten magma. — —

Dr. Adams states that the reaction rims are independent of the cataclastic and gneissic structure developed in the rock. But the metamorphism due to crushing at great depths may be considerably different in character and effects from the paramorphism due to chemical and molecular action at less depth and with perhaps the assistance of water. The two are, it is true, usually associated, but either may occur without the other, and it is the latter to which, if secondary, the actinolite zones must be ascribed. The former may be said to be more characteristic of the Canadian highlands and the Adirondack region; the latter of the bordering and outlying metamorphic rocks along the Atlantic coast and elsewhere.»

Kemp has observed reaction rims around olivine which he regards as secondary, in the gabbros of Lake Champlain, and describes them in the following way: [1]

»The commonest reaction rims or zones of minerals elsewhere noted have been around olivine and apparently due to its proximity to feldspar. In this case we usually see next the olivine a rim of hypersthene granules, outside of which is actinolite in radiating fibers, often with small spinels entangled, and then the plagioclase. Various modifications of this succession have also been recorded, a brief review of which is given below. In the Lake Champlain gabbros the following zones were noted around olivine: Next the olivine is a zone of granular hypersthene, next quartz, next garnet and then feldspar (slide 121), or we may have olivine, hypersthene, brown hornblende, garnet, feldspar (slide 146). There may even be nests of hypersthene bits, with garnet rims, the olivine having apparently been exhausted. In the same specimen of rock (slide 146) the slide shows also the ramifying branches and rods of pyroxene such as were figured by W. S. Bayley and regarded as original intergrowths. They occur in great numbers in some of the writer's slides, almost forming streams outward from the olivine. In the outcrop north of Port Henry, along the lake shore, most interesting passages of the ophitic gabbro into bands of thinly foliated, gneissoid structure can be traced. This has doubtless been induced by pressure, and the gneissoid character has been caused by the stretching of the dark silicates and of the feldspar into elongated, parallel lenses. In such specimens brown hornblende becomes especially prominent and replaces quite entirely the pyroxene. It would appear to be secondary. Evidence of dynamic effects is everywhere present in the slides».

In an article on the gabbros in the south-western Adirondack region, Smyth (1894) describes an interesting occurrence of hypersthene which shows much similarity to the phenomena mentioned by Bayley: [2]

»At the same time that the gneissoid structure becomes marked, the structure of the hypersthene undergoes a conspicuous modi-

[1] l. c. p. 221.

[2] C. H. Smyth, Jr., On Gabbros in the Southwestern Adirondack Region. Amer. Journ. Sci. 3d Ser. Vol XLVIII. 1894, p. 59—60.

fication. The mineral not only becomes shattered like the other constituents, but sends out slender tongues into the surrounding feldspar. These tongues range from slight projections of the hypersthene to string-like extensions which radiate from a hypersthene core. In still more extreme cases this core is lacking and the hypersthene forms curious rosettes. It is often impossible to determine directly the nature of the mineral in the tongues, but it may be safely regarded as hypersthene as there is a complete gradation between them and the larger extensions plainly composed of this mineral. The large tongues of hypersthene unusually form a granophyric intergrowth with the feldspar presenting an appearance somewhat like that described by Bayley in the augite of Lake Superior gabbros. — — The tongues wander irregularly through the feldspar, often extending between adjacent individuals. — —

This stringing out of the hypersthene shows a most intimate connection with the development of gneissoid structure — — The stringing out — — becomes more and more conspicuous as the gneissoid structure increases. It seems a necessary inference that the phenomenon is a result of metamorphism but the rational of the process is not clear, and it seems best to defer any attempt at explanation until more data are available».

Holland described in the year 1896 »reaction rims» around olivine in the norites from southern India and thereby made the following statement:[1]

»14. But the most striking feature in connection with these olivines is the occurrence of very well defined and broad »reaction-rims» between this mineral and the felspar, similar to these which have so frequently been recorded in basic and ultra-basic rocks. The reaction-rims are composed of an external layer of feathery green actinolite abutting against the felspar, considerably wider, as a rule, than the inner zone of granular, colourless mineral, which exhibits a double refraction distinctly lower than that of the actinolite.

The colourless mineral in this case is regarded as enstatite, because it has been found in several instances in crystallographic continuity with larger adjoining original crystals of that mineral. It is frequently found also that both the augite and the enstatites are separated from the olivine by a very narrow zone of this colourless mineral, which sometimes exhibits crystallographic continuity with the enstatite, appearing thus as a secondary extension of the min-

[1] Thomas H. Holland, On some Norite and associated Basic Dykes and Lava-flows in Southern India. Rec. Geol. Survey of India, XXX, Part. 1. 1896, p. 21.

eral, like the well-known secondary enlargements of quartz, felspar, augite, hornblende and mica (Fig. 1).

15. The question of the origin of these so-called reaction-rims which so frequently characterise the olivines of very basic rocks has frequently been discussed, and very different explanations have been offered, both as to the precise nature of the reaction products and the mode of their formation, which is not a surprising result, seeing that both the compositions of the reacting minerals, as well as the physical conditions of formation must, within certain limits, be variable. Although the present instances do not appear to offer conclusive evidence, the general assemblage of facts point, in my own opinion, to the origin of the rim as the result of the reaction between the olivine and a more siliceous mineral, felspar, under the particular physical conditions which are attended with various other structural characters — primary and secondary — that distinguish plutonic rocks from lavas. In this case the reaction-rims occur in a rock which shows the schillerization and other phenomena characteristic of deep-seated rock-masses, whilst all these structures are absent in the Jootoor lava, which mineralogically is the very evident equivalent of this rock. But in the lava a pilitic decomposition of the olivine has taken place (vide infra para. 23) which is certainly secondary and confined by the original limits of the olivine crystals. The evidence points also to the formation of the pilite with the aid of compounds derived from the adjoining decomposing felspar.

16. That the fibrous and granular borders are real reaction-rims is therefore supported indirectly by the peculiar nature of the secondary decomposition of the olivine in the lavas; but the question as to whether the reaction-rims are formed during the consolidation of the rock — as late G. H. Williams supposed to be the case in the very similar and now well-known occurrence near Peekshill, N. Y. — or subsequently, is not determined by this evidence, as there are so many instances to show that the structures produced rapidly during the primary consolidation of a molten magma can be closely imitated by those produced more slowly during secondary changes subsequently induced in the consolidated rock».

In describing fig. 3, plate II, he further says:

»Reaction-rim between olivine and plagioclase. O = Olivine, P = Plagioclase, E = Enstatite with its secondary enlargements, e, which are in crystallographic continuity with the original crystal E, and in one place form part of the reaction-rim with the green actinolite, a. It will be noticed that the actinolite, a, appears only between the secondary enstatite, e, and the plagioclase, not between the latter mineral and the primary enstatite, E. E. shows feebly the pleochroism of hypersthene, whilst e is perfectly colourless».

In the older edition of his Microscopical Physiography of the Eruptive Rocks, Rosenbusch expressed the opinion that the coronas around olivine were of secondary origin, but later, in 1895, he says, when resuming the observations of Bayley:[1]

»Damit wäre das gewünschte Bindeglied zwischen der normalen und dieser besonderlichen Structur des Olivingabbro gegeben und die oben S. 312 ausgeführte Erklärung der normalen, sowie Adams Erklärung wären wesentlich ident. Damit wäre aber ein Hauptproblem der Gabbrostructuren seiner Erklärung zugeführt und recht heterogen erscheinende Thatsachen unter einen einheitlichen Gesichtspunkt geordnet».

Kolderup has observed, in 1898, coronas in the gabbro of Lofoten and Vesteraalen of Norway, e. g. in the olivine-labradorite of Kvalvik. I quote his description in translation:[2]

»Around the olivine there is a double zone of radiating minerals of which the inner one in polarized light has almost the same colour as olivine and is therefore not easily distinguished from it. The boundary, however, is often very distinct. In polarized light its difference from the olivine is detected on account of its less intense colours of interference, and upon which we also discern that it is composed of a number of radiating individuals. Around this zone there is another outer zone which is rather sharply defined on the inner side by a dark-green line. On the outer side of this line it has at first an impure green colour, whereupon it assumes a purer and lighter green tint together with a radiating arrangement of the minerals. In several places, the boundary between the inner and the outer zone is well defined and presents to view a finely barbed line. A similar, more coarsely barbed line forms the outer boundary between the green zone and the plagioclase.»

In the description of the olivine from the olivine monzonite from Aarsteinen in Vaagen, Kolderup mentions.

»*Olivine* with interesting mantles. In one place there are two olivines surrounded by two different mantles. The inner of these, which is thinner, consists of a light yellowish radiating mineral which I regard as monoclinic pyroxene, because it shows the extinction angle of this mineral. In the outer mantle the radial structure is

[1] H. Rosenbusch, Mikr. Physiographie der Massigen Gesteine. 3. Aufl. 1896, p. 317.

[2] G. F. Kolderup, Lofotens og Vesteraalens gabbrobergarter. Bergens Museums Åarbog 1898. Nr. VII. p. 9, 10 and 25.

less pronounced, but it can be observed between crossed nicols. The mineral, which has a pale red tint, but no greater pleochroism, is probably a bronzite. The orthosilicate has been changed into a metasilicate».

Lacroix described in the year 1900 the basic rocks which accompany the lherzolites of the Pyrenees, among them an ariégite from Tuc d'Ess near the road to Portet. This rock contains great crystals of diopside and bronzite surrounded by coronas of pyroxene, spinel and plagioclase:[1]

»On y distingue à l'oeil nu de gros cristaux de diopside et de bronzite, entourés par des parties compactes vertes; l'examen microscopique montre que celles-ci ont une constitution singulière, elles sont en effet formées par de grandes plages dentelliformes de pyroxène incolore englobant des petits grains ou des larmes de spinelle vert; les jours de la dentelle ainsi formée sont remplis par de grandes plages d'anorthite ou de bytownite.

Ces plages pyroxéniques sont tantôt globuleuses et orientées sur le diopside de la roche quand elles se trouvent à son contact (Pl. XIII, Fig. I), et tantôt disposées en grand nombre contre lui, l'entourant ainsi d'une sorte d'enveloppe kélyphitique. Il est à remarquer que, contrairement à ce qui se passe dans toutes les roches feldspathiques qui seront décrites plus loin, celle-ci ne présente pas trace d'actions mécaniques.

J'ai rencontré enfin ce même type pétrographique au Moun Caou, près Louvie-Juzon (Basses-Pyrénées). La roche a subi des actions mécaniques puissantes; c'est dans les zones offrant la structure en mortier et notamment au voisinage de grands cristaux de spinelle que l'on rencontre des petites plages de plagioclases basiques, trop petites pour être déterminées avec précision; au milieu d'elles se détache une dentelle de diopside et de spinelle. Il n'est pas douteux que ce développement de kélyphite ne soit contemporain de la déformation dynamique de la roche. Tous les silicates de cette roche renferment en quantité prodigieuse des inclusions liquides à bulle».

Other garnetiferous ariégites from Prades, the valley of Sue and Moncamp, (Haute-Garonne) show coronas containing garnet:

»La structure est la même que dans les roches sans grenat (Pl. XIII, fig. 1), le pyrope joue le même rôle que le spinelle auquel il est souvent accolé: parfois englobé dans les pyroxènes, on le voit souvent les mouler. Le feldspath est absolument absent des roches a

[1] A Lacroix, Les roches basiques accompagnant les lherzolites et les ophites des Pyrenées. Congr. géol. intern. Comptes rendus de la VIII:e session, Paris 1900, II, p. 810—813.

structure non déformée (Prades): on le voit apparaître au contraire dans les ariégites fortement dynamometamorphisées de la vallée de Suc et de Lherz, dans celles de Moncaup. A Lherz et à l'Escourgeat, la roche présente un remarquable développement de la structure en mortier; les grains de spinelle et surtout de grenat sont entourés par une zone kélyphitique souvent extrêmement régulière, constituée par une dentelle de pyroxène renfermant du spinelle vermiculé, des plus élégants: elle est englobée par des grains d'anorthite. Dans quelques échantillons, la zone kélyphitique devient extrêmement fine et il n'est plus possible d'en déterminer avec précision les éléments; dans certains cas, le pyroxène est ouralitisé et dans d'autres (Prades) chloritisé.

L'ariégite pegmatoïde de Moncaup permet d'étudier plus facilement encore ces associations kélyphitiques: les grands cristaux de diallage, renfermant parfois des bandelettes de bronzite, englobent les gros grains de grenat dont il a été question plus haut. Des actions mécaniques extrêmement puissantes les ont tordues comme si elles avaient constitué une matière plastique; c'est le long de leurs cassures et tout autour des grains de grenat, entre ceux-ci et leur hôte, que s'est développée une délicate kélyphite (Pl. XIII, Fig. 2), dans laquelle on distingue, comme dans les cas précédents, du pyroxène coloré en vert par de délicates vermiculisations de spinelle, sur un fond d'anorthite finement maclée. Dans quelques cas, la zone kélyphitique est exclusivement constituée par des fibres vertes très serrées, dépourvues au moins en apparence de feldspath et de spinelle, elles paraissent être constituées par de la hornblende; peut-être faut-il les considérer comme le résultat de la décomposition de la kélyphite décrite plus haut».

Otto Hecker gave (1903) the following description of the coronas around the olivine in a gabbro occurring between Leprese and Diavolo in Switzerland.

»Der Olivin ist fast immer von Diallag und brauner Hornblende umrandet, und zwar liegt zunächst dem Olivin meistens Diallag, der seinerseits von brauner Hornblende umschlossen wird. Letztere bildet öfters auch allein die Umrandung.

Neben diesen eben erwähnten Umrandungen durch Diallag und Hornblende findet man an sehr vielen Olivinen zwei Randzonen anderer Art. Die innere Zone besteht aus einem im Dünnschliff farblosen, breitstengeligen Mineral, welches schief auslöscht, dessen Auslöschungsschiefe aber nicht genaue bestimmt werden konnte.

[1] O. Hecker, Petrographische Untersuchung der Gabbrogesteine des oberen Veltlin. Inaug.-Diss. Stuttgart 1903.

Auf diese farblose, breitstengelige Zone folgt nach aussen hin eine dunkel lauchgrüne, die durchschnittlich 2 bis 3 Mal so dick ist als die innere. Sie besteht aus kleinen, meist verworren angeordneten Fasern und Stengeln, die sich häufig senkrecht zum Rand stellen und dann den Eindruck eines Eisenbartes an einem Magneten hervorrufen. Die maximale Auslöschungsschiefe dieser Stengel konnte mit ungefähr 16° gegen die Längsrichtung bestimmt weren. Beide Zonen greifen zackenartig ineinander und gehen fast unmerklich ineinander über, während die innere helle Zone scharf gegen den Olivin abgegrenzt ist (Taf. XVIII, Fig. 1).

Ich glaube diese beiden Zonen für sekundäre Hornblende halten zu können, und zwar die innere helle für Tremolit, die äussere für Aktinolith, und führe die Entstehung des ersteren auf den Diallag, des letzteren auf die braune Hornblende zurück. Die Umwandlung der braunen Hornblende in Aktinolith ist an verschiedenen Präparaten deutlich zu verfolgen (Taf. XVIII, Fig. 2 und Taf. XIX, Fig. 3). Zuerst findet Ausbleichung, Umwandlung der braunen Farbe in grüne statt und weiterhin sieht man den Übergang der zuerst noch compacten grünen Hornblende in ein faseriges, ausgefranstes Aggregat von Aktinolith.

Derartige Neubildungszonen um den Olivin wurden von anderen Forschern schon früher beschrieben, und zwar zuerst von Törnebohm, später von Becke und von Lacroix».

Harker pronounces his verdict as regards the problem concerning the genesis of corona structures, with the following words:[1]

»Crystals originating in a magma only little supersaturated have a strong tendency to attach themselves to existing crystals of earlier-formed minerals. With a definite sequence of the several minerals, this must give rise to a more or less pronounced arrangement of them in concentric zones about the earliest mineral as a nucleus. Such an arrangement is scarcely perceptible in the more acid plutonic rocks (apart from distinct »spheroids»), but in basic rocks it is sometimes developed in a remarkably regular manner. This is the corona structure, common in gabbros and norites (Fig. 88, A). For instance, a crystal of olivine may be surrounded by a ring of enstatite grains, and this by a second ring, composed of augite, felspar, as the latest mineral, filling the interspaces between aggregates of this kind. Often there is a radiate arrangement of the crystals in these bordering growths, and sometimes two minerals have crystallized together in a radiate fibrous intergrowth. The »celyph-

[1] Alfred Harker, The Natural History of Igneous Rocks. London 1909, p. 269—270.

ite» borders round the garnets of some eclogites and peridotites are structures of the same kind; they are of pyroxene, hornblende, etc., in different cases (Fig. 88, B). Corona-structures have been regarded by some petrologists as of secondary origin, a pyroxene border interposed between olivine and felspar, for example, being attributed to chemical reactions between these two minerals, and referred to dynamic metamorphism. This is doubtless the true interpretation in some cases; but in others the reactions postulated are of a kind unknown in dynamic metamorphism, or are chemically impossible. Numerous types of »couronnes» have been described and figured by Lacroix; and others have been recorded, often under the name »reaction-rims», by the American petrologists».

Fearnsides mentions (1914) the corona structures among the consolidation structures of eutectic magmas:

»In rocks the ferro-magnesian minerals augite, hornblende and hypersthene, associated in the »corona structure» of the norites, afford a parallel. (Fig. 14., Plate VI). The »celephytic» arrangement of hypersthene, olivine or garnet in eclogite and some peridotites, is similar in appearance.»

There are possibly important communications on the same subject which have escaped my notice. While apologizing for these possible omissions, I will here briefly resume the literature quoted above.

As we are aware, there is, among the mineral combinations which have been called coronas or couronnes, (I prefer to use, in some cases, the term *coronites,* which has been used by Brögger in his lectures) a variety of different phenomena regarding which the opinions of petrologists still widely differ.

We find among these structures several different groups:

In one of these groups, the zones which are usually double, occur only where olivine is in contact with plagioclase. They are synantetic in the strictest sense of the word.

The most common of these coronites consist of two zones of radially arranged minerals of which the inner one is colourless, while the outer consists of a green strongly pleochroic mineral. This zone is sometimes also brownish in hue. In some instances there is a third, outermost zone which has a granular texture. In several cases the innermost, lighter zone consists of hypersthene, (Lacroix, Adams, Matthew, Kemp) diallage, (Bayley, Hecker) enstatite, (Hol-

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[1] W. G. Fearnsides, First Sorby Lecture »On some Structural Analogies between Igneous Rocks and Metals». Sheffield Society of Engineers and Metallurgists, Febr. 28th 1914.

land) or monoclinic pyroxene, (Kolderup) but Törnebohm, Lacroix and Hecker have also observed tremolite, and Teall, antophyllite. Svedmark mentions light green actinolite as constituting the inner zone, Kolderup brown bronzite as composing the outer zone which observations are contrary to all others. Lacroix and Svedmark have observed a narrow zone of magnetite grains next to the olivine.

The green mineral of the outer zone has generally been interpreted as actinolite or as »hornblende» (Törnebohm, Becke, Williams, Teall, Lacroix, Adams, Matthew, Kemp, Holland, Hecker).

Lacroix has observed »pegmatites» of amphibole and labradorite, Bayley pyroxene and plagioclase, as constituents of the coronas around olivine, also as granophyre-like bunches, sometimes occurring more irregularly, and Smyth has observed a granophyre-like intergrowth of hypersthene and felspar. Rather isolated does the observation of Julien stand, according to which biotite and viridite should occur in the interior of the olivine, talc as a shell around it.

In the second group the changes seem to have advanced farther. The minerals of the coronas are more compactly crystalline and differ more from the original constituents of the rock. Thus we have the combination hypersthene and garnet, or hypersthene (or augite), amphibole and garnet, sometimes together with felspar or quartz, (Lacroix, Kemp) or actinolite (or hypersthene and actinolite) in combination with spinel (Adams, Lacroix, Matthew, Kemp). Coronas of amphibole and garnet may also (Lacroix) occur around ilmenite surrounded by biotite, or around pyroxene surrounded by ilmenite and pyroxene, coronas of diopside, plagioclase and spinel, around diopside, or bronzite. These coronas already show analogies with the kelyphitic rims around garnets and other similar things which we will mention later on, and also occur in the same rocks.

Adams has observed that garnet occurs as rims around iron ore surrounded by pyroxene only where plagioclase meets, thus as a strictly synantetic mineral.

Also the interpretations of the origin of the coronas differ in a high degree. While some petrologists pronounce no definite opinion, others, again, are divided between the theories of a secondary and a primary origin. The former opinion is held by Törnebohm, Becke, Williams, Lacroix, Matthew (as to the outer zone of the coronas), Kemp and Hecker, while Schuster, Bayley and Adams, on the contrary, believe that the coronas belong in some way or other to the phenomena connected with the consolidation of the eruptive magma.

Rosenbusch, after having, formerly, been an adherent of the idea of the metamorphic origin of the coronas, later expresses an opinion which is in favour of the opposed theory. Bayley's observations seem to him to be conclusive as to this main problem of the origin of the structures of the gabbros, and also appear apt to bring many different phenomena under a common point of view. A similar opinion has also been pronounced by Harker and Fearnsides. According to Rosenbusch, there is an analogy between the coronas and the roughly centric structures which originate in gabbros, by the grouping of later crystallizations around the olivine crystals.

In my opinion, this analogy is apparent and delusive, and we also here have to keep in mind that »multa fiunt eadem, sed non in eodem modo». I will now proceed to the description of my own observations which are in favour of the metamorphic theory.

Observations of the Author and their Bearing upon the Problem of the Origin of the Coronas, &c.

Coronas, and corona-like structures in Fenno-Scandian rocks.

Fig. 3, plate I, shows a case which seems to me to correspond to Rosenbusch's idea about the occurrence of a roughly centric structure in certain gabbros. It is a slide of an olivine gabbro from Ylivieska in Ostrobothnia which is of old Archæan age. Several grains of olivine are grouped together and cemented by ore, which is bordered by narrow zones of brown hornblende. At the right side of the olivine grain in the centre of the photograph there is, between this hornblende and the olivine, a narrow zone of a light mineral, which is an augite of a pale red colour. Outside of all these minerals lie the plagioclase laths (andesine with 35 % An).

The augite rim is also found at the left side of the olivine grain, between the aforesaid and the grain in the left upper part of the section. These augite rims are continuous with a larger crystal of diallage which is seen in the middle of the uppermost part of the section.

The olivine shows, in many places, a coating of augite of a similar kind which has a very irregular breadth, and often merges into the greater crystals of augite or diallage, analogous to the description given by Bayley. It is beyond doubt a primary phenomenon. Where this coating of primary pyroxene is not present, and where the olivine is in direct contact with the andesine, there we also find in this case the common coronas of radially arranged fibers of green hornblende which, according to my opinion, are secondary.

Fig. 4, plate I, shows a photograph of a thin section of the typical »hyperite» of Törnebohm from a specimen, which I have taken myself at Ölme from the northern shore of Lake Wenern in Sweden. Into the olivine which forms a core surrounded by the two zones described by Törnebohm, an inner colourless zone and an outer green one, protrude two slender laths of plagioclase, both of which have been entirely replaced by the minerals of these zones, in the manner of pseudomorphs. How could this be explained, if the coronas were due to a centric arrangement of the minerals crystallizing in a magma? If such were the case, the coronas ought to be found only around the olivine. This appears to me to be a proof of their metasomatic and secondary origin. A similar observation has also been made by Becke.

I have also been able, thanks to the courtesy of Dr. Gavelin, to study the thin sections of specimens from the same locality belonging to the Geological Survey of Sweden, but have nothing of importance to add to the masterly description which Törnebohm has given of the same rock.

Fig. 5, plate I, shows another very typical corona from a gabbro occurring in a little rocky island S.E. from Tunnholmen, in the parish of Borgå in southern Finland. It belongs to the formation of very old Archæan (Lower Bothnian) volcanic rocks which I have studied in great detail during these last few summers, especially in order to determine the changes which they have suffered when they have undergone granitization. The gabbros grade into diabases and basalts. The latter rocks are entirely uralitized, and form very typical uralite-porphyrites. The gabbros and diabases are often better preserved, but also these are partly uralitized, and there is no doubt that their metamorphism, like that of the associated uralite-porphyrites, has taken place in connection with the intrusion of the granites which inject the basic rocks on all sides.

Among the most instructive of these rocks are an ophitic fine-grained diabase, or dolerite, from Virskär in Pernå, and the gabbro first mentioned. Both are so well preserved as to allow of a determination of the primary features with certainty. Also in the gabbro, the structure approaches the ophitic, although the felspar laths (andesine with $42\,^0/_0$ An) are broader and not so regularly shaped as in the other rock. Between the felspars lie the darker minerals, augite and diallage, brown hornblende, olivine and ore. The hornblende which seems in a large measure to be primary, (cf. p. 7) often forms thin borders around the ore. In many cases the olivine nearly fills out the room beetween the andesine laths, or between the latter and the hornblende coating. If then, the remaining room is filled out by augite, this must necessarily form a border-like zone around the olivine. This is particularly noticeable in the rock from Virskär (fig. 6. plate I). Although this primary border-zone may sometimes be more regular in thickness, so as to resemble the coronites, its pyroxene is not radially arranged and has often over large areas the same optical orientation as the neighbouring augites.

The corona zones are very typical in the gabbros, and consist of radially arranged fibrous minerals, forming an inner, uncoloured, and an outer, green zone. The latter may occasionally again grade into a lighter coloured, outermost zone, which seems to consist of the same mineral in less compact tufts. These corona zones occur only where the olivine meets plagioclase.

Where the lighter zone is in the neighbourhood of a thin zone of augite of uniform breadth, they may appear to belong together, but there are places where the light zone of the corona may be found in contact with augite in which case their separate character can be ascertained. The corona mineral has a lower refraction index than the augite and has not the same optical orientation. I believe it to be tremolite. The green zone of the corona is certainly hornblende.

In the doleritic rock the olivine almost everywhere lies in a matrix of augite. In consequence thereof, we find no well developed coronas, but where the olivine occasionally meets plagioclase, the two zones, however, appear here as well. There is also much secondary biotite around the ore grains, and around olivine which has been filled with ore.

The plagioclase further contains small prisms of green hornblende irregularly interspersed, and, in several places, intergrowths of plagioclase and vermicular hornblende which very much resemble the myrmekite of the acid rocks. To these interesting things we shall return later on.

Thus, I think, we are able to discriminate, although in many cases not without certain difficulties, between a primary and a secondary coating of the olivine. Only the latter should be referred to as the coronas. The observations of Becke quoted above (p. 9) also seem to bear in the same direction.

If the true coronas, of the kind here described, should be primary crystallizations of the magma, it is inexplicable why they are entirely absent in such gabbros and diabases that have evidently undergone no later metamorphism, while they are so common in ancient basic rocks which have undergone metamorphism (except where this metamorphism has been strong enough to obliterate those rather delicate structures). In the eastern parts of Fenno-Scandia, to the east of the post-Silurian mountain chain), we do not find coronas in any diabases of Jotnian age. These rocks have not undergone any metamorphism, in regions to the east from the Kölen-mountain. But coronas are common in earlier olivine-diabases and gabbros of the same region. Especially when the coronas consisting of tremolite and hornblende, or of pyroxene and hornblende, are associated with garnet, as is the case with the old hyperites of Sweden and so many rocks from elsewhere, described by various authors, I consider it impossible to regard them as primary phenomena.

No doubt it is true, as Holland justly remarks, that »the use of the term secondary when applied to rock alteration is but relative.» As he says, »the minerals of early consolidation may be attacked and altered soon after their formation by the vapours originally included in the magma and excluded to the mother liquor, or they may become attacked at a distinct, and subsequent period. In the former case, the processes of primary crystallization and secondary alteration are continuous and, in reality, phases of the same process.»

The formation of biotite, around ilmenite, and of viridite in the non-metamorphic olivine-diabase from the shores of the Gulf of Bothnia, described above, are examples of »secondary» processes of the latter-mentioned kind, caused by gases, or liquids, belonging to the magma of the rock itself.

Judd, already long ago, called the attention to the importance of such processes, and showed that the »schillerization» and similar phenomena were, at least in certain cases, due to them.[2]

Further, he also wished to explain the granophyric structures in acid rocks as secondary, including even the typical micropegmatite.[3] It is true that this idea is contrary to the opinion now prevalent, but Judd's great merit was, also in this case, that he was one of the first to call attention to these interesting questions.

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[1] T. H. Holland, On a peculiar form of Altered Peridotite in the Mysore State. Mem. Geol. Survey of India. Vol. XXXIV, Part I, 1901, p. 8.

[2] J. W. Judd, On the Tertiary and Older Peridotites of Scotland. Quart. Journ. Geol. Soc., 1885, p. 354—418.

Idem, On the Statical and Dynamical Metamorphism. Geol. Mag. Vol. VI. 1889. p. 243.

[3] J. W. Judd, On the Growth of Crystals in Igneous Rocks after their Consolidation. Quart. Journ. Geol. Soc. 1889, p. 176—185.

As to the majority of the phenomena here described, especially that of the typical coronas, I am, as already said, inclined to consider them as truly secondary and metamorphic.

The gabbros and diabases of eastern Canada and the adjacent parts of New England, where we find so many different and typical examples of corona structures, are all older than the mountain-making processes, followed by granitization and metamorphism, which the same regions have undergone, and some of these rocks may even be regarded as rather highly metamorphic. At a time when regional metamorphism and »dynamometamorphism» were regarded as identical, a reference to the independence of the corona structures of the cataclastic structure may appear as a convincing proof of their primary origin. But regional metamorphism, in as much as it concerns the formation of new minerals, has certainly, in many cases, more to do with increased temperature at great depths, and the action of solvents, than with the mechanical crushing and other purely »dynamical» influences. To me »regional metamorphism» is often identical with contact metamorphism at great depths, or »plutonic metamorphism». The influence of the disturbances has often merely consisted in forcing the rocks, by heaping on them other overthrown rockmasses, in such a position that they arrived into the realm of the metamorphosing influences of the depth.

Some of the phenomena in question, and especially also of the synantetic minerals, occur in rocks which have undergone contact action of the most unquestionable character, and which we will describe in the following.

As to the chemical character of the coronas, it is easy to understand that the inner zone, which has replaced olivine, should consist either of tremolite, or rhombic pyroxene. It is more difficult to understand why the outer zone, replacing plagioclase, consists of a green hornblende, richer in iron. However, there are many analogous cases where felspar has been filled with interpositions of hornblende, biotite, or even iron ore, which shows that there is a certain sympathy between these minerals when rocks undergo metamorphism of the kind here in question. It may be the content of alumina that has caused the formation of hornblende; but also the lime and alcalis of the plagioclase enter readily into such a compound.

As a general rule, the synantetic minerals of the basic rocks now mentioned originate at the boundaries between plagioclase on one side, and magnesium silicates, (or in some cases iron ore) on the other. Augite is not apt to give rise to coronites, but is simply uralitized in a more irregular way. Obviously the alumina, lime and alcali constituents enter more readily into combination with the augite, which has a more complex chemical constitution, than with the magnesium ortho- or metasilicates.

The process by which the coronites have originated has not consisted exclusively in a reaction between the adjacent minerals. These minerals have supplied only a part of the constituents of the coronas, while another part has been transported in solution from more distant places of the same rockmasses.

MYRMEKITE-LIKE INTERGROWTHS OF PLAGIOCLASE AND VERMICULAR HORNBLENDE, IN THE NEIGHBOURHOOD OF OLIVINE (OR HYPERSTHENE) AND OF BIOTITE.

In several basic rocks I have found minute intergrowths between a basic plagioclase and vermicular hornblende which are of very great interest, because they present a close analogy to the myrmekite of the acid rocks. I have already quoted observations made by Lacroix, Bayley and Smyth on similar intergrowths.

The structures which I have studied occur e. g. in the dolerite from Virskär, already mentioned. In the neighbourhood of the olivine, often next to its borders, occur such minute crust- or wart-like intergrowths which seldom reach a size of more than 0,15 mm in diameter. (Fig. 7, plate II). They always lie in plagioclase and consist of a plagioclase which shows a higher index of refraction than the neighbouring primary andesine and which thus must belong to the series labradorite-anorthite, intergrown with small vermicular rods of a light green, almost colourless monoclinic mineral which are arranged in the main radially, as in the common myrmekite. I regard it, for reasons which will be stated in the following, by describing similar structures from other rocks, as hornblende, rather than pyroxene.

In some instances, these intergrowths lie at places where no femic mineral occurs in the neighbourhood, generally at the junction of several plagioclases. In most cases then biotite, or chlorite which seems to have originated by the alteration of biotite, occur in the neighbourhood at least in small tufts. Also when the warts lie near to the olivine, they seem to favour such places where biotite has been formed (as is usual around grains of ore). However, most of the biotite crystals have no such fringes, and the occurrence of these myrmekite-like intergrowths is, in general, rather irregular.

In the diabase from Tuulasoja in Merijärvi which contains the »porcupinitic» biotite described on page 6, also myrmekite-like intergrowths of hornblende and basic plagioclase occur. They lie in the andesine laths generally near to their boundaries against the femic minerals. The bunches usually turn their convex ends from the pyroxene against the felspar (fig. 8, plate II), but also the reverse was observed (fig. 9, plate II). Here probably the growth of the structure has begun from a crack dividing the plagioclase. The felspar of the intergrowth is richer in lime than the andesine of the rock. The vermicular rods probably consist of tremolite.

The relation between these intergrowths and the secondary biotite of the rock is also in this case of interest. Very often biotite occurs between the intergrowths and the adjacent pyroxene, and sometimes this mineral and the intergrowth seem to form successive although not very regular rims reminding one of the zones of a corona. But this connection does not always exist. In many cases these minerals occur quite independently of each other. The biotite occasionally contains the vermicular rods of hornblende as inclusions and thus seems to have been formed, at least in some cases, later than the intergrowth of hornblende and plagioclase, replacing the latter. Although not visible in the section olivine may have been, originally, near the intergrowth.

A connection between the intergrowth in question and biotite is apparently still more obvious in a rock from Mäntyharju belonging to the anorthosites which occur at the north-western border of the great rapakivi area of Wiborg, and which have undergone, in several places, a very intense contact-metamorphism, and in some cases a solution, through the action of the rapakivi granites. These processes have been described by Frosterus who also communicates a photograph of the intergrowth of different minerals in the rock from Nurma, here in question.[1]

The rock is an anorthosite, containing besides diallage, which forms the main part of the filling between the andesine laths, also some olivine and ore. The latter mineral is surrounded by biotite, which forms irregular crystals around it often radiating to all sides, and, in many cases, terminating with what Frosterus calls »fingerlike projections» whose interstices are filled with quartz (fig. 10, plate II = fig. 15 in Frosterus description; cf. fig. 11, plate II). These forms are very characteristic of the biotite, occurring under analogous circumstances, also in granitic rocks, from which I will show several examples in the following. I propose to designate it as d a c t y l i t i c[2] biotite.

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[1] Benj. Frosterus, Beskr. till bergartskartan af sektionen C 2 St. Michel. 1902, p. 70—71.

[2] Not to be confounded with the term *dactylotype* proposed by Shand.

Around the biotite flakes there often are, especially around those ends which are dactylitic or fringed, crusts consisting of a myrmekite-like intergrowth of plagioclase and a pale greenish mineral forming vermicular rods. It is somewhat coarser than the common myrmekite, the length of the warts, or breadth of the crust reaching 0,25 mm. Frosterus regards the greenish mineral as olivine. It has, however, quite different optical characters from this mineral which can be seen when they are in contact with each other. It is more similar to the diallage or augite of the same rock, but I have been able to determine that its refraction is lower where it is in contact with these minerals. I regard it as being most probably a tremolitic hornblende, or possibly diopside. The plagioclase of the »warts» has a higher index of refraction than the primary andesine and belongs thus to the series labradorite-anorthite.

This myrmekite-like intergrowth always occurs within the border-zones of the primary plagioclase. It forms fringes around the biotite but behind that mineral, in several cases, olivine is to be found which has probably existed earlier in many places where it is now entirely obliterated. It seems therefore rather difficult to determine whether the intergrowth in question is, to a certain extent, synantetic between olivine and plagioclase, or biotite and plagioclase.

The connection between the formation of the myrmekite-like intergrowth, and the formation of biotite and quartz, may be explained in two different ways. Both of these phenomena may have been chemically dependent of each other. Solvents may have acted upon the primary ore grains, and the olivine, whereby biotite has been formed, whereafter the surplus of silica crystallized, forming intergrowths with the biotite. Some parts of the material in solution, and, perhaps, fluoric gases which have been concomitant at the formation of the biotite, have acted in their turn upon the neighbouring plagioclases, replacing them with the myrmekite-like intergrowth of basic plagioclase and vermicular hornblende. Or, the formation of the myrmekite-like intergrowths may have happened earlier, mainly at places where plagioclase and olivine, or other femic minerals, met, and biotite and quartz may have been formed later at the same boundaries where chemical or physical conditions rendered it easy of access.

At first the former explanation seems much more probable, almost the only one possible, but, at a closer scrutiny, facts are detected which speak more in in favour of the latter theory. Olivine is observed which is surrounded by continuous rims of the intergrowth in question, although no biotite is present. And, on the other side, biotite crystals exist which have no such rims. Flakes of biotite seem to intrude into the myrmekite-like intergrowth, in such a way as to postulate the supposition that the latter was of earlier date (fig. 11, plate II). The biotite also here includes portions of the vermicular hornblende.

In every case both phenomena in question seem to be, in many, although not in all cases, very nearly connected. As we will find in the following, also the formation of the common myrmekite of the acid rocks is very often connected with the formation of a myrmekite-like intergrowth of biotite and quartz.

In the latter case, however, the biotite seems to be still more decidedly of a later date than the myrmekite, having in part replaced its felspar. The myrmekite is there certainly synantetic between plagioclase and microcline, but the formation of a zone of myrmekite has been f o l l o w e d by that of a zone of biotite intergrown with quartz. As is well known, myrmekite is formed in most cases w i t h o u t any such close connection with the formation of biotite.

Although the formation of myrmekite-like structures, together with biotite, in basic rocks, and the formation of myrmekite and biotite, in acid rocks, show, when studied under the microscope, much analogy, they are chemically different, and it is also possible that the sequence of events has not been identical in both cases.

In another anorthositic rock, from Kousa in Mäntyharju, also studied by Frosterus,[1] intergrowths of plagioclase and a femic mineral occur which are somewhat different from those in the rock from Nurma. The plagioclase is more compact in the former case and has a diameter of 0.2—0.8 mm (fig. 2 in the text and fig. 12, plate II). It has a refraction index which is only slightly higher than that of the primary andesine (about 40 % An) of the rock which it has replaced, and is thus an andesine or labradorite. It contains small straight prisms of a femic mineral rather sparingly dispersed. It is a pale green, fibrous mineral which in transversal sections occasionally shows prismatic angles which are very similar to those of hornblende. These rods are almost parallel with each other, in some cases, however, slightly convergent.

These intergrowths of plagioclase and hornblende always lie at the boundary between the primary andesine and the femic minerals of the rock. Nothing of its original pyroxene, nor olivine, is preserved, but they are there changed to a fibrous green hornblende, together with some biotite and chlorite. This hornblende, which has replaced the larger pyroxene crystals, is in some cases

[1] l. c. p. 70.

directly continued by the rods included in the newly formed plagioclase.

Here the hornblende is not vermicular, and the plagioclase intergrown with it has more compact forms than elsewhere, but the phenomenon shows so much similarity to those described in the foregoing, that there is no doubt about their analogy.

The greatest interest of the last mentioned occurrences lies in the positive knowledge that these phenomena have originated by the contact action of a granite. Frosterus has given an account of the phenomena of the contact between the basic rocks in question and the rapakivi

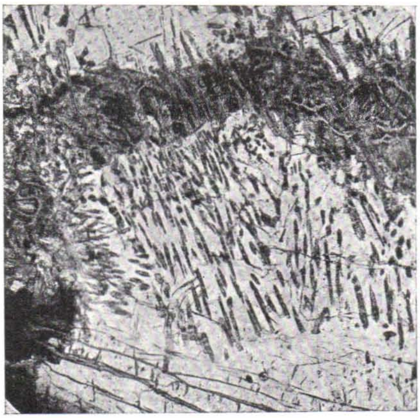

Fig. 2. Intergrowth of plagioclase and hornblende, replacing andesine, in an anorthosite from Konsa in Mäntyharju, S.W. of St Michel. Specimen taken by Benj. Frosterus, 1895. N:o 184. Ordinary light. × 40.

granite which leaves no doubt as to the fact, that the latter has caused a re-crystallization, and in part, a refusion of the earlier basic rock at, or, in the neighbourhood of the contact. The mineralogical changes are much of the same character as those of the fragments of older basic rocks included in the rapakivi, which have also been described by Frosterus in the same treatise and which disclose so much analogy to those described by Lacroix in his classical memoir on the inclusions of the volcanic rocks.

I have entertained doubts as to whether the myrmekite-like intergrowth of basic plagioclase and vermicular hornblende should be called myrmekite, or be designated by some other name. Structurally, the two phenomena are quite identical. Moreover, their origin also seems to be analogous, but chemically they are entirely different. As we may find, there are still a great variety of other, similar intergrowths of different minerals, and if we should call them all myrmekite, using that word only as a designation of structure, we ought to term the common myrmekite plagioclase-quartz myrmekite, or designate it by some other attributive, which will cause lengthiness. As the use of the word myrmekite for the intergrowths of plagioclase and vermicular quartz, i. e. an analogon of the primary felspar-quartz micropegmatite, is already traditional, it is preferable to use another designation for the structure. I should prefer to call all such intergrowths containing some mineral showing vermicular forms v e r m i c u l i t e s, but this name has already been used for a mineral. I therefore propose to use for these intergrowths of two minerals plaited together, and generally of secondary origin, the common designation s y m p l e k t i t e s (or symplectites) from *συμπλέκω*, plait together. Such symplektites wherein the mineral which determines the shape, shows finger-like projections, should, as already proposed, be called dactylites. Thus we have hitherto had to deal with plagioclase-hornblende- (perhaps also plagioclase-pyroxene-) symplektites, biotite-dactylite etc., besides which I will mention many other types in the following.

After having written the foregoing, I became aware that the word symplektic has already been used before by Naumann and Loewinson-Lessing.

In the Lexique pétrographique compiled by the latter author and edited in the Compte rendu of the VIII Geological Congress (Paris 1900), the term s y m p l e k t i s c h e S t r u k t u r Naumann, is defined in the following way: »Structure déterminée par l'entrelacement intime de deux masses minérales différentes, comme dans l'ophicalcite, le calcschiste, etc.» Again, the term s y m p l e k t i s c h e V e r w a c h s u n g e n, Loewinson-Lessing, is so defined:» Les assemblages symplektiques sont réalises par les structures pegmatiques, granophyriques, poecilitiques, d'implication (Loewinson-Lessing, Aciditäts-Coefficient, p. 131)».

The term symplektic has thus been used both for secondary and primary structures, although Loewinson-Lessing wishes to restrict the use to structures of the latter kind. But the employment of the term as designation for metamorphic structures is older. In any case there are already a number of good terms for the primary graphic structures, and I therefore take the liberty of proposing that the term symplektic, or symplektitic, should be used preferably as a designation of s e c o n d a r y intergrowths of two different minerals.

ON THE KELYPHYTIC ZONES AROUND GARNET IN GABBROS, ECLOGITES, SERPENTINES, LEPTYNITES, & C., AND RELATED STRUCTURES.

Besides the coronas around olivine which are among the most typical of all synantetic mineral structures, there are also analogous phenomena, often closely connected with them, which are due to a stronger metamorphism and do not show quite as regular an occurrence.

Also these may often occur as zones radiating from a certain core mineral. They have been described by various authors under the name of coronas. Their minerals frequently grade more imperceptibly with those of the surrounding rock, and the core mineral may, in itself, already be a crystalloblast.

Among these structures, whose metamorphic origin seems to me to be a fact beyond dispute, the most typical are the k e l y p h y t i c border-zones around garnets, but there are also other very analogous phenomena in different basic and ultrabasic rocks, as will be evident from the following quotations.

As I have myself not studied these structures, and will therefore not enter into any more detailed discussion of their mode of formation, I will herein only briefly resume the history of their petrological investigation, mainly using the valuable communications of Mrha and Hezner, which summarize much of the older literature. I shall, however, quote at greater length some additional descriptions which are not mentioned in these articles, and which may prove of considerable interest.

H. Müller[1] is the first who has described (1846) these peculiar shells of a green mineral surrounding garnet, from a serpentine at Greifendorf in Saxony.

Hochstetter[2] communicated in 1854 descriptions of a similar mineral from the serpentine of Krems near Budweis in the Bohemian Forest.

Schrauf[3] gave (1882) to this garnet, surrounded by a green shell, the name k e l y p h i t e and regarded it as a homogeneous mineral. He thought that the shell had originated as a contact product between pyrope and olivine.

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[1] H. Müller, Geognostische Skizze der Greifendorfer Serpentin-Partie. Jahrb. f. Min. 1846. p. 262. Quoted from Mrha.

[2] Hochstetter, Geognostische Studien aus dem Böhmerwalde. Jahrb. d. K. K. geol. Reichsanst. 1854, 5, p. 30.

[3] S. Schrauf, Beiträge zur Kenntnis des Associationskreises der Magnesiasilicate. Zeitschr. f. Krist., VI, 1882, p.

Becke[1] described in the same year a similar structure from a serpentine from Steinegg in the Forest region of Lower Austria. He discerned an inner mantle, 2—4 mm in thickness, which consisted of a radially arranged, light-coloured birefringent mineral together with a brown biotite, and an outer mantle which measured 0.5—1 mm in thickness and consisted of hornblende, bronzite and diallage.

Von Lasaulx[2] described also in the same year analogous coronas around garnet from serpentine from Greifendorf in Saxony, Col de Pertuis in the Vosges and Pargas in Finland, and compared them with garnet from a fragment of cordierite gneiss in volcanic bombs from the Laacher See. His conclusion was that the kelyphitic border-zones were of secondary origin.

Schrauf[3] defended in 1884 his former opinion regarding the pyrogene nature of the kelyphite.

J. Lehmann[4] has also described similar structures (1884) in his great and ingenious work on the leptynites of Saxony, a book which not only deserves to be called a classic, but also frequently to be re-read as such, by every student of crystalline schists, or Archæan geology.

He remarks that in the »pyroxene-granulites» the darker minerals often form what Becke calls »centra of growth», whereby the minerals show a regular succession on the whole. Garnet is in general, although not always, the oldest mineral, and pyroxene surrounds it, at times in the shape of wedge-like radiating prisms »as algæ around a weathering piece of stone» replacing the garnet more and more, sometimes completely (cf. Fig. 5, Table XXIV in his Atlas, showing this structure in a rock from Chemnitzgebirge near Mohrsdorf). Also amphibole and biotite form concentric zones around the garnet, replacing it gradually.

In the serpentines, he also studied the kelyphitic shells around pyroxene, especially those of garnet, e. g. in a serpentine from Zschöppichen near Mittweida (Fig. 6, Table XXII in his Atlas). The plagioclase also occurs as zones surrounding the garnet (Fig. 3, 5 and 6, Table XXIII of the Atlas).

Becke[5] showed in 1886 by exact methods of determination that picotite was present in the shell of the kelyphite. He thought that

[1] F. Becke, Gneissformation des niederösterr. Waldviertels. Tschermaks Min. u. Petr. Mitth. 1882. IV, p. 324.

[2] A. v. Lasaulx, Über die Umrindung von Granat etc. Verh. d. naturh. Ver. d. preuss. Rheinlande u. Westph. 1882. 39 Jahrg. Sitzungsber., p. 114.

[3] A. Schrauf, Ueber Kelyphit. Neues Jahrb. f. Min. etc. 1884, p. 21.

[4] J. Lehmann, Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine etc. Bonn, 1884, p. 231—233 & 275.

[5] F. Becke, Notizen aus dem niederösterr. Waldviertel. Ueber »Kelyphit» Schrauf, Tschermaks Min. u. Petr. Mitt. 1886, p. 253.

the reaction which had given rise to this mineral might have been the following:

$$\underset{\text{Pyrope}}{Mg_2\,Al_2\,Si_3\,O_{12}} + \underset{\text{Olivine}}{Mg_2\,Si\,O_4} = \underset{\text{Spinel}}{Al_2\,MgO_4} + \underset{\text{Amphibole}}{Mg_4\,Si_4\,O_{12}}$$

J. S. Diller has described (1886) an occurrence of pyrope surrounded by kelyphite in a peridotite of Elliot Co., Kentucky[1]. The garnet »occurs in the form of spherical or elliptical grains varying from one to more than a dozen millimeters in diameter. — — »The border is composed of several essentially different substances which are always present although varying much in proportions. — — — A dark powder of magnetite is frequently so abundant upon the outer edge of the border as to render it opaque. The inner substance of the ring is of a grayish or reddish brown color and generally fibrous in structure, perpendicular to the periphery of the garnet. The fibres have occasionally very strong absorption in the direction of the longer axis and have nearly a quite parallel extinction, indicating that the mineral is biotite. This conclusion is completely demonstrated by a border in part of which the uniaxial negative, strongly dichroic folia of biotite may be clearly discerned. The biotite extends far into the fissures of the garnet and evidently results from its alteration. Associated with it are small triangular and quadratic sections of a yellowish brown isotropic mineral, which in all probability is picotite — — So far as I am aware the presence of biotite in this connection is here noted for the first time.»

Camerlander described (1887) in his memoir on the granulites occurring at the eastern border of the Bohemian Forest »micropegmatitic» intergrowths of different minerals as augite and felspar, garnet and augite, hornblende and plagioclase. The augite which is intergrown with felspar occurs as vermicular, radiating rods. The same mineral also surrounds the garnet as kelyphitic rims. Hornblende also occurs as slender rods intergrown with the plagioclase. Sometimes augite, diallage, hornblende, plagioclase and quartz occur together.

Very peculiar aggregates showing a centric arrangement of the constituents occur also, according to Lacroix, (1889) in the highly metamorphic basic rocks of Salem in Massachusetts[2]:

[1] J. S. Diller, Notes on the Peridotite. of Elliot Country, Kentucky. Amer. Journ. Sci. 3 Ser. Vol. XXXII, 1886, p. 121.

Idem, Peridotite of Elliot county, Kentucky. Bull. U. S. Geol. Survey N:o 38, 1887, p. 15—17, and Idem, Ibid. N:o 150, p. 292—294. In these writings he gives a more detailed description of the same occurence.

[2] G. v. Camerlander, Zur Geologie des Granulitgebietes von Prachatitz am Ostrande des Bömerwaldes. Jahrb. der K. K. Geolog. Reichsanstalt, Bd. XXXVII, 1887, p. 131—137.

»4:o Le quatrième type est caractérisé par l'amphibole c); il se rapproche des gneiss amphiboliques communs en Auvergne, formés d'amphibole et d'oligoclase. Tantôt les éléments ont à peu près la même dimension et la roche est massive; tantôt, au contraire, l'amphibole en grands cristaux allongés suivant la zône $h^1 g^1$ (100) (010) est orientée et détermine la schistosité de la roche. La plus grande variété existe dans les proportions relatives de ces deux minéraux auxquels s'adjoignent souvent le quartz comme élement essentiel et le sphène comme accessoire.

Le grenat n'est pas distribué uniformément dans la roche: il se concentre en cristaux atteignant la grosseur du poing entourés par une couche d'environ 1 centimètre d'amphibole verte peu adhérente à la roche qui la renferme: aussi, il est facile d'en détacher le grenat et son enveloppe qui ressemble alors à un fruit.

L'amphibole de cette couronne semble plus claire que celle de la roche: cette apparence est due à la présence d'éléments blancs. Des segments parallèles à la fibrosité apparente de l'enveloppe, montrent en effet qu'elle est composée de secteurs d'amphibole allongés suivant la zône $h^1 g^1$ (100) (010) et dont l'axe vertical est normal à la surface du grenat. Ces cristaux d'amphibole sont creusés de cavités. Ils représentent une sorte de dentelle que viennent remplir oligoclase et quartz (fig. 57).

Il y a dans ce cas un phénomène analogue à celui qui a été signalé dans le type 3, mais beaucoup plus régulier. Lorsqu'on fait tourner la préparation entre les nicols croisés, on voit successivement s'éclairer et s'éteindre les divers secteurs. La cristallisation des plages d'amphibole diversement orientées dans ces secteurs s'est opérée simultanément, car on voit souvent une même plage feldspathique associée en groupement pegmatoïde avec éléments amphiboliques différentes».

In the pyroxene leptynite of Ceylon Lacroix also has observed similar micro-structures.[2]

»*Leptynite à pyroxène.*

A trois milles environ au nord de Colombo, sur les falaises bordant la mer, se trouve une variété de la roche précédente qui, par l'introduction du pyroxène vert fortement polychroïque, passe au premier des gneiss à pyroxène qui seront décrits plus loin. — —

Le *pyroxène* appartient à la variété très ferrugineuse et poly-

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[1] l. c. p. 319—320.

[2] l. c. p. 296—298.

chroïque qui sera décrite quelques pages plus loin; cependant il est ici d'une biréfringence plus faible, ses cristaux sont très souvent brisés, et dans les fissures se développe, à la manière du chrysotile dans le péridot, un minéral jaune verdâtre polychroïque avec maximum d'absorption dans les teintes jaunes suivant n_g, parallèle à l'allongement.

L'extension est longitudinale: $n_g - n_p = 0{,}025$ environ.

Parfois le pyroxène est complètement transformé en cette substance au milieu de laquelle se développent de très fines vermiculisations de quartz dessinant une élégante micropegmatite, analogue à celle qui s'observe également dans quelques feldspaths de la roche (fig. 47).»

In the article on the gabbros of the south-western Adirondacks already quoted Smyth described (1894) a very peculiar form of hypersthene occurring in the hornblende gneiss associated with the gabbro which occurs on the north shore of Metcalf Lake and contains garnet abundantly in masses of various size[1].

»The most conspicuous feature of the rock is its structure, due to the peculiar form of the hypersthene and hornblende. These two minerals, though often in irregular masses, show a decided tendency to extend in radiating tongues, with a length often ten or twelve times their breadth. These tongues may start from any portion of the section, but commonly radiate from a mass of pyroxene or more particularly from garnet when it is present, thus giving rise to the radiating bands seen around this mineral in hand specimens. The tongues are usually curved and when developed from several centers give a remarkably beautiful effect under the microscope, impossible to describe or to figure with accuracy — —. This structure is analogous in every respect to that described in the gneissoid gabbro, differing from it only in being on a larger scale, with all of the constituents coarser, and in the presence of tongues of hornblende as well as of hypersthene. The analogy is rendered even more complete by the fact, not previously stated, that in the sections of gneissoid gabbro which contain grains of garnet the latter are partially surrounded by radiating tongues like those around the garnet of the gneiss, but often so slender as to make difficult an accurate determination of the mineral composing them.»

In his important article on the origin and growth of garnets and of their micropegmatitic intergrowths in pyroxenic rocks, Holland (1896) gave the following[2]

[1] l. c. p. 60.

[2] Thomas H. Holland, On the Origin and Growth of Garnets and of their Micropegmatitic Intergrowths. Rec. Geol. Survey of India. Vol. XXIX, 1896, p. 29.

›Summary of Conclusions.

32. The garnets occurring so abundantly in the pyroxenic rocks of India frequently exhibit fibrous reaction-borders generally composed of felspar, actinolite and somtimes magnetite, and display a radiate arrangement of the fibres similar to the structure characteristic of Schrauf's kelyphite.

33. The reaction-border occurs only between the garnet and a ferromagnesian silicate, never between garnet and felspar or quartz (para. 13).

34. The ferromagnesian silicate nearest the garnet is generally green actinolite which can be traced out in some cases (Manbhúm, Parasnath) to augite, and is evidently derived from the latter mineral by the ordinary process of amphibolitization (para. 14).

35. The augite undergoing the paramorphic change into hornblende is darkened by the minute regularly-arranged inclusions which characterize diallage and present the ordinary phenomena of schillerization. The passage into hornblende is accompanied by the absorption of these dark ferruginous inclusions and clear green actinolite is the result (para. 15).

36. Where the rock is composed almost entirely of pyroxene changing to hornblende, the garnets develope with a regular crystalline outline, and several crystals developing in close proximity often exhibit crystallographic parallelism to one another. Where felspar and quartz occur in quantity as primary constituents, the garnet exhibits no crystal-outline, but is moulded on the white minerals, and the line of contact in such cases never shows a reaction-border (para. 16).

37. The garnets are frequently found bellying out opposite the pyroxenes, whilst felspar and quartz occupy the bays and inlets. A continuation of the growth of the garnet results in the gradual enclosure of such felspar and quartz crystals and their consequent appearance in section as isolated masses (para. 30).

38. The alteration of the original schillerized pyroxene is, therefore, not a simple paramorphic change, but is a decomposition which results in the simultaneous formation of a more basic mineral, garnet, and a more acid one, felspar.

39. The simultaneous development of these two minerals results in their micropegmatitic intergrowth. In the case of the felspar the similarity of optical orientation of isolated portions proves their crystallographic parallelism. In the case of the intergrown garnet the occurrence of numerous small crystals developing around a larger central one exhibiting parallelism of crystal-outline with

the larger central garnet and with one another, results in the ultimate formation of one large crystal of garnet, in which both original felspar and quartz, as well as the secondary felspar formed during the destruction of the pyroxene, become entangled to produce a micropegmatitic structure (paras. 29 and 31).

40. The micropegmatitic structure is thus considered to be of secondary origin as has recently been shown to be true for similar cases of the more common intergrowth of quartz and felspar.

41. The development of felspar as a by-product during the formation of garnet from pyroxene explains the more frequent record of micropegmatitic intergrowths of garnet with felspar than with any other mineral.

42. The reaction border occurring around garnets may therefore represent a stage in the *development* of garnet from the products of the molecular disintegration of original ferromagnesian silicates, and does not always indicate the *destruction* of garnet as has generally been considered to be the case with kelyphite borders.

43. The evidence offered by the microscopic characters briefly indicated in the previous paragraphs is corroborated by the field relations of the pyroxenic and garnetiferous rocks. Compact pyroxenic rocks, with a perfect granitic structure, become friable and imperfectly foliated near their margins, where the pyroxene disappears, garnet, in about the same proportions, takes its place, and the rock becomes granulitic in structure (para. 19).»

Holland[1] also has described, (1900) in his interesting treatise on the rocks of the Charnockite Series of India, coronas of garnet and quartz around the hypersthene in a biotite-augite norite from Nagaramalai near Salem:

›The garnets are often very irregular in their shape and spongy in structure on account of the inclusion of numerous vermiform or otherwise-shaped pieces of white mineral (quartz or felspar) which I regard as the acid byeproduct separated during the break-up of the pyroxene to produce garnet. Sometimes the garnets form a sort of corona to the hypersthenes, and all stages are found from a narrow ring around the pyroxene to a complete broad ring of garnet surrounding a core of granular quartz (Plate VII, fig. 6).»

Mrha[2] published, in 1900, a very elaborate treatise on the kelyphite, in which he arrives at the following conclusions:

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[1] Thomas H. Holland, The Charnockite Series, a group of Archæan Hypersthenic Rocks in Peninsular India. Mem. Geol. Surv. of. India. Vol. XXVIII. Part. 2, 1900, p. 161.

[2] J. Mrha, Beiträge zur Kenntnis des Kelyphit. Tschermaks Min. u. Petr. Mitth. 19. 1900, p. 111.

»Fasst man die Resultate dar optischen Untersuchungen zusammen, so ergibt sich, dass die Kelyphitrinde aus vier Mineralen zusammengesetzt ist:

Aus eisenarmem Bronzit oder Enstatit, monoklinem Pyroxen, Picotit und Hornblende. In den einzelnen Vorkommen tritt entweder die Hornblende gegen den Bronzit oder dieser gegen die Hornblende in den Hintergrund, so dass das eine oder das andere dieser beiden Minerale auch fehlen kann. Monokliner Pyroxen und Picotit sind, wenn auch in wechselnder Menge, stets vorhanden.»

A number of chemical analyses gave the composition of these minerals, and another shows, that if the kelyphytic zone has originated by a change of 2 molecules of pyrope and 1 mol. of olivine to 4 mol. pyroxene and 1 mol. spinel, then the molecular volume has been increased from 275 to 312.7. He concludes with the remark:

»Es findet also eine bedeutende Vergrösserung der Molecularvolumen von 275 auf 312 auf. 312.7 also um 37.7 statt.

Die Bildung der Kelyphitrinde gehört somit nicht unter jene Umwandlungen, die sich unter Raumersparnis vollziehen und durch Dymainometamorphose begünstigt werden, sondern unter jene, bei denen eine Volumsvermehrung einritt. Der Granat ist als Erstarrungsprodukt flüssiger Magmen unter Atmosphärendruck nicht bekannt. Zu seiner Bildung ist daher, wie auch aus der Unmöglichkeit, ihn aus seiner Schmelze krystallisirt zu erhalten, hervorgeht, bedeutender Druck erforderlich. Der bei diesem Drucke vorhandene Gleichgewichtszustand zwischen Pyrop und Olivin wurde jedoch gestört, als das Olivinmagma, das die Pyrope enthielt, unter geringern Druck gelangte. Das Resultat dieser Störung war die Ausbildung einer Contactzone von Mineralen mit grösserem Molecularvolumen».

Holland gives in his paper upon the geology of the neighbourhood of Salem (1901) nearer information about the occurrence of the rocks described by Lacroix which had been collected by Leschenault de la Tour in the year 1819. Holland also described several interesting garnetiferous basic rocks, e. g. that which occurs at Nagaralami about which he says:[1]

»In the garnetiferous varieties the garnets sometimes attain the size of a fist, and are often surrounded by large crystals of hornblende and augite, forming patches in the rock having the composition of hornblende-eclogites. Under the microscope the garnets show a very spongy structure through inclusion of blebs and gran-

[1] Thomas H. Holland, Geology of the Neighbourhood of Salem, Madras Presidency. Mem. Geol. Survey of India, XXX, p. 125—126.

ules of a colourless mineral resembling quartz. Frequently the garnets are seen to be grown, coronal fashion, around the hypersthenes; in such cases vermiform cavities are arranged radially, whilst near the hypersthene the garnet is particularly spongy (fig. 2). In some sections the garnets form complete rings surrounding a perfectly granulitic fine-grained mass of quartz (fig. 3).

The disposition of these garnet crowns around the hypersthenes, and the peculiar structure they exhibit, suggest their secondary formation at the expense of the ferromagnesian silicate; in this case the colourless quartz would represent the supplementary silica relieved by the formation of the less siliceous garnet from pyroxene.

Some pyroxeneic rocks in Bengal described elsewhere show a similar formation of spongy garnet with concomitant separation of quartz; but in the Bengal rocks the formation of the garnet is preceded by amphibolitization of the pyroxene, and the details of the change can be more perfectly traced than in these Salem rocks.»

Laura Hezner[1] also discussed (1903) the question of the origin of the kelyphite, in her interesting work on eclogites and amphibolites which also contains a very complete list of the earlier literature about kelyphite and eclogite. As to its genesis she arrived at the following conclusions:

»Dafür also dass sich der Kelyphitring auf Kosten des Granats entwickelt, sprechen folgende Beobachtungen:

1. Im allgemeinen wächst die Hülle proportional dem Kleinerwerden des Granatkerns.

2. An vielen Stellen frisst sich das Leistenaggregat in tiefen Einbuchtungen in den Granat hinein.

3. Bei rissigen Granaten liegen nur mehr kleine Reste des Minerals in dem von der äusseren Hülle und den innern Spaltenausfüllungen gebildeten Hornblende-Plagioklas-Magnetitkomplex.

4. Es existieren Übergänge von jenen ganz kompakten Hornblende-ringen der Eklogitamphibolite, die wie wir sahen, sich oft bis zur vollkommenen Verdrängung des Granats verbreiten, zu der radialstengeligen Hüllenform.

Doch handelt es sich auch hier wohl nicht um einfache Pseudomorphose. Wir haben schon bei den Eklogitamphiboliten gesehen, dass bei vollständig oder fast vollständig verdrängtem Granat nur die äussersten Zone reine Hornblende ist, dass sich innerhalb dieser Zone immer noch andere Mineralien, besonders Feldspat und Epidot

[1] L. Hezner, Ein Beitrag zu Kenntnis der Eklogite und Amphibolite etc. Inaug.-Diss. Sep.-Abdr. aus Tschermaks Min. u. Petr. Mitt. XXII, 1903, p. 68—69.

der Pseudomorphose beimengen und haben aus der Form der Hülle geschlossen, dass besonders unter Mitwirkung der anliegenden Substanzen zustande kommt, also »reaktionrim» sei. Wahrscheinlich ist das innere Gemisch vielmehr dem Granat allein zuzuschreiben; fremde Substanzen können schwerer in die Mitte eindringen. Bei den Kelyphiten nun in vollkommenster Entwicklung geht das gleiche zentrisch angeordnete Mineralaggregat bis zum innersten Granatkorn; aber es setzt sich im wesentlichen aus denselben Substanzen zusammen, welche auch die Grundmasse bilden. Die Stoffmischung scheint in diesem Gesteinstypus eine viel weitergehende zu sein, die Umkrystallisation eine vollendetere. In dem Zwischending zwischen Pseudomorphose und Perimorphose mag sich die Wagschale öfter zu Gunsten der letzteren neigen. Wo die Formen sich mehr der kompakten Hülle nähern, finden sich denn auch, wie bei den Pseudomorphosen der Eklogitamphibolite, fremde Mineralien hauptsächlich nach innen den Kelyphitsubstanzen beigemengt.

Aber rein zentrische Strukturformen sind die Kelyphitkränze, weningstens in den Ötztaler Amphiboliten nicht. Sie können darum auch nicht als Erstlinge der Krystallisation gelten, sondern sie sind wahrscheinlich mit den diablastischen Strukturen auf eine Stufe zu stellen: »Umkrystallisation von Mineralien im eingeengten Raum», durch veränderte Existenzbedingungen und Verschiebung ihrer Gleichgewichtslage. Damit stimmt schön die Beobachtung überein, dass echter Kelyphit nur in Amphiboliten mit mikrodiablastischer Struktur vorkommt».

Dr. Hezner also communicates very good photographs of these structures (Fig. 5 and 6, plate IV in her book), the latter of which has been re-published by Grubenmann in his important work on the crystalline schists (fig. 1, plate I; cf. also fig. 3, plate 3 which gives another microphotograph of the kelyphite) as a type of the microdiablastic structure. I reprint here the first-mentioned photograph (fig. 3).

Weber discusses in a paper on the metamorphic inclusions of the magmatic rocks (1910) the origin of the kelyphitic and similar structures. He thinks that it is a magmatic crystallization, whereby assimilated older rocks have taken part in the composition of the magma and also the picotite of the core as well is to be regarded as a »foreign» material. He also mentions from a granulite or leptynite of the Bohemian Forest an occurrence of cordierite, which forms with quartz myrmekite-like intergrowths and is usually associated with garnet.

[1]) M. Weber, Metamorphe Fremdlinge in Erstarrungsgesteinen. Sitzungsber. der K. Bayer. Ak. der Wiss. Math.-phys. Klasse, 1910, 13 Abh., p. 23 and 13.

Fermor regards the garnet as the typical mineral of »infra-plutonic» rocks formed at an extremely high pressure. He thinks that this mineral is broken down, with increase of volume, into less dense minerals such as pyroxene and olivine, when the »infra-plutonic» rocks pass upwards during the progress of the erosion [1]. »Under certain special circumstances however, particularly if a slow reduction in pressure is accompanied by a more rapid reduction of temperature, due to the lowering of the isogeotherms in a given part of the earth's crust, we may expect the eclogites finally to

Fig. 3. Kelyphitic structure in a garnetiferous amphibolite from Aschbach, Oetztal, Tyrol. Ordinary light. ×24. From Dr. Hezner's memoir.

arrive at the surface; although even then, there may often be a partial breaking up of the garnet with the production of the well-known *kelyphite* rims or *reaction borders* of garnetiferous peridotites».

Many of the last mentioned examples of kelyphitic and related structures concern cases where the secondary minerals are not synantetic in the strictest sense, inasmuch as they are not restricted to the boundaries of certain minerals. No doubt, however, they are also here metamorphic and, as has been remarked by several of the authors quoted, to a certain extent reaction products between the mineral forming the core, and the surrounding minerals. But the zone of secondary minerals here fades away among the neighbouring minerals which it has replaced and from several of which it has probably also obtained material.

[1] L. L. Fermor, Preliminary Note on the Origin of Meteorites. Journ. and Proc. Asiatic Soc. of Bengal. New Series. Vol. VIII. N:o 9, 1912, p. 316—317.

Also these cases, however, show much analogy to the typical synantetic minerals, and we find gradations between both kinds of structures. Some of the structures which have been here referred to the coronas, may as well be regarded as kelyphites, and have been called so by the authors who have described them By studying these fascinating phenomena, we may hope to find a clue to some of the most difficult of the remaining problems concerning the origin of the crystalline schists. Especially the origin of the leptynitic rocks may be elucidated by comparative studies of the synantetic minerals proper, and the kelyphite, &c. No doubt most of the basic leptynites are rocks which have originally been gabbros, diabases and the like, and which have undergone a metamorphism of the same kind which we find in its incipient stage in the rocks with coronas around the olivine. But the more intimate details of this process are still very little known and may therefore be elucidated by such studies.

It is very difficult to decide, why in some cases the metamorphism of basic eruptive rocks has led to the formation of »leptynites» rich in garnet, while others have been simply uralitized. In Fenno-Scandia uralitized »metabasites» are by far more common than garnetiferous. It is especially in certain zones where the basic eruptives, as well as also other rocks, both acid eruptives and sediments, have been mixed in a large measure with aplitic and pegmatitic veins, that we find rocks rich in garnet. This is especially the case in a zone stretching from Lake Enare in Lapland to Kantalaks at the White Sea. Here obviously, a very lively exchange of material between the salic and femic constituents of the migmatitic rocks has happened. This interchange has probably, in many cases, been mediated by waters, or gases, percolating the rocks at the time when at least part of the same were already solidified. The garnet seems often to have been formed towards the end of crystallization processes, either during the waning phases of the solidification of a magma or during a later period of metamorphism, and is very often, if not always, a crystalloblastic mineral which has replaced constituents of earlier date.

The formation of garnet, however, may also be favoured by other circumstances, as e. g. the occurrence of calcite in the rock, before its metamorphism set in. Therefore we find garnet in such basic rocks as have undergone weathering at a date before their metamorphism.[1] It seems probable that basic rocks with a green-

[1] Cf. J. J. Sederholm, De bottniska skiffrarnas undre kontakter. Geol. För. i Stockholm Förh. Bd. 37, 1915, p. 66.

stone character are more apt to become changed into garnetiferous rocks than such fresh rocks as are common in the great northern Archæan territories. In other instances, the existence of rocks rich in salic constituents, in the neighbourhood of the basic rockmasses, may favour the formation of the garnet. Observations of Törnebohm and others seem to point in this direction.

In most cases, however, the formation of garnet in basic rocks is probably dependent of the character of the metamorphism.

In India, as well as in Lapland, richness in garnet seems to be a characteristical feature for many different rocks, partly eruptive, partly sedimentary. This seems to prove that they have all together undergone a metamorphism of the same character, whereby garnet has been formed in great quantities.

In many cases the formation of garnet seems to indicate a metamorphism of stronger degree than the uralitization, i. e. have taken place at a higher pressure. But we also find basic rocks which have undergone the latter process in immediate contact with great granitic masses where, obviously, both pressure and temperature have been very high at the time of the metamorphism. In the eruptive breccias occurring in the Pellinge region near Borgå in southern Finland, and consisting of old Archæan uraliteporphyrites and granites, of different ages, garnets are almost nowhere visible. As results from the observations on the metamorphism of basic rocks quoted above, the formation of garnet and hornblende may alternate in the same rock. It is hardly possible to think that temperature and pressure have changed every time when this has happened. These alternations in the character of the metamorphic minerals formed, are sooner, in such cases, due to variations in the chemical conditions which may have taken place many times during the same period of metamorphism.

PART II. SYNANTETIC MINERALS, OR SYMPLEKTITES, IN ROCKS CONTAINING CALCITE.

SYMPLEKTITES OF DOLOMITE AND CALCITE, AND OF CHONDRODITE AND CALCITE.

Lacroix has observed vermicular calcite in the impure crystalline limestones (cipolins) of Ceylon forming symplektites with dolomite, and also intergrowths of chondrodite and calcite. He describes them in the following words[1]:

[1] l. c. p. 337—338 and 342—343.

»La *calcite* ne joue qu'un rôle secondaire dans la roche; elle ne sert pas de ciment à la *dolomie.*

Elle se trouve dans cette dernière sous forme de grains arrondis, de lames ou de grandes plages dentélées à formes pittoresques ou bien encore en petites palmes constituées d'éléments très fins et affectant toutes les formes que l'on trouve dans le quartz de corrosion au milieu des feldspaths. —

Il semble que la calcite soit ici un produit secondaire formé après consolidation définitive de la roche. Cette hypothèse est confirmée par ce fait signalé plus loin de la cristallisation de la calcite au milieu ou à la place de la chondrodite altérée. — —

Rarement transformée d'une façon complète, la chondrodite présente cependant des altérations nombreuses et intéressantes. Elle est souvent brisée et dans chacune de ses fentes se produit un mince filonnet de chrysotile qui parfois entoure entièrement le cristal et le sépare de la calcite qui l'enveloppe; plus fréquemment sur le pourtour du cristal se trouve une zone d'environ 1/10 de millimètre dans laquelle la chondrodite est réduite en fins débris restant orientés comme le cristal dont ils proviennent, mais cimentés par de la calcite; souvent cette dernière se trouve en particules extrêmement fines.

Dans quelques cas, entre cette zone en voie d'altération et la dolomie en grandes lames, se trouve un manchon de granules de calcite, accolées tangentiellement au cristal de chondrodite, de telle sorte que leur axe principal est normal à la surface des grains cristallins qu'ils entourent.»

SYMPLEKTITE OF EPIDOTE AND QUARTZ.

In the year 1914 P. Eskola found a rock in the Baikal region of Siberia which consists mainly of allotriomorphic grains of microcline, with some plagioclase, quartz, deep-green hornblende, epidote and calcite. The epidote especially occurs at the limits between calcite and microcline and has its crystal surfaces turned against the latter. It contains vermicular quartz (fig. 13, plate III) sometimes also small grains of hornblende. We have thus to deal with a symplektite of epidote and quartz which seems to be synantetic between calcite and microcline.

A CORONA-LIKE RIM OF ZOISITE AROUND HORNBLENDE.

In a quartzdioritic rock from Iknonvaara in Pielisjärvi in Finland, Wilkman has observed phenomena which show some similarity to those described by Eskola. Between the plagioclases of the rock lies a felt of minute hornblende threads which has probably replaced pyroxene. Around those portions, at their limits against the plagioclase, projections of minute crystals of zoisite appear, forming a rim of uneven contours (fig. 14, plate III). Very possibly calcite has been earlier present in the hornblende felt.

SYMPLEKTITE OF SCAPOLITE AND QUARTZ.

Laitakari mentions in his description of the calcitic gneiss from Kirmonniemi on Ovensor in Korpo in south-western Finland the occurrence of plagioclase which, in this rock forms myrmekite with the quartz[1]. A thin section of that rock which he has kindly lent me shows, however, an intergrowth of *scapolite* with *vermicular quartz* (fig. 15, plate III). The mineral is colourless and displays in places where the quartz-worms are wanting, two cleavages nearly at 90 degrees. Its refraction indices are somewhat higher than those of quartz. Its birefringence is high and hence it has, between crossed nicols, lively yellowish and reddish colours. One section, seen in convergent light, distinctly showed the cross of the monoaxial crystals.

The intergrowth has also a character which is rather different from the common myrmekite, the quartz worms being coarser and more irregularly bent than in the former structure.

On one side of the structure in question there are, in several cases, small grains of calcite, while the intergrowth also often borders on microcline. Its occurrence is not that of the typical synantetic minerals, but it is not improbable that it may possess a similar origin.

Sustschinsky has observed, in a thin section of a specimen from the well-known scapolite occurrence of Laurinkari, S.W. of Åbo, a myrmekite-like intergrowth of scapolite and vermicular orthoclase[2]. His figure shows very much similarity to the intergrowth of scapolite and quartz observed by me. In every case, the occurrence of othoclase is not probable, because the potash felspar, in Finnish rocks of that age, is always microcline. And if that mineral should occur, the twinning lamellation ought to be visible somewhere.

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[1] Aarne Laitakari, Le gisement de calcaire cristalline de Kirmonniemi à Korpo en Finlande. Bull. Comm. géol. de Finlande N:o 46, 1916, p. 19.

[2] П. П. Сущинскій, Матеріалы по изученію контактовъ глубинныхъ породъ съ извѣстняками въ юго-западной Финляндій. Trav. Soc. Imp. Natur. de St. Pétersbourg. Vol. XXXVI. livr. 15, Sect. de Géol. et de Min. 1911, p. 136 (fig. 4) and 418.

Sustschinsky has also observed a very interesting myrmekite-like intergrowth of bytownite and vermicular pyroxene, occurring at the contact of crystalline limestone and granite at Frugård N. of Helsingfors.[1]

In general, lively reactions between the different minerals have certainly been common in impure limestones. To the examples which we have given here, a great many others will certainly be added when the attention has been drawn to these structures.

PART III. SYNANTETIC MINERALS OF ERUPTIVE ROCKS CONTAINING POTASH FELSPAR.

While the synantetic minerals of the basic rocks originate mainly where femic and salic minerals meet, the corresponding structures of granites and similar rocks are formed especially at the boundaries of plagioclase and potash felspar. This is especially the case with the typical myrmekite. There are also some very analogous phenomena in other rocks, containing potash felspar which seem as well to be due to the reaction between constituents containing lime-soda- and such containing potash-alumo-silicates. But also in granitic and similar rocks, synantetic minerals may originate at the boundaries of femic and salic minerals, like the corresponding structures of basic rocks. Also here, biotite may be formed synantetically between ore and felspar, and the formation of a primary biotite crystal be continued by the growth of crystalloblastic biotite within the borders of the adjacent felspar. The formation of this biotite, which is often intergrown with quartz in the same way as the plagioclase of the myrmekite, often occurs in such close connection with that structure, as to make it advisable here to treat both together.

I will here begin by giving an abstract of the former literature, reprinting especially such communications which are less easy of access. Some of the most important communications can only be resumed or quoted in the abstract because of their greater extension. The last mentioned communications, however, embrace such that are accessible everywhere and ought frequently to be consulted by every student of microscopical petrology who devotes any attention to these matters.

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[1] l. c. p. 124, 416, 434, 440 and fig. 6. plate VII.

Abstract of the Literature Concerning Myrmekite and Related Structures, as well as Biotite-Quartz-Symplektite, of Granitic and Monzonitic Rocks.

Michel Lévy has communicated the first description of the intergrowth of quartz and felspar which I have later called myrmekite. He gave to the worm-like quartz occurring in this association the name q u a r t z v e r m i c u l é.

Already in his treatise »Structure microscopique des roches acides anciennes» he communicated (1874) a figure of the »Granite porphyroïde de Vire» which showed this phenomenon. He described it in the following words: [1]

»Les débris de feldspath ancien, noyés dans l'orthose récent, sont souvent corrodés et infiltrés sur leur bords, et aux Nicols croisées, ces infiltrations, comme guillochées présentent des jeux de coloration très caractéristiques».

In the description of the figure he says: [2]

»Quelques cristaux en débris présentent des corrosions et des infiltrations vermiculées, à l'aspect caractéristique».

In the following year Michel Lévy gave another more detailed description of the same phenomenon, from which is evident, that he regarded the felspar as orthoclase and thought that the quartz had been infiltrated in cavities formed by corrosion: [3] »Le feldspath récent des granites a souvent exercé une action corrosive des plus remarquables sur les débris feldspathiques qu'il englobe. Ces derniers sont par place arrondis, mamelonnés et pénétrés à son contact par de petites infiltrations vermiculées qui leur forment bordure. Bien qu'elles rappellent par leur aspect géneral les formes des micropegmatites, on les en distingue facilement; car ces infiltrations sont composées de canaux sinueux et irréguliers.

La substance, qui les remplit, est orientée suivant quelques directions cristallines principales; c'est du quartz et il est naturel de supposer qu'il est en relation avec la nature souvent siliceuse des feldspaths récents».

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[1] A. Michel Lévy, Structure microscopique des roches acides anciennes. Granite porphyroïde de Vire. Bull. Soc. Géol. de France. Tome III, 1874, p. 201. Quoted by Becke. The original was not accessible to me at the time of the printing of this treatise.

[2] l. c. p. 222. Cf. Tab. IV, Fig. 1.

[3] Annales des Mines, VIII, P. 396, quoted in Michel Lévy, Contribution à l'étude du granite de Flamanville. Bull. Carte géol. de France. N:o 36, p. 27.

In the same year (1875) Fouqué and Michel Lévy gave another description of the same intergrowth with an almost identical interpretation: [1]

›*Quartz de corrosion.* — Le quartz de seconde consolidation injecte fréquemment les minéraux plus anciens: ainsi dans le granite et dans la granulite, les feldspaths de première consolidation sont souvent pénétrés par les injections siliceuses qui affectent des formes hiéroglyphiques à contours courbés ou des apparences vermiculaires. Ces figures rappellent grossièrement celles des pegmatites graphiques; mais on voit immédiatement que les quartz ne s'est pas consolidé simultanément avec le minéral qu'il a corrodé; les formes sont arrondies et relativement irrégulières; parfois elles s'englobent les unes les autres, comme si la corrosion s'était produite en plusieurs temps›.

The photograph, however, which they give on Planche XI, Fig. 2, of an ›orthose imprégné de quartz de corrosion› is no doubt, in this case, of the same character as the typical micropegmatite. In his pamphlet on the granite of Flamanville Michel Lévy gave another figure of the ›orthose a structure vermiculée›, which shows a very typical myrmekite, and mentions it in the following words: [2]

»On trouve des plages vermiculées dans tous les granites; mais dans les bordures de contact, sur quelques dixièmes de millimètres d'épaisseur, elles se multiplient et les orthoses récents paraissent s'être résolus en assez petits grains tous vermiculés: c'est ici une façon de consolidation simultanée du quartz et du feldspath et un mode de structure pour les roches acides. La photographie XII, fig. 22, des Annales des Mines (minéral n:o 95) montre, avec assez d'évidence, que si la parenté avec la micropegmatite est patente, il n'est pas possible d'identifier ces deux structures et je propose définitivement pour la première le nom de *structure vermiculée;* l'étude du granite de Flamanville montre qu'elle possède une réelle importance et sa définition peut être donnée en quelques mots: *association de feldspath (genéralement orthose) et de quartz en petits canaux sinueux et irréguliers développés au bord de chaque plage feldspathique et affectant géneralement une direction grossièrement radiale*›.

The same conception concerning the origin of the *quartz vermiculé* was prevalent among French petrologists for a long time.

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[1] F. Fouqué et Michel Lévy, Minéralogie micrographique, Roches éruptives françaises. Mém. Carte géol. de la France. 1879, p. 193.

[2] l c. p. 27.

R. D. Irving described (1883), in his work on the copper-bearing rocks of Lake Superior, [1] intergrowths of felspar and quartz which he regarded as secondary. They occur in the augite-syenites and the associated acid rocks which he calls granitells. The secondary quartz occurs in the felspar, »either in rows of club-shaped» or »graphic» particles, which often follow the »cleavage direction of the crystals, or in very fine lines radiating in fan-shape from a central line».

The »quartz saturation» has been found affecting the other borders of the plagioclases, but not their cores which seems to prove »that the replacing process has gone on from without, inwards».

Although this description reminds one of many of the descriptions of myrmekitic intergrowths, it seems evident from the figures of Irving that the phenomena which he has observed are not of the same character. It is even very dubious if they are secondary at all, since some of them greatly resemble primary micropegmatite.

Romberg described and figured in his petrographical researches upon granites from Argentina (1892) intergrowths of felspar and quartz of different kinds which he regarded as secondary, probably formed in connection with secular weathering. Some of these entirely resemble micropegmatite of primary origin, but there is also a photograph (Fig. 17, Plate IX) of an intergrowth which is certainly myrmekite. He describes it in the following words[2]:

»Wir sehen am Rande grösserer Durchschnitte von Kalifeldspath Anhäufungen eines Gemischs von Quarz mit einer Feldspathsubstanz, die keine Zwillingslamellirung erkennen lässt. Es ist ein Adernetz feiner, wurmförmig gekrümmter Canäle vorhanden, die sich werzweigen, auch vielfach durch Unterbrechungen ihres Laufs zu einer Reihe winziger Tropfen aufgelöst erscheinen. Diese Gebilde setzen über die Grenzen des Feldspaths fort oder erscheinen als schmale, wellenförmig begrenzte Ränder desselben, sodass die Innenseite, entsprechend der Kante des Feldspaths, oft geradlinig verläuft. Zu grösseren, rundlichen Massen vereinigt, greifen solche zungen- oder buchtenförmig in das Innere der Krystalle ein (Fig. 15, 17)».

Rombergs ideas were disputed by Becke (1892) who had studied, with his usual extreme exactness, similar intergrowths of plagioclase and quartz occurring in the tonalite of Rieserferner in

[1] R. D. Irving, The Copper-bearing Rocks of Lake Superior. U. S. Geol. Surv. Monogr. Vol. V, 1883, p. 112—115.

[2] J. Romberg, Petrographische Untersuchungen an argentinischen Graniten. N. Jahrb. für Min. etc. VIII, 1892, p. 314.

Austria. He called them micropegmatite and regarded them as primary constituents. Important was the statement, that these intergrowths generally began from a core of plagioclase containing no quartz, and that they always occurred at the margin of the microcline crystal and were turned with their point inwards, »as if the aggregates had in a certain way eaten their way into the microcline». The description of Becke reads as follows: [1]

»Diese Verwachsungen treten stets am Rande oder in der Nähe des Randes in den Mikroklinkörnern auf; dort, wo sie mit dem Rand des Durchschnittes in Verbindung stehen, erkennt man eine zapfenähnliche Gestalt, die mit gerundeter Oberfläche in das Innere des Mikroklinkorns vordringt. Wo derartige Gebilde mit dem Rande nicht unmittelbar zusammenhängen, liegen sie diesem doch so nahe, dass man ganz gut annehmen kann, die Verbindungsstelle sei über oder unter der Schliffebene vorhanden gewesen und durch den Schliff entfernt worden. Die Durchschnitte sind in diesem Falle annähernd kreisrund.

Diese Mikroklinzapfen lassen in polarisirtem Lichte die Zusammensetzung aus zwei durcheinander gewachsenen Individuen erkennen. Bei Anwendung starker Blendung oder schiefer Beleuchtung kann man sich von dem verschiedenen Lichtbrechungsvermögen der verwachsenen Minerale überzeugen. Das Mengenverhältnis von Feldspath und Quarz ist ziemlich constant, und zwar ist stets vom Quarz weniger vorhanden, so dass das mikroskopische Bild aus einer einheitlich auslöschenden Grundsubstanz besteht, die durch gelegentliche Spaltrisse ihre Feldspathnatur bekundet, in welche dünne, wurmähnlich gekrümmte Quarzstengel eingebettet sind. Die genauere Untersuchung der Lichtbrechungsunterschiede in geeigneten Schnitten lässt zunächst erkennen, dass an diesen Gebilden schwach lichtbrechender Mikroklin nur in sehr geringen Mengen theilnimmt; nur am äusseren Rand der zapfenartigen Durchschnitte greift hier und da Mikroklinsubstanz in das Gebilde ein, so dass der Rand wie gezähnelt aussieht; sie ist dann parallel orientiert mit dem umgebenden Mikroklinkorn. Die Hauptmasse besteht aus Plagioklas und Quarz.

Ich habe den Versuch gemacht, auf Grund der Lichtbrechungsunterschiede den Plagioklas dieser Gebilde genauer zu bestimmen. —

— Der Plagioklas des Mikropegmatit gehört — — immer den natronreicheren Gliedern an, selbst wenn im Gestein kalkreicher Pla-

[1] F. Becke, Petrographische Studien am Tonalit von Rieserferner. Tschermaks Min. und Petr. Mitt. XIII. 1892, p. 411—414.

gioklas vorhanden ist. Nie wird aber so natronreicher Plagioklas vorgefunden, wie er in den »Adern» der Plagioklase vorliegt.

Die Anordnung der auseinanderlaufenden Quarzstengel lässt in günstigen Schnitten eine bestimmte Wachsthumsrichtung erkennen, welche immer vom Rande des Mikroklinkornes einwärts gerichtet ist, als ob die Aggregate sich in den Mikroklin gewissermaassen eingefressen hätten. Dies scheint manche Beobachter zu der Meinung veranlasst zu haben, dass die Zapfen sich durch Corrosion des Mikroklins gebildet hätten; man hat sogar die Verwitterung für diese Gebilde verantwortlich gemacht. Die Art und Weise, wie an frischen Stellen Mikroklin und Mikropegmatit verzahnt sind, schliesst aber den Gedanken an eine secundäre Verdrängung aus, und fordert eine andere Art der Erklärung.

Noch wäre schliesslich zu erwähnen, dass diese Mikropegmatitzapfen häufig von benachbarten Plagioklaskrystallen ausgehen, mit denen dann auch der Feldspathantheil parallel orientirt ist. Seltener setzen sich solche Zapfen an benachbarte Mikrokline oder Quarze an. — —

Ich sehe also in den mikropegmatitischen Zapfen nicht das Resultat einer späteren Corrosion oder gar der Verwitterung, sondern die zuletzt gleichzeitig mit dem Rand der Mikroklinkörner erstarrten Magmaantheile».

Matthew communicated (1893) a figure of a »microperthite» at a crystal of plagioclase in a pre-Cambrian quartzdiorite from New Brunswick which he described in the following way:

»*Microperthite* is not uncommon, sometimes forming a partial ring around plagioclase crystals at their contact with quartz, (Fig. 2) more often scattered in small masses between the other constituents. In the former case it looks rather like a reaction rim, and may be produced in a similar way».

The figure shows a very typical myrmekitic structure. The mineral adjacent to the plagioclase is not pictured but only shown by a schematical shadowing. It may be questioned whether it is really quartz everywhere or whether there is not, as usual, potash felspar at the contact with the myrmekite.

Michel Lévy communicated in 1893 the first description of the peculiar intergrowth of biotite and quartz, which shows so much analogy to the myrmekite and whose origin we will discuss in the following. He found it in a granite from the quarries of l'Ozette, near Limoges, and describes it with the following words: [2]

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[1] l. c. fig. 21, p. 190 and p. 191.

[1] Michel Lévy, Granite de Flamanville. Bull. Carte Géol. de la France N:o 30. 1893. P. 28.

»Au microscope, cette pegmatite se montre assez riche en cristaux d'amphibole, tandis que le granite n'en contient pas; en outre une partie des lamelles de mica noir est de consolidation récente, moule les grands cristaux de feldspath voisins, et se montre criblée de *quartz vermiculé;* cette association presque pegmatoïde de quartz et de biotite est unique à ma connaissance et je n'en ai pas retrouvé un second exemple.»

Futterer published in 1894 very interesting observations and remarks on the secondary intergrowth of felspar and quartz. He calls it micropegmatite, and regarded the felspar as orthoclase but also mentioned the contemporaneous crystallization of two plagioclases. He pointed out that the »micropegmatite» spindles occur on seams in crushed and granulated felspars and regarded them as secondary crystallizations which originated later than the mechanical metamorphism of the rock. I will here quote the most important parts of his description: [1]

»Die Form der mikropegmatitischen Verwachsungen ist nicht immer diejenige von Zapfen am Rande der Mikroklineinsprenglinge. In den Rissen z. B. legen sich häufig die mikropegmatitischen Körner an die unregelmässigen Begrenzungen der Feldspäthe an, und zwar häufig so, dass bei ausgezackter Begrenzung der letzteren immer längs einer Kante auch ein gleichmässig orientirtes Mikropegmatitkorn liegt und an der Biegung oder der Ecke einer solchen Kante auch ein weiteres anders orientirtes Korn beginnt. Die wurmförmigen Quarztheilchen divergiren gegen die Begrenzung zum Feldspath hin; im Innern der breiteren Risse sind die Verwachsungserscheinungen bedeutend reducirt und erreichen weder die Grösse noch die schöne Ausbildung der an die Feldspatheinsprenglinge selbst angrenzenden Theile. Man kann sich nur schwer dem Eindruck verschliessen, dass die Feldspathmasse der grossen Einsprenglinge, nachdem in den letzteren klaffende Risse entstanden waren, auf Lösungen, welche circulirten, noch einen Einfluss ausübte, der bei gleichzeitiger Ausscheidung von zwei sauren Plagioklasen zur Bildung dieser mikropegmatitischen Verwachsungen führte. Weiter gegen die Mitte der Risse hin sind dann bei abnehmender Grösse der Körner auch die gesetzmässigen Verwachsungen geringer, und auch vereinzelte an ihrer Lamellirung kenntliche Plagioklase wurden ausgeschieden inmitten eines körnigen Gemenges von Quarz und nicht gestreiften saurem Plagioklas. — — Es scheint daher für die mir vorliegenden Gesteine wenig wahrscheinlich, dass

[1] K. Futterer, Ueber Granitporphyr von der Griesscharte in den Zillerthaler Alpen. N. Jahrb. für Min. etc. IX Beil. Bd. 1894—95, p. 541—544.

die nur gelegentlich auftretenden Mikropegmatit-Zapfen und Körner ganz generell als letzte Ausscheidungen anzusehen sind, wie das Becke für das Tonalitgestein der Riesenferner will. — — Ebensowenig möchte ich in demselben das Resultat von Corrosion und Verwitterung der Einsprenglinge sehen, sondern die Möglichkeit folgender Vorgänge in den Vordergrund stellen.

Die starken Druckwirkungen, welche in dem Gesteine überall zum Ausdruck kommen und welche die Zerstörung der idiomorphen Gestalten der meisten Einsprenglinge, die Bildung der Risse und Triturationszonen zur Folge hatten, mussten bei der inneren Verschiebung der Bruchstücke und der Reibung der Körner an einander durch diese Bewegungen auch Räume entstehen, welche in ihrer Continuität gelöst und durch keine Gemengteile ausgefüllt waren und sich erst secundär mit solchen wieder ausfüllten. Das ist der Fall mit den im Schnitte dreiseitigen, sonst conischen Räumen, die in der Streckungsrichtung des Gesteines hinter den noch erhaltenen widerstandsfähigen Feldspatheinsprenglingen liegen und deren Ausfüllung durch secundäre Neubildungen in ausgezeichneter Weise an den Quarzporphyren von Thale zu beobachten war. Dieselben Räume sind auch hier in ungleich grösserem Maasse entwickelt, und es ist nicht Zufall, dass in einem durch einen solchen Raum geführten Schliffe die mikropegmatitischen Verwachsungen in ausgezeichneter Schönheit, und was das Wichtigste ist, in grösserer Menge und Verbreitung auftreten, als dies sonst der Fall ist im Verbande des Gesteines. In demselben Maasse, wie an der ausgezogenen Spitze des Raumes mehr Grundmasse mit ihren Biotiten sich einstellt, um so seltener werden die mikropegmatitischen Körner, die in der Grundmasse selbst fehlen.

Es scheint kein gewagter Schritt zu sein, auf Grund dieser Beobachtung nunmehr anzunehmen, dass an den Grenzen der die Widerstände gegen die mechanische Bewegung bildenden Feldspatheinsprenglinge, sowie in den entstandenen Rissen und den Triturationszonen ebenfalls stellenweise Räume freiblieben zwischen den ausgezackten Umrissen der Einsprenglinge und den Trümmeranhäufungen, die sich dann je nach den gegebenen Umständen secundär ausfüllen, wobei es zu gesetzmässiger Durchdringung von zwei Feldspathen in bestimmten Fällen kam. — — Werden diese Voraussetzungen zugegeben, so wären allerdings die mikropegmatitischen Zapfen und Körner secundärer Entstehung und erst nach der mechanischen Deformation des Gesteines entstanden, über deren zeitliches Verhältniss zur Verfestigung des Gesteines und deren letzte Erstarrungsproducte keine Anhaltspunkte vorliegen».

Somewhat later (1897) Graber entirely adopted Beckes opinion, describing, himself, new instances from the tonalitic gneiss of southern Carinthia. He describes them under the head of micropegmatite:[1]

»Die mikroskopische Untersuchung lehrte, dass die Mikropegmatitzapfen im Tonalitgneiss ganz ähnlich auftreten, wie in anderen granitischen und dioritischen Gesteinen: sie sind immer in die Ränder der Mikroklinkörner eingesenkt. Diese Beobachtung wurde schon öfters gemacht, aber verschieden erklärt, weshalb hier eine kritische Beleuchtung der vorhandenen Anschauungen gestattet sei.

Nach Rombergs Ansicht beruht die Bildung der Mikropegmatitzapfen, die »zungen- und buchtenförmig in das Innere der Mikroklinkörner eingreifen», auf Verwitterung.

Futterer schreibt dem Gebirgsdrucke eine gewisse Bedeutung bei der Bildung der Mikropegmatitzapfen zu, hält sie also für Produkte der Dynamometamorphose. Ohne die Möglichkeit eines Zusammenhanges zwischen den Mikropegmatitzapfen und der Dynamometamorphose für einzelne Fälle bestreiten zu wollen, muss ich dagegen die Thatsache erwähnen, dass in den von einer Dynamometamorphose fast gänzlich unberührten Granititen der Aufbruchzone die Mikropegmatitzapfen im Rande der Mikroklinkörner bedeutend häufiger vorkommen und schöner ausgebildet sind als im stark kataklastischen Tonalitgneiss, so dass Beckes Vorschlag, die Mikropegmatitzapfen sammt den Mikroklinen als jüngste Ausscheidung anzusehen, die grössere Wahrscheinlichkeit hat. Die mikroskopische Beobachtung lässt für den Tonalitgneiss (und auch für den Granitit) nur die zuletzt angeführte Erklärung zu».

In the author's work on the schists of the Tammerfors region such intergrowths of felspar, generally oligoclase, and quartz vermiculaire, in 1897, were described and their simultaneous formation was emphasized. I pointed out that these intergrowths were certainly different from the micropegmatite and proposed for them the name myrmekite which later has been generally accepted by continental petrologists. My opinion concerning their origin was that they were formed by processes which were nearly related to contact metamorphism, i. e. that they originated at a time when the temperature was high and solvents were present in abundance. This, I assumed, was the case during the (regional) metamorphism of the granites of the Tammela

[1] H. V. Graber, Die Aufbruchzone von Eruptiv- und Schiefergesteinen in Süd-Kärnten. Jahrb. d. k. k. geol. Reichsanst. 1897. 47 Bd. 2 H., p. 225.

region in which I had observed the myrmekite. I reprint in the following my description and subsequent conclusions.[1]

By describing the »post-Bothnian» porphyritic granites I said:

»An den gegenseitigen Grenzen der Feldspate, z. T. auch als sie durchziehende Schnürchen, treten Reihen von Orthoklaskörnchen auf, welche mit radialstrahlig angeordneten, wurmartig gekrümmten Quarzstängeln (*Quartz vermiculaire* von Michel Lévy) verwachsen sind. Bald liegen diese Gebilde, die wie kleine Warzen aussehen, als selbständige Körner zwischen den Feldspaten, in der Art, als wenn sie von aussen in diese eingewachsen wären. Bald ist wieder der äusserste Rand des Feldspates von »Quarz vermiculaire» durchwachsen, so dass es aussieht, als ob die Verwachsung nur bei einer Fortsetzung des Zuwachsens der Feldspate entstanden wäre. Zuweilen

Fig. 4. (= fig. 62 in the former memoir of the author »Wart-like intergrowth of oligoclase and quartz, in an granite from Mahnala in Tavastkyrö. Polarized light. × 80.

werden diese »Warzen» so zahlreich, dass man in den Dünnschliffen auf einer Fläche von mehreren Quadratmillimetern nur solche Dinge beobachtet. Zu diesen recht interessanten Gebilden werden wir noch in folgenden zurückkehren.»

Further, by describing even-granular grained belonging to the same group I remarked:

[1] J. J. Sederholm, Über eine archäische Sedimentformation im südwestlichen Finland etc. Bull. Comm. Géol. de Finlande N:o 6, 1897, p. 108 and 111—114.

»Die Feldspate werden auch oft durch Zuwachs verunstaltet, in dem sich zapfenförmige Protuberanzen an ihnen einstellen. Besonders reichlich findet man in vielen von diesen Graniten die schon erwähnten *warzenähnlichen Verwachsungen* zwischen Feldspat, ganz vorwiegend Oligoklas, und wurmartig gekrümmten Quarzstengelschen. Die Figg. 62 und 63 (= figs. 4 and 5 in the present treatise) geben eine Vorstellung von dem Aussehen dieser Gebilde, welche noch reichlicher wie hier in denjenigen Graniten vorkommen, welche älter als die Tammerforsschiefer sind (Siehe Fig. 63). In einigen Fällen können die einzelnen Stengel noch feiner werden, so dass die Verwachsungen blumenkohlartige Zartheit darstellen. Zum Teil bilden nun diese Verwachsungen schmale Fransen und Säume um die Feldspatkrystalle, wobei der von »Quartz vermiculaire»

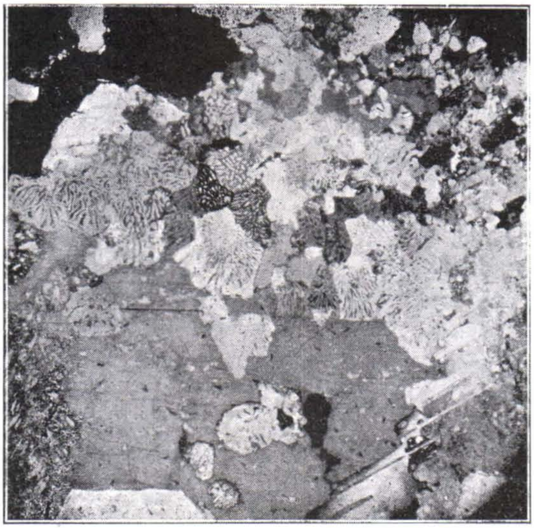

Fig. 5. (= fig. 63 in the former memoir of the author.) »Wart-like intergrowths of oligoclase and quartz in an older granite from the railway north of Sarkkila in Kangasala». Polarized light. × 18.

durchwachsene neugebildete Feldspat mit der Substanz der Krystalles, den er umsäumt, gleich orientiert ist. Dann kann es oft scheinen, als ob der ganze Feldspat eine ursprüngliche Bildung wäre, in dessen durch Corrosion angegriffene Ränder ein sekundärer Quarz später eingedrungen wäre. Gegen eine solche Annahme, nach welcher der Quarz als eine »Quartz de corrosion» im Sinne der französischen Petrologen aufzufassen wäre, sprechen jedoch mehrere Umstände, welche zu beweisen scheinen, dass sowohl der »Quartz vermiculaire» wie der Feldspat, den er durchwächst, auch in diesen »Fransen» gleichzeitig entstandene sekundäre Bildungen sind. Sie zeigen nämlich oft gegen den von ihnen umsäumten Feldspat eine recht bestimmte Grenze und kommen überhaupt niemals in genetischer Verbindung mit unzweifelhaft primären Gemengteilen vor.

In der Mehrzahl der Fälle treten aber diese Verwachsungen selbstständiger auf, indem sie die schon erwähnten und in den Figg. 62 und 63 abgebildeten Körner bilden. Die Grösse dieser Gebilde ist eine auffallend gleichförmige. Im Durchschnitt messen sie ungefähr 0.2 mm in der Länge. 1 mm kann man als ein selten erreichtes Maximum, 0.06 mm als ein Minimum der Länge der gut ausgebildeten Quarz-Feldspatwarzen angeben.

Es wäre bequem, für diese eigenartigen Gebilde, welche von dem echten Mikropegmatit, Poikilit und ähnlichen Bildungen leicht zu unterscheiden und zweifelsohne auch genetisch verschieden sind, einen besonderen Namen zu besitzen, da die von Michel Lévy eingeführte Bezeichnung »Nodules de feldspat à quartz vermiculaire» lang und in den germanischen Sprachen schwer zu brauchen ist. Ich erlaube mir deswegen vorzuschlagen, diese warzenähnlichen Bildungen als *Myrmekit* oder myrmekitische Verwachsungen (von μυϱμηκία, Warze) zu bezeichnen, welche auch für die fransenartig auftretenden ähnlichen Gebilde (Myrmekitsäume oder -fransen) anzuwenden wäre.

Diejenigen Gesteine, welche solche Myrmekitkörner in reichlicher Menge enthalten und in welchen sich die grösseren Quarzpartien in einer Menge kleinerer Körner geteilt haben, zeigen oft sehr ausgeprägt die Struktur welche Törnebohm *Mörtelstruktur* genannt hat. — —

In Anbetracht des vollkrystallinischen Charakters dieser Neubildungen glaubte ich früher annehmen zu müssen, dass alle diese Erscheinungen, und zwar sowohl die Myrmekitbildung wie die Entstehung der Mörtelstruktur, vor der vollständigen Krystallisation des Magmas entstanden wären. Nachdem ich den Gang der Metamorphose näher kennen gelernt habe, kann ich nicht mehr daran zweifeln, dass bei dieser auch Neubildungen entstanden sind, welche denselben Charakter wie die primären Mineralien der Tiefengesteine besitzen. Ein Teil dieser Veränderungen sind aber erweislich *erst nach der vollständigen Verfestigung des Gesteins eingetreten* und dasselbe dürfte auch von der Myrmekitbildung gelten.

Nun findet man myrmekitische Bildungen, wie mir mein College Frosterus gezeigt hat, auch in den durch eine Art Contactmetamorphose umgewandelten Einschlüssen in den Rapakivigraniten.

Sie können somit erweislich bei contactmetamorphen Processen entstehen, da diese Gesteine nicht regionalmetamorphosirt worden sind. Dagegen fehlen sie sonst vollständig in denjenigen Gesteinen der Rapakivigebiete, welche nur echte Eruptivstrukturen aufweisen.

Es scheint somit der Myrmekit nur metamorph und zwar bei solchen Processen gebildet zu werden, welche der Contactmetamorphose nahe stehen, also bei erhöhter Temperatur und Vorhandensein von reichlichen Lösungsmitteln. Es ist sehr wahrscheinlich, dass diese Bedingungen bei der Metamorphose der Granite der Tammerforsgegenden, welche wahrscheinlich in grosser Tiefe vorsichging, vorhanden waren.»

In the same memoir, I also described true micropegmatite, partly changed by dynamical influences, and micropegmatite-like intergrowths of quartz and felspar which I thought were secondary, having originated in previously weathered pebbles of Archæan conglomerates, and compared these phenomena with each other, as well as with the intergrowths described by Romberg (cf. p. 65) whose wide application of the latter interpretation I contested.[1]

C. W. Hall described in 1899, similar structures occurring in gneisses from south-western Minnesota, among them[2]

»Vermicular quartz in and around the feldspathic individuals, more particularly those which show strong evidences of alteration.

Of peculiar interest in these granitoid rocks is this vermicular quartz, which is very widely distributed. As a rule it is microscopic, very rarely appearing in areas sufficiently large to be detected with the unaided eye. Almost without exception its secondary origin is evidenced by its distribution, for it is found within the boundaries of the older rock constituents, particularly the feldspars. Within this group of minerals no particular preference seems to be shown; it as frequently invades orthoclase or microcline as it does the plagioclastic species. The contorted, vermicular passages through which the silica has made its way into the corroded constituents can be seen on Pl. XVIII, B, taken from the hornblende-biotite-gneiss (sp. 5396) of sec. 30, T. 112 N., R. 38 W., the town of Vesta, in the prairie region of western Redwood County.»

The plate XVIII, B, shows »vermicular quartz, within an area of albite feldspar», with plagioclase on *both* sides. Else it is a very typical myrmekite.

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[1] l. c. p. 25—29 and 118—119.

[2] C. W. Hall, The Gneisses, Gabbro-Schists and Associated Rocks of southwestern Minnesota. Bull. U. S. Geol. Survey N:o 157, 1899, p. 51.

Further plate XIX, B, shows a »contact zone between microcline and oligoclase where the boundary is not distinct. A finely granular mineral not easily identified lies between the two recognizable feldspars. That either is secondary to the other does not appear.» — No doubt this is a zone of myrmekite, as usual synantetic between plagioclase and microline.

C. A. Mc Mahon is one of the few petrologists writing in English who has given (1900) any attention to the intergrowths here in question. In describing the Gilgit granite of the Himalayas, he communicates a photograph of typical myrmekite which he refers under the head of granophyric structure. Concerning this he says as follows:

»The granophyric structure, so common in these rocks, is only, it seems to me, an example of the same process in an incipient stage. When the process of resolution set in, and the liquid quartz began to eat its way into the crystals, the felspars yielded (according to my theory) almost simultaneously at many separated points of weakness, and the invading molecules of silica were influenced in the direction which they took by the planes of solution and of cleavage within the crystal. The result was that, when the process of resolution was arrested in its initial stage the corroding quartz assumed those graphic shapes so commonly seen in granophyre.

Those who have watched crystallization take place from a solution on a glass slide will have noticed that sometimes crystallization begins almost simultaneously at many points separated one from the other. Resolution seems to follow a similar course. Whereever a point of weakness presents itself, the corroding liquid begins its inroad. Occasionally residual quartz may be seen actually passing into granophyre: an illustration of one such case is shown in Pl. XXIII, fig. 6.»

Mc Mahons conception is thus nearly related to that of Michel Lévy and Fouqué.

W. Bergt is one of the first authors who has discussed (1902) the question regarding the genesis of the myrmekite. In a granitic gneiss from Copenkrissi and in the river Abrahamsteen in the valley Coppename in Surinam he found myrmekite, which he thinks was of primary origin[2]:

[1] C. A. Mc Mahon, The Geology of Gilgit. Quart. Journ. Geol. Soc. vol. lvi, 1900, p. 366—367.

[2] W. Bergt, Zur Geologie des Coppename- und Nickeritales in Surinam (Holländisch-Guyana). Sep.-Abdr. aus Samml. d. Geol. Reichs-Mus. in Leiden. Ser. II, Heft II. Leiden 1902, p. 117—187.

»Eine Eigentümlichkeit der körnigen Gneisse ist noch die Anwesenheit jener zuweilen warzenähnlich gestalteten Verwachsungen von Feldspat mit wurmförmig gekrümmten Quarzstengeln, die zuerst *Sederholm* beschrieben und *Myrmekit* genannt hat. *Sederholm* hält den Myrmekit für nachträglich entstanden und somit in der Bildung verschieden vom Mikropegmatit, Poikilit und ähnlichen Dingen. — — Obwohl der Myrmekit in dem körnigen Gneiss mit dem *Sederholms* vollständig übereinstimmt, liegt hier nicht die geringste Veranlassung vor, ihn für secundär zu halten. Sein den übrigen Gemengteilen durchaus gleichwertiges und gleichartiges Auftreten lassen ihn als eine dem Mikropegmatit entsprechende ursprüngliche Verwachsungsform erscheinen. — Die ürsprüngliche *Struktur* des Gesteines zeigt keinerlei Veränderungen durch Druck, auch an den Gemengteilen, selbst an dem empfindlichen Quarz sind keine mechanischen Trümmererscheinungen zu bemerken und optische Druckwirkung nur in ganz geringem Grade festzustellen.»

Fig. 6. Fig. 7.
»Plagioclase with granophyric corrosion vein, Graphite City». From Osann's memoir.

Osann has described (1902) very interesting intergrowths of quartz and felspar, which he thought was orthoclase, in a Canadian hypersthene-biotite-gabbro, in the following words: [1]

»A few paces north of the entrance main pit the same rock occurs again. Macroscopically, it cannot be distinguished from the one last described. Under the microscope, it exhibits very peculiar appear-

[1] A. Osann, Notes on certain Archæan Rocks of the Ottawa Valley. Geol. Surv. of Canada. Part O. Ann. Rep. Vol. XII, p. 70.

ances. Here again by far the greater part of the feldspar is plagioclase. This plagioclase is completely intergrown with quartz. All those phenomena described as *quartz de corrosion, quartz vermiculé,* &c., may here be studied in peculiar beauty. From the edges of the feldspar sections there run inwards tube and worm-like developments of quartz which frequently unite and form a regular network. Fig. 2, plate XI, (= fig. 7 in this memoir) shows a typical example of this latter variety; the isolated plagioclase particles are much rounded, as though roughly broken up and in part somewhat displaced with regard to one another. In other sections the plagioclase has a sieve-like appearance, caused by numerous inclusions of quartz, generally irregularly outlined but frequently similarly oriented optically. In other cases these quartz inclusions are longer and spindleshaped, and are then arranged parallel to one another and to the twinning lamellæ of the albite. Not infrequently, the quartz is replaced by a very fine granophyric intergrowth of feldspar (orthoclase?) and quartz. Fig. 1, plate XI, (= fig. 6 in this memoir) shows a place where such an aggregate has eaten its way like a tube into a large plagioclase and which ends at its point in pure quartz. Bäckström has described and figured very similar appearances in inclusions in Scandinavian diabase, and called them corrosion phenomena. Such an explanation is also applicable here».

Weber mentions (1904) the occurrence of myrmekite in the potash syenite of Piz Guif in the Aar massive of Switzerland in the following words:

»Sehr verbreitet ist die mikropegmatitähnliche Durchwachsung dieser randlichen und zapfenartigen eingesenkte Albitpartien mit Quarz, der sich je nach der Schnittlage bald in geraden oder wurmgangförmig gekrümmten, baumartig verzweigten Stengeln, bald inrunden oder ovalen Körnern (Querschnitte) darbietet, die jeweilen innerhalb desselben Plagioklasindividuums einheitlich auslöschen oder doch nur wenigen Quarzindividuen mit verschiedener optischer Orientierung angehören (Implikationsstruktur). Diese Einlagerung von Quarz (»quartz vermiculé») gestattete sehr oft die genauere Bestimmung des damit zu dem sogenannten M y r m e k i t *(Sederholm)* verwachsenen Plagioklases mit Hülfe der vorzüglichen Methode von *Becke* (Vergleich der Lichtbrechung). Nur in einem einzigen Schliff, der sich durch grosse Frische der Feldspäte auszeichnet, wurde basicher Oligoklas bis saurer Andesin, meist ohne Zwillingslamellierung, konstatiert — — in allen übrigen Schliffen ergab die Be-

[1] Friedrich Weber, Über den Kali-Syenit des Piz Giuf und Umgebung (östliches Aarmassiv). Beitr. zur Geol. Karte d. Schweiz. Neue Folge, XIV Lief. 1904, p. 15—17.

stimmung stets übereinstimmend sauren Oligoklas — — bei Abwesenheit von Epidot und Zoisit, dagegen Albit — — bei reichlicher Einlagerung von Epidot und Zoisit oder Klinozoisit, häufig nebst einem feinschuppigen farblosen Glimmer; diese Neubildungen erfüllen gewöhnlich nur das Innere und lassen einen schmalen, reinen Randsaum (Oligoklas? oder primärer Albit?) frei. — —

Der Plagioklas-Myrmekit-rand des Mikroklins lehnt sich in der Regel an die vorwiegend allotriomorphen Individuen von Oligoklas-Albit (meist mit den obenerwähnten Neubildungen erfüllt), Mikroklin, Orthoklas und Quarz, die den Mikroklinmikroperthit umlagern.»

In his pamphlet on the rocks of the Brixen mass Petrascheck gives (1904) very detailed descriptions of myrmekite, to which he devotes a special chapter. He found that the amount of lime very rapidly sinks against the borders of these structures, so that the core may belong to the oligoclase-andesine series, while the margin is oligoclase. He points out the allegiance of myrmekite to microcline saying:

»Niemals aber trifft man Myrmekitsäume an der Grenze zwischen Plagioklas und Quarz. Unsere Fig. 1 auf Taf. IV illustriert ein Beispiel wie ein breit entwickelter Myrmekitsaum dort scharf absetzt, wo an Stelle des Orthoklas Quarz an den Plagioklas herantritt. Dass der Myrmekit immer in Verbindung mit Kalifeldspat auftritt, ist bereits von Becke beobachtet worden; es ist aber die Abhängigkeit in unseren Gesteinen eine so auffällige, dass sie hier nochmals ausdrücklich hervorgehoben werden muss. Immer sind es Glieder der Albitreihe, welche die als Myrmekit bekannten Verwachsungen von Plagioklas und Quarz bilden».

Petrascheck discusses the earlier interpretations of these intergrowths at some length and arrives to the conclusion, that the myrmekite is a primary crystallization in the magma, although he thinks it probable that myrmekite-like phenomena may originate in different ways. I quote the most important part of his descriptions and conclusions:

»Zweifellos sind es oft verschiedene, nur äusserlich ähnliche Erscheinungen, die man bald als Granophyr oder Mikropegmatit, bald als quartz vermiculé, bald als Myrmekit beschrieben hat, Erscheinungen, die keineswegs immer derselben Entstehungsart sein müssen. Was Becke in Tonalit des Riesenferner als Mikropegmatit behandelt hat, ist mit unserem Myrmekit identisch. Die strenge Ab-

[1]) W. Petrascheck, Über Gesteine der Brixener Masse und ihrer Randbildungen. Jahrb. K. K. Geol. Reichsanst. LIV Bd 1904, p. 50 and 70—74.

hängigkeit von Kalifeldspat wurde schon oben hervorgehoben. Auch aus den Darstellungen SEDERHOLMS geht die Verbindung des Myrmekits mit dem Kalifeldspat hervor. Er tritt in Gestalt von Säumen oder Zapfen auf, die die Plagioklase umgeben oder diesen anhaften. Wird ein solcher Zapfen vom Kristall durch den Schliff abgeschnitten, so scheint er frei als Korn im Orthoklas zu liegen. Es kommt aber auch vor, dass kleine Myrmekitkörner, für welche die unmittelbare Verwachsung mit Plagioklas nicht wahrscheinlich ist, isoliert auftreten. Solche kleine, meist etwas länglich geformte Körner liegen hie und da an der Grenze von zwei Orthoklasen und man könnte sich wohl vorstellen, dass Lösungen, die zwischen die Orthoklaskörner eingedrungen sind, diese Myrmekitkörnchen hier abgesetzt haben.

Nahezu immer war in unseren Präparaten Myrmekit dort vorhanden, wo Plagioklas mit Orthoklas in Berührung kam, so dass man den Eindruck bekommt, als sei der Myrmekit das Produkt einer Reaktion des einen Minerals auf das andere. Wo aber ein Quarz oder ein anderer Plagioklas oder Biotit angrenzt, schneidet der Myrmekitsaum ab. Ein solches Beispiel für Quarz illustriert unsere Abbildung Taf. IV, Fig. 1. Eine Ausnahme von dieser Regel machten häufig nur die sauren Plagioklase, die in basischen Ausscheidungen mit Orthoklas in Berührung kamen, indem hier die Myrmekitsäume gänzlich fehlen konnten. Dagegen ist die Erscheinung viel intensiver, d. h. die Myrmekitsäume viel deutlicher und breiter, wenn der Orthoklas ein Mikroperthit ist. Schon hieraus kann man schliessen, dass Beziehungen zwischen den Perthitspindeln und dem Myrmekit bestehen. Dies wird aber durch manche optische und chemische Erscheinungen zur Gewissheit.

Dem Myrmekit ist nicht ein Feldspat von ganz bestimmter Zusammensetzung eigentümlich. Nur das lässt sich sagen, dass stets die sauren Glieder der Plagioklasreihe an seiner Bildung beteiligen. BECKE fand sauren sowohl wie basichen Oligoklas unter Anwendung seiner Methode durch Vergleich der Lichtbrechung mit der des Quarzes.

Nicht selten kann man beobachten, dass sich die Zwillingslamellen des Plagioklases in den Myrmekit hinein fortsetzen, woselbst sie aber, weil viel saurer, oft entgegengesetzte Auslöschung zeigen. — —

In dem Pegmatit, dessen Plagioklas sehr sauer war, fehlen die Myrmekitsäume meist. — — Der Umstand, dass bei basischen Kristallen der Plagioklas des Myrmekits nicht ebenfalls wesentlich basicher ist, dass vielmehr dann ein plötzlicher Umschlag in die saure

Zone des Myrmekits eintritt, während in allen anderen Plagioklaszonen die Änderung sich langsamer und kontinuierlicher vollzieht, dieser Umstand scheint darauf hinzudeuten, dass sich der Myrmekit nicht in derselben Weise wie die anderen Zonen ausgeschieden hat. Könnte dem Orthoklas die Fähigkeit, neben Plagioklassubstanz auch noch Quarz zu lösen, zugesprochen werden, so könnte durch Ausfall der letzteren die Bildung der Quarzstengel erklärt werden. In diesem Falle aber sollte man vermuten, dass Myrmekit sich aus dem Orthoklas auch gegen Quarz hin, soweit solcher schon verfestigt war, ausgeschieden habe, wovon aber nichts zu bemerken ist. Eine chemische, von Abscheidungen von $Si\,O_2$ begleitete Wechselwirkung zwischen Orthoklas und den kalkreichen Plagioklasen ist nicht denkbar, obgleich das mikroskopische Bild sehr zur Annahme einer solchen verleitet. Wir können uns demnach noch keine Vorstellung davon machen, wie der quarzstengelführende Myrmekit enstanden sein soll. Das letzte Erstarrungsprodukt kann dieses Quarz-Plagioklasgemisch nicht sein, da sich nach ihm noch aus Orthoklas der quarzfreie Albitsaum abgeschieden hat. *Auf jeden Fall aber halten wir den Myrmekit für eine primäre und magmatische Bildung.*

Die Quarzstengel des Myrmekits als einen »quartz de corrosion» aufzufassen, der, wie BAUER ausführt, eingreifen muss, wenn der Feldspat, wie es unter bestimmten Voraussetzungen der Fall ist, bestandesunfähig wird, ist nicht angängig, weil die Einfügung der quarzführenden Zone in die Zonenstruktur der Plagioklase und ebenso der Umstand, dass dem Myrmekit ganz bestimmte, nämlich saure Plagioklase eigentümlich sind, sich damit nicht in Einklang bringen lassen. Auch ist die Wirkung der Korrosion, wie zum Beispiel die Quarze von Porphyren zeigen, eine ganz andere. Sie führt nicht zur Herausbildung so feiner, annähernd parallel gestellter oder, was in den Zapfen der Fall ist, divergierender Kanäle, wie so häufig im Myrmekit zu beobachten sind.

Ebenso können wir den Myrmekit nicht, wie Futterer wollte, als eine Ausfüllung von bei der Kataklase entstehenden Hohlräumen betrachten. Es spricht dagegen nicht nur die Art des Auftretens in Säumen und Zapfen zwischen Plagioklas und Orthoklas, sondern auch, die völlige Unabhängigkeit der Myrmekitbildung von der Pressung. In ganz oder fast ganz von Gebirgsdruck verschont gebliebenen Gesteinen beobachten wir reichlich Myrmekit, in den stark veränderten Tonalitgneisen fehlte er dagegen. — — Auf jeden Fall halten wir es für wahrscheinlich, dass äusserlich dem Myrmekit ähnliche Gebilde auf verschiedene Entstehungsursachen zurückzuführen sein können, weshalb es zur Vermeidung von Verwechslungen nötig ist, sie nach ihrem Auftreten genau zu scheiden.»

In his study of the Coziagneisses of the the Roumanian Carpathian Mountains, Reinhardt (1906) very often mentions the occurrence of myrmekite, and discusses its origin at some length, resuming also the former literature. As to the origin of this intergrowth he says as follows:

»Ein ähnlicher Erklärungsversuch wie für die perthitischen Verwachsungen, die Myrmekite also durch Entmischung erklären zu wollen, scheint ausgeschlossen. Quarz und Feldspat, sei es Plagioklas oder Orthoklas, können offenbar ihrer grossen krystallographischen Unterschiede wegen unter keinen Umständen Mischkrystalle bilden.

Eine Erscheinung, welche sich bei der Untersuchung des Coziagneisszuges aufdrängt, muss ins Auge gefasst werden: dass die myrmekitischen Verwachsungen namentlich in den Kontaktzonen des Eruptivgesteines mit dem Schiefermantel sich anreichern. Wäre die Art der Verwachsung durch blosse gleichzeitige Auskrystallisation der beiden Mineralien zu Stande gekommen, so bliebe diese Tatsache unerklärt. Ebenso unbegreflich wäre es, warum hier die gleichzeitige Auskrystallisation zu solchen Gebilden führt, während die Erstarrung des eutektischen Gemisches Quarz-Kalifeldspat zu der konstanten Kombination des Pegmatites führt, dessen durchwegs gleiche Zusammensetzung seine Natur zur Genüge beweist Die beiden Strukturen der myrmekitischen und schriftgranitischen Verwachsung sind einander ähnlich, aber nicht identisch und müssen auseinandergehalten werden. Während die Pegmatite das Produkt rein magmatischer Erstarrung des eutektischen Gemisches Quarz-Kalifeldspat sind, scheinen sich die myrmekitischen Verwachsungen ebenfalls durch gleichzeitige Krystallisation der beiden Komponenten am Ende der Verfestigungsperiode gebildet zu haben, begünstigt durch den Einfluss der entweichenden Gase und Dämpfe. Sie sind wohl neben Quarz und etwas Alkalifeldspat das Resultat der Erstarrung der letzten Reste des auskrystallisierenden Magmas und ihre Struktur wird durch die freigewordenen Mineralisatoren bedingt.

Dass saure Magmen grosse Mengen von Gasen abzugeben vermögen, ist eine längst bekannte und namentlich von französischen Forschern verfochtene Tatsache. Neuerdings haben die Eruptionen der Montagne Pelée mit ihren grossartigen »nuées ardentes» positive

[1] M. Reinhardt, Der Coziagneisszug in den Rumänischen Karpathen. Inaug.-Diss. Bukarest, 1906, p. 78—79 and 100.

Beweise für die Existenz dieser Gase und Dämpfe erbracht. Brun berechnet, dass ein saures Magma das zehnfache von seinem Volumen an Gasen aufzulösen vermag. Dass die granitischen Magmen keine trockenen Schmelzen darstellen, ist ein Faktum, welches sich schon längst aufgedrängt hat. Man wird mit grosser Wahrscheinliehkeit annehmen dürfen, dass die entweichenden flüchtigen Stoffe auf die Ausbildungsweise der zuletzt sich ausscheidenden Myrmekite in den Kontaktzonen, und ihre Verbreitung in Gesteinen von pegmatitischen Habitus wird dadurch nicht nur erklärt, sondern gefordert.

Eine ähnliche genetische Bedeutung scheinen die Quarztropfen am Rande der Kali- und Kalknatronfeldspate zu haben. In einem später noch zu beschreibenden Kontaktgestein erscheinen die Plagioklase völlig durchlöchert, infolge der grossen Menge runder Quarzeinschlüsse. In allen Pegmatiten und pegmatitischen Gesteinen ist ihre Verbreitung ebenfalls eine ausgedehnte.

Feinmaschige, verworrene Aggregate von Albit, Quarz und Kalifeldspat, in welchen oft Krystalle von Myrmekiten eingebettet sind, dürften ebenfalls eine analoge letzte Ausscheidung sein. Solche Vorkommnisse können leicht mit ähnlich aussehenden verwechselt werden, welche lediglich durch Zertrümmerung grösserer Individuen entstanden sind. — —

Die *Myrmekite* wurden *für die Gesteine des Coziagneisses* als genetisch verwandt mit den Feldspaten mit Siebstruktur und den feinkörnigen Kalifeldspat-Quarz-Aggregaten aufgefasst. Diese Gebilde scheinen das letzte Verfestigungsprodukt des auskrystallisierenden Magmas zu sein und die unregelmässigen Verwachsungen sind wohl das Ergebnis der unruhigsten Krystallisationsphase: der entweichenden Gase und Dämpfe, welche in »Abzugskanälen» zu pegmatitischen Gesteinen führten und im Schiefermantel die exogenen Kontakthöfe bedingten».

Shand has described (1906) very interesting intergrowths of orthoclase and zeolites from the borolanite of Cnoc-na-Sroine in Scotland which had been partly mentioned already before by Bonney, Horne and Teall. I quote here the description of Shand:[1]

»Die eigentümlichen mikroskopischen Verwachsungen, die sich im Orthoklas befinden, sind schon erwähnt worden. Darüber schreibt Bonney folgendes:

»The ground of the slide appears to consist partly of a felspar, in patches of a most irregular form (with perhaps a little

[1] J. Shand, Ueber Borolanit und die Gesteine des Cnoc-na-Sroine-Massivs in Nord-Schottland. N. Jahrb. XXII Beil.-Bd. 1906, p. 429—433.

quartz), and a mineral which occurs in rather wavy bunches, like tufts of long thread or rootlets, or a kind of »canal system». It seems to have replaced the felspar, and may be one of the fibrolite group.»

Horne and Teall schreiben von diesen Verwachsungen:

»Orthoclase .... is often micropegmatitically intergrown with a substance which is probably an alteration-product after nepheline».

Dieselben Autoren führen auch Debby an wie folgt: »he has found a micropegmatitic intergrowth of orthoclase and nepheline in some of the pseudo-leucites».

In seiner zweiten Mitteilung über diese Gesteine schreibt Teall:

In the pseudo-leucites and even in the ground-mass of certain borolanites the two minerals (nämlich Orthoklas und Nephelin) form beautiful micrographic intergrowths».

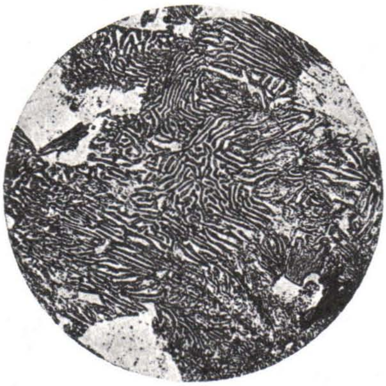

Fig. 8. Myrmekite-like intergrowth of orthoclase and sodalite, showing »dactylo type« texture, in a borolanite from Cnoc-na-Sroine in Scotland. (The pale minerals consist of orthoclase together with whom there occurs biotite on two places). Ordinary light. × 47. From Shand's memoir.

Die erwähnten Verwachsungen kommen ausschliesslich im Orthoklas vor und besonders in den grösseren Individuen. Sie bestehen aus Fasernsystemen, deren Fasern mehr oder weniger parallel verlaufen, dabei aber wurmartige Krümmungen zeigen; sie durchdringen den Orthoklas in allen Richtungen (Taf. XVI, Fig. 3 = fig. 8 in the present treatise). Im Querschnitt unter dem Mikroskop gesehen, ähnelt die Struktur einem Fingerabdruck und man könnte diese Struktur füglich »dactylotyp» nennen. Sie kommt in den Leucitborolaniten meistens in den weissen Flecken oder Pseudoleuciten vor; in dem nicht gefleckten pyroxenhaltigen Borolanit vom

Nordosten des Cnoc-na-Scroine finden sie sich überall in der Grundmasse; auch in einzelnen der weissen, fast granatfreien oder leukokraten Abarten des Aultnacallagach-Gesteins durchtränkt sie die ganze Grundmasse.

Die einzelnen Fasern schwanken zwischen 0.005 und 0.01 mm im Durchmesser und werden durch Zwischenräume ähnlicher Grösse voneinander getrennt. Ein einziger Faden lässt sich manchmal über eine Strecke von fast einem Millimeter verfolgen. Im Querschnitt sind die einzelnen Fäden abgerundet. Die Richtung der Fasern scheint in keinem gesetzmässigen Verhältnis zu den kristallographischen Richtungen oder Umrissen des Orthoklases zu stehen; nicht selten verläuft ein Faden eine gewisse Strecke ziemlich gerade und ist dann am Ende hakenförmig gekrümmt. Zuweilen kommt die Verwachsung nur in der äusseren Zone eines Orthoklaskristalles vor, und in diesem Falle ist sichtbar, dass die Richtung der Fasern annähernd senkrecht zu den Umrissen des Kristalles steht. Die Auslöschung erfolgt im allgemeinen nicht gleichmässig in den verschiedenen Teilen eines solchen Fadens; auch anliegende Fäden paralleler Richtung löschen nicht gleichzeitig aus.

Der Mineralinhalt dieser Fasern ist hauptsächlich zweierlei Art. Bei weitem am häufigsten in den echten Borolaniten ist eine Substanz, die helle Polarisationsfarben erster und zweiter Ordnung zeigt; hier und da aber, und kaum zu merken ohne stärkste Vergrösserung, wird diese Substanz durch eine zweite ersetzt, die erst bei gekreuzten Nicols sichtbar wird. Dann erscheint sie als dunkler Streifen in dem weissen Feldspat. Diese Substanz ist in den Borolaniten nur in verhältnismässig sehr geringer Menge gegenüber dem vorherrschenden hell polarisierenden Mineral vorhanden, aber in dem später zu beschreibenden Gestein, dem Augitsodalithsyenit, kommt dieselbe Struktur in ausgezeichneter Weise vor. Es enthält dann fast ausschliesslich die dunkel polarisierende Substanz. Da ich sie für den ursprünglichen Inhalt der Fasern und das hell polarisierende Mineral für sein Umwandlungsprodukt halte, so sollen sie in dieser Reihenfolge zur näheren Beschreibung gelangen.

Die Eigenschaften jenes Minerals, so weit wie seine fast untermikroskopischen Dimensionen die Bestimmung gestatten, sind folgende. — Der Brechungsexponent ist niedrig und nach der einzigen, in diesem Falle möglichen Messungsmethode, derjenigen von Becke, ist er niedriger als derjenige des Orthoklases. Doppelbrechung scheint vollkommen zu fehlen oder ist nur mittels Gipsplatte zu erkennen. Das Mineral gelatiniert unter Einwirkung von Salzsäure, und die Lösung setzt beim Eintrocknen Kochsalzwürfel ab.»

Shand regards this mineral as sodalite. The other mineral, which shows bright colours in polarized light, is probably a mica, belonging to the pinite-series.

Also the augite-sodalite syenite of the same district contains orthoclase showing a similar »dactylotype structure.»[1]

Shand also briefly mentions the same structures in later publications.[2]

P. J. Holmquist often mentions, in his important work on the granites of Sweden (1906), myrmekite which he has found in very varying amounts in different granites of Sweden.

In the rapakivi granites he has found it almost entirely absent. »Als negatives Kennzeichen der Rapakivigranite sei das beinahe

Fig. 9. Myrmekite in a granite from Bohuslän in Sweden. × 55. Crossed nicols. From. P. J. Holmquist's memoir.

gänzliche Fehlen der wohlbekannten mikromorphologischen Bildungen *Myrmekit* und *Quartz de corrosion* erwähnt. Wie Högbom betont hat, unterscheiden sich die postarchäischen Granite von den Urgraniten durch das Fehlen oder wenigstens durch die sehr unbedeutende Ausbildung pegmatitischer Massen». (p. 87—88).

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[1] l. c. p. 445.

[2] cf. S. J. Shand, On Borolanite and its Associates in Assynt (Sec. Comm.) Transactions Edinburgh Geol. Soc. Vol. IX, Part V, 1910, p. 385, p. 416, fig. 1 and 2, plate XXXIX.

The younger Archæan granites (durchbrechende archäische Granite), Stockholm granite, &c., possess a micro-structure which is characterized by »quartz de corrosion», and »quartz vermiculé»:

»Als »quartz vermiculé» oder besser ***Myrmekit*** bezeichnet man bekanntlich das eigentümliche mikropegmatitähnliche *Zusammenwachsen von Quarz und Plagioklas*, die sich als blumenkohlähnliche Aggregate aus den Fugen der grösseren Körner hier und da in den Mikroklin verbreitet. (Taf. 17, Fig. 10)» (p. 115—116). Through the courtesy of Prof. Holmquist I am able here to reprint this microphotograph (fig. 9).

»Alle diese Strukturzüge sind dem Granit und Gneiss der metamorphischen Gebiete eigen, und sie kommen in ganz unmetamorphosierten Graniten nicht vor.»

About the Fellingsbro granite he says p. 131 that myrmekite and undulating contours are very common phenomena. He also mentions their occurrence, where plagioclase borders to microcline, in the Jerna (p. 138), Rätan (p. 139), Refsund (p. 141) and Alö (p. 153) granites, and in several Småland granites (p. 148), but he has not found it in the Wirbo granite (p. 151) nor in any thin section of the Filipstad granites (p. 171). The same is the case with the Åmål granite (p. 176) and the vein granite of the järngneisregion of western Sweden (p. 221). In the granites of Upland it is again present (p. 184) and also in the Lina granite (p. 197) and other granites of Norrland.

Lacroix has described (1907) an intergrowth of orthoclase and a monorefringent mineral which he thinks is sodalite, occurring in a monzonite or leucite (sommaite) from Monte Somma, with the following words: [1]

»Parfois, l'orthose, au voisinage de la leucite, présente une structure vermiculée avec un minéral isotrope moins réfringent qu'elle (fig. 6, pl. VII), que j'attribue à la sodalite, la roche donnant parfois une faible réaction du chlore. Peut-être est-ce là une transformation de l'ordre de celle qui donne un mélange d'albite et d'*eucryptite* à structure vermiculée aux dépens du triphane de Branchville »

Backlund made (1907) the following observations on myrmekite in acid gneisses from northern Siberia[2]:

»An der Grenze zwischen Orthoklas und Plagioklas wuchert überall sehr feiner *Myrmekit* vom Plagioklas in den Orthoklas hin-

[1] A. Lacroix, Étude minéralogique des produits silicatés de l'eruption de Vésuve. Nouv. Arch. du Museum. 4 Sér. T. IX, 1907, p. 148.

[2] H. Backlund, Über ein Gneissmassiv im nördlichen Sibirien. Trav. Musée Géol. Pierre le Gr. St. Pétersbourg. Tome I, 1907, p. 118—119.

ein, doch scheint er an gewisse Texturrichtungen des Gesteine gebunden zu sein: Schliffe, die das Gestein senkrecht zur Parallelstruktur trafen, zeigen meist keine Spur von Myrmekit, während Schliffe in der Ebene der Paralleltextur Myrmekitbildung in Massen aufweisen; dieses Verhalten findet vielleicht darin eine Erklärung, dass die Plagioklase in der Texturebene fast durchweg eine bestimmte, gleichförmige Orientierung aufweisen, und der Myrmekit, wie Becke erwähnt, an bestimmte Richtungen des Plagioklases gebunden ist. Auch zeigen die äussersten Ausläufer der Plagioklassubstanz im Myrmekit in $\perp \alpha$ orientierten Schnitten des Plagioklases eine merkbare Abnahme der Auslöschungsschiefe, also ein Sauerwerden, wie sie schon Petrascheck beobachtet har. Im übrigen machen sich die von Becke aufgestellten Existensbedingungen vollkommen geltend bis auf eine: wo ein Individuum des Kalifeldspats von drei Seiten vom Plagioklas umsäumt ist, an der vierten dagegen an Quarz grenzt, macht sich manchmal ein Übergreifen des Myrmekits auf diese Seite hin bemerkbar und der Kalifeldspat ist doch von allen vier Seiten von Myrmekit umgeben, der sich also auch zwischen Quarz und Orthoklas findet. Häufig begegnet man mehreren Generationen des Myrmekits: an dem quarzfreien Saum der ersten Generation haftet sich eine zweite, dann eine dritte an diese, und die Quarzstengel werden in jeder Generation successive feiner, bis sie kaum zu unterscheiden sind; auch wird der Plagioklas des Myrmekits, wie die Lichtbrechungsunterschiede zeigen, anscheinend immer saurer. Mehr als vier Generationen konnten, vielleicht der Feinheit wegen, nicht unterschieden werden.»

Trüstedt mentions in his description of the orefield of Pitkäranta (1907) a »greisen», occurring at the pit Franziska, that contains myrmekite. On both sides of a fracture, which has been filled with quartz, the neighbouring granitic gneiss has been changed into a rock consisting mainly of quartz and mica. This zone has a breadth of about one meter. In a note Trüstedt remarks:[1]

»Nach freundlichen brieflichen Mittailungen von Herrn Professor D:r R. Beck beobachtete er in einem Dünnschliffe dieses greisenähnlichen Gesteins die von J. J. Sederholm Myrmekit genannte, eigentümliche, an die eutektische Struktur gewisser Legirungen erinnernde warzenähnliche Verwachsung von Feldspat und Quarz, welche letzterer als sekundär im Zusammenhang mit kontaktmetamorphen Prozessen entstanden ansieht. Diese Erklärung

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[1] Otto Trüstedt, Die Erzlagerstätten von Pitkäranta am Ladoga-See Bull. Comm. géol. de Finlande N:o 19, 1907, p. 145.

ist offenbar auch für das obengenannte Vorkommen die am nächsten liegende.»

Becke published in 1908 a very important memoir concerning the myrmekite in which he arrives at the following conclusions:

1. Der Myrmekit besteht aus halbrunden oder kegelförmigen oder krustenartigen Partien von Plagioklas mit wechselndem, aber meist niedrigem Anorthitgehalt, welche von gekrümten, bisweilen verästelten Quarzstengeln durchwachsen sind. Die Quarzstengel sind in der Regel partienweise Teile desselben Individuums.

2. Myrmekit findet sich ausschliesslich im Zusammenhang mit Kalifeldspat (Mikroklin), und zwar am häufigsten in die Rinde der Mikroklinkörner eingesenkt, dort wo diese an Plagioklas grenzen, nicht aber an der Grenze gegen den Quarz. Bisweilen umsämt er auch im Mikroklin eingeschlossene Plagioklase und siedelt sich auch auf Klüften und Sprüngen des Kalifeldspates an.

3. Es besteht kein konstantes Verhältnis zwischen der Grösse der Kalifeldspates und der an seinem Rande auftretenden Myrmekitzone. Der Myrmekit kann den Kalifeldspat auch völlig verdrängen.

4. Der Plagioklas der Myrmekitkörner hat keine gesetzmässige Orientierung zum Kalifeldspat, in den er eingesenkt ist, aber er erweist sich häufig als orientierte Fortwachsung benachbarter Plagioklase. Die Myrmekitpartien setzen sich selten an die P-Flächen des Plagioklases, häufig dagegen an die Vertikalkanten, an die *y*-, *x*- und *o*- Flächen. Nur wenn Myrmekit als Fortwachsung an orientierten Plagioklaseinschlüssen des Mikroklins auftritt, ist er natürlich so wie diese parallel zum Wirt orientiert.

5. Der Myrmekitfeldspat grenzt sich gegen den Kalifeldspat stets durch konvexe Flächen ab und die Quarzstengel sind divergent strahlig und ungefähr normal zu dieser Oberfläche gestellt; die gabelig verästelten Quarzstengel richten den offenen Winkel der Gabel immer dieser Oberfläche zu. Hierdurch entsteht der Eindruck, als würde der Myrmekit stets einwärts in den Kalifeldspat hinein wachsen. In frischen Gesteinen erscheint die Grenze zwischen Kalifeldspat und Myrmekit stets vollkommen scharf, bisweilen etwas gekerbt oder gezähnelt.

6. Die Zusammensetzung des Plagioklasgrundes im Myrmekit schwankt, wie es scheint, mit der Beschaffenheit des Gesteins, in dem er auftritt. Durch Vergleichung der Lichtbrechung mit der

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[1]) E. Becke, Über Myrmekit. Mitt. der Wiener Mineralog. Gesellsch. Tschermaks Min. u. Petr. Mitt. XXVII, 1908, p. 381—390.

der Quarzstengel lässt sich die Bestimmung leicht vornehmen. Je basischer das Gestein im ganzen, je anorthitreichere Plagioklase es enthält, desto anorthitreicher ist auch der Plagioklasgrund des Myrmekit. — —

7. Die Quarzmenge im Myrmekit unterliegt Schwankungen, die mit dem Anorthitgehalt des Plagioklasgrundes in Beziehung stehen. — —

Die Art des Auftretens des Myrmekit, die augenfällige Bindung an Mikroklin, seine Entwicklung dort, wo Plagioklas an Kalifeldspat grenzt, das Fehlen an den Quarz-Mikroklingrenzen, die parallele Orientierung des Plagioklasgrundes zu benachbarten Gesteinsplagioklase, die Struktur, welche gleichzeitige Bildung von Plagioklas und Quarz beweist und ein Wachstum des Gebildes vom Rand des Kalifeldspatkornes einwärts vermuten lässt, alle diese Momente drängen dazu, für den Myrmekit eine sekundäre Entstehung anzunehmen. Damit soll gesagt sein:

Die Verdrängung des Kalifeldspates durch den Myrmekit muss zu einer Zeit stattgefunden haben, als der Kalifeldspat schon vorhanden war, also nach seiner Krystallisation, sonst wäre das Vordringen des Myrmekit längs Sprüngen im Mikroklin nicht zu verstehen. — —

Mit der eigentlichen Kataklase hat Myrmekit, wie ich glaube (und wie auch Sederholm andeutet), nichts zu tun. Denn gegenüber der kataklastischen Zertrümmerung verhält er sich passiv. Wenn sich in den alpinen Zentralgneisen um Mikroklinaugen Gleitflasern von Muskovit entwickeln, so bilden sie sich ausserhalb der Myrmekitsäume, schneiden eher die Wurzeln der Myrmekitzapfen durch und diese bleiben im Feldspatauge stecken.

Was mich bei diesen Gebilden am meisten gefesselt hat, ist aber die Beziehung zwischen Quarzmenge und Anorthitgehalt des Feldspatgrundes. Dieses Abhängigkeitsverhältnis in Verbindung mit den übrigen Eigenschaften und dem Auftreten des Myrmekits legt die Auffassung nahe, dass sich Myrmekit aus Kalifeldspat unter Ersatz des K durch die äquivalente Menge Na, beziehungsweise Ca bilde. Diese Hypothese gestattet die Quarzmenge im Myrmekit mit dem Anorthitgehalt des Plagioklasgrundes in eine quantitative Beziehung zu setzen, die durch die Beobachtung geprüft werden kann.»

Becke points out, that his observations on myrmekites of different composition and measurements according to the Rosiwal method in general well agree with his theoretical deductions and seem to show that the quantity of quartz in the myrmekite varies in the same proportion as the amount of anorthite in its plagioclase. He gives the following table:

	Anorthitgehalt. %	Index
Albite	0—5	∞—17.0
Oligoklas-Albit....................	5—16	17.0—5.0
Saurer Oligoklas	16—22	5.0—3.8
Basischer Oligoklas................	22—30	3.8—2.7
Saurer Andesin	30—41	2.7—1.9
Basischer Andesin	41—48	1.9—1.6

In concluding, Becke makes the following statement:

»Ganz abgesehen von diesen merkwürdigen Quantitätsverhältnissen, die durch die aufgestellte Theorie ziemlich gut dargestellt werden, scheint aber dem Auftreten des Myrmekits noch eine fernere Bedeutung zuzukommen. Die Bildung des Myrmekits auf Kosten des Kalifeldspats bindet Na und Ca in einer bestimmten Entwicklungsphase des Gesteins und macht K frei. Sollte nicht hierin eine der Quellen liegen für eine ganze Reihe von Bildungen, die den Petrographen manche Schwierigkeiten bereiten, aber durch die Aufweisung einer solchen Kaliquelle viel von ihrer Befremdlichmeit verlieren?

Ich denke dabei an die mannigfaltigen Glimmerbildungen in den Tiefengesteinen, von denen manche evident späterer Bildung sind als die primäre Erstarrung des Gesteins; an die häufige Bildung von Biotit auf Kosten der Hornblende, an die häufige Entstehung von Muskovit, bezüglich dessen bald primäre, bald sekundäre Entstehung behauptet wird; endlich an die wohl kaum abzuleugnende Abgabe von K an den Kontakthof der Tiefengesteine, die durch die stets reichliche Glimmerbildung in den Kontaktgesteinen verraten wird.

Bemerkenswert ist noch, dass die Ersetzung von Kalifeldspat durch Myrmekit zu den raumsparenden Vorgängen gehört. Die Ersparnis beträgt für jede Molekel Albit 109.4 — 100.3 = 9.1 oder 8.3 % des ursprünglichen Volumens; für jede Molekel Anorthit 218.8 — 192.3 = 26.5 oder 12.1 % des Volumens von Kalifeldspat. Der Vorgang müsste somit durch Druck und Pressung begünstigt werden.»

Schwantke[1] while reasoning (1909) over the rôle of the lime-silicate which occurs mixed with the potash silicate $K_2Al_2Si_6O_{16}$ in orthoclase built up theoretical conclusions of much interest, also concerning the probable process of formation of the myrmekite. It is

[1] A. Schwantke, Die Beimischung von Ca in Kalifeldspat und die Myrmekitbildung. Centralbl. für Min. Geol. u. Pal. 1909, p. 311—318.

generally thought that the lime occurs as the anorthite-silicate $Ca\,Al_2\,Si_2\,O_8$. A higher amount of this silicate will lower the $Si\,O_2$-amount in orthoclase, while a higher amount of the albite-silicate will increase it. It will sink more by addition of the former silicate than it rises by addition of the same amount of the latter Thus by addition to orthoclase of equal quantities of *Ab* and *An* the amount of silica will be lowered.

Some analyses are in accordance with these assumptions, but others are in conflict with them. In order to make the formulæ of albite, anorthite and orthoclase more analogous to each other, we may write them

$Na_2\,Al_2\,Si_2\,Si_4\,O_{16}$
$Ca_2\,Al_2\,Al_2\,Si_4\,O_{16}$
$K_2\,Al_2\,Si_2\,Si_4\,O_{16}$

But if there is to be a real isomorphous substitution of equivalent amounts of Na and K for K and Ca, it is necessary to have a Ca-silicate $Ca\,Al_2\,Si_6\,O_{16}$. Schwantke thinks that the assumption of the existence of such a silicate would well account for the results of many analyses of orthoclases containing lime.

He adopts the theory of Vogt who thinks that the microperthite is formed by an »Entmischung» of the soda and lime contents of the felspar silicates in the *solid* phase. If now the lime would be present as a constituent of the hypothetical silicate $Ca\,Al_2\,Si_6\,O_{16}$, $Si\,O_2$ would be liberated at its »Entmischung», which is not the case. It is therefore more probable that in this case the lime-silicate has had the constitution $Ca\,Al_2\,Si_2\,O_8$.

But by formation of myrmekite, $Si\,O_2$ has been formed simultaneously with plagioclase, and, according to Becke, in corresponding quantities. If now the lime silicate should have the hypothetical composition $Ca\,Al_2\,Si_6\,O_{16}$, this would give the same result as that according to the formulæ of Becke. However, we might then, according to Schwantke, regard the whole process as an »Entmischung» in the solid phase. The plagioclase of the core would have simply acted as a »germ crystal» which has initiated the re-crystallization. The only difficulty presenting itself, is that at some time the orthoclase has been entirely substituted by myrmekite, but Schwantke is of the opinion that in this case a metastable mixture of the silicates $Na_2\,Al_2\,Si_6\,O_{16}$ and $Ca\,Al_2\,Si_6\,O_{16}$ may have existed from the beginning.

The fact that the plagioclase of the myrmekite is rather poor in lime seems to him to be well in accordance with these assumptions, considering that there is generally much more soda present in the orthoclase, than lime.

Gavelin mentions (1910) intergrowths of felspar and quartz occurring in the fragments of granites included in the gabbros of the Loftahammar-region in Sweden as follows (in English translation:[1]

»Structurally this granite (inasmuch as I could find, however only the coarse varieties which occur in the centre) is characterized by beautiful implication structures. Both potash felspars and plagioclase, as well as biotite form with quartz micropegmatitic intergrowths (Plate III, Figs. 1 and 2). Also scapolite partly occurs in granophyre-like intergrowth with the felspars, although it also in the usual way forms border-zones around them and penetrates them as more irregular string-like zones. The quartz-felspar micropegmatite structure somewhat resembles myrmekite. Frequently also small, typical myrmekite quartz-oligoclase warts are seen protruding in the usual way into the microcline. It can hardly be doubted that the myrmekite in question is of the same character as the micropegmatitic intergrowths of quartz and felspar.

In my opinion the implication structures in question are genetically quite analogous to the micropegmatitic structures which in so many places in southern Sweden have originated by an intense contact action of post-Archæan diabases on their neighbouring rocks, or on included fragments.»

Brouwer has observed (1910) myrmekite-like intergrowths of orthoclase and zeolites in an aegirine-foyaite from Transwaal. His description reads in translation as follows[2]:

»At last merits to be mentioned a peculiar granophyric intergrowth, probably of zeolites with unchanged sodalite (Fig. 1, Pl. I). In appearance they are very similar to the intergrowths of orthoclase and sodalite which *A. Lacroix* mentions from the orthoclase crystals of the sommaite (Somma), where those are adjacent to leucite crystals. An analogous structure also shows the spodumene from Branchville (Conn.) which has been changed into an intergrowth of albite and eucryptite of lithium nepheline.»

In the description to Fig. 1, Plate I, (= fig. 10 in the present treatise) which shows a very typical symplektitic structure, Brouwer says:

[1] A. Gavelin, Om relationerna mellan graniterna, grönstenarna och kvartsit-leptit-serien inom Loftahammar-området. Sveriges Geol. Und. Ser. C. N:o 224, 1910, p. 56—57.

[2] H. A. Brouwer, Oorsprong en Samenstelling der Transvaalsche Nepheliensyenieten Ac. Diss. Gravenhagen, 1910, p. 40.

»The sodalites are in the rock very much changed to zeolites; the two components of these intergrowths show the characters of the sodalite and the zeolites.»

In a noseane-micromonzonite from the Archipel of Los in French Guinea Lacroix has observed (1911) very similar things:[1]

»Enfin il me reste à signaler une particularité très remarquable, qui demande une discussion. On a vu plus haut que le plagioclase est inclus dans l'orthose; très fréquemment, entre les deux minéraux, se trouvent (pl. V, fig. 3 à 5) de petites plages, qui ressemblent d'une façon frappante à celles qui, dans les granites, renferment le quartz vermiculé, association que M. Sederholm a proposé de désigner sous le nom de *myrmékite.* Ici, cette structure vermiculée

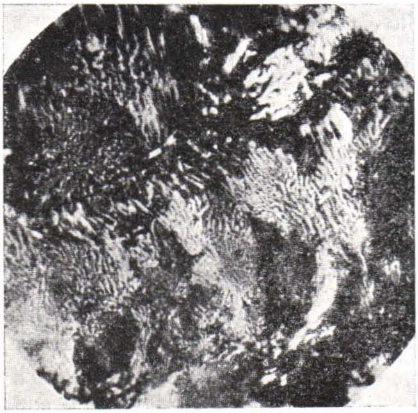

Fig. 10. Intergrowth of orthoclase and sodalite in ægirine-foyaite from Leeuwfontein in Transwaal. Polarized light. × 135. Reprinted from Brouwer's memoir.

(pl. X, fig. 6) est constituée par l'association d'un minéral biréfringent qui est certainement de l'orthose, car il est parfois possible de constater sa continuité avec les grandes plages d'orthose normale de la roche et une substance monoréfringente incolore, dont je n'ai pu déterminer la nature. Elle n'est constituée ni par une zéolite, ni par un minéral du groupe haüyne-noséane, ni enfin par de la leucite, car sa réfringence est plus grande que celle de l'orthose.»

Tschirwinsky directly opposed (1911) the theory of Schwantke, as well as the explanation given by Becke.[2] It is more probable

[1] A. Lacroix, Les syénités néphéliniques de l'archipel de Los. Nouv. Arch. du Muséum. 5 Sér. Tome III, 1911, p. 53.

[2] P. H. Чирвинскій, Количественный минералогическій и химическій состаръ гранитовъ и грейзеновъ. Исданіе Алексѣевскаго Донского Политехическаго Института. Москва, 1911, p. 608—613.

that the lime content of the orthoclase occurs as anorthite-silicate than in the hypothetical silicate postulated by Schwantke. The relative amounts of felspar and quartz in the myrmekite agree well with the composition of the common graphic intergrowths of these minerals which Tschirwinsky explains, according to the theory of Vogt, as eutectic mixtures. He also regards the myrmekite as a primary structure.

Luczizky devotes, (1911) in his interesting memoir about the rapakivi granites of the Kiew region, considerable attention to the question regarding the origin of myrmekite. I reprint this part of his memoir in English translation: [1]

»Myrmekite. Myrmekite or vermicular quartz occurs in the Kanewski rapakivi in rather great quantities either as oval or round grains of plagioclase, intergrown with thinner or thicker rods of quartz in varying quantities, or as border-zones around the plagioclase grains which are intergrown with a greater quantity of such rods.

Especially the myrmekite often occurs at the boundary between grains of plagioclase on the one side, of microcline on the other, whereby it most frequently forms separate round grains, which are often elongated along the boundary between both minerals; sometimes the grains of myrmekite are very much elongated and show more flattened forms. Not seldom one may observe that along the boundary between microcline and plagioclase occurs a zone of such rounded or flattened grains, whereby in all these grains the vermicular rods are perpendicular against the boundaries of the minerals between which they are situated. The size of these rods is variable; their thickness varying between 0,002 and 0,005 mm. In those cases where the sections are normal against the longest diameter, one is able to state that the intersections generally show isometrical dimensions with irregular rounded forms, and consequently the rods are not longitudinal sections; often in such cases transversal sections occur which resemble the quartz crystals in some pegmatites.

In other rarer cases quite similar grains of myrmekite, sometimes also as a zone of flattened grains, occur along the boundary between two grains of microcline; a connection between such a myrmekite and the greater grains of plagioclase may exist below the thin section, although one is not able to observe it in the slide.

It rarely occurs that myrmekite is also found at the boundary between grains of quartz and microcline, or of quartz and plagio-

[1] В. Н. Лучицкій, Рапакиви Кіевской губерніи и породы, его сопровождающія. Исвѣстіи Варшавск. Полит. Інститута 1911 г. Варшава 1912, p. 60—66.

clase. In such cases the quantity of the myrmekite is very small. Also in such a position of the myrmekite it is not possible to exclude the possibility of its connection with myrmekite which lies between plagioclase and microcline, as pointed out by Becke.

Sometimes myrmekite occurs in very great quantities as fine-grained aggregates with an average diameter of the grains of 0.15 mm. In other cases those grains are arranged as chains along the boundaries between plagioclase and microcline grains, or two grains of microcline, and are followed by grains of transparent quartz which otherwise shows the same form as the myrmekite grains.

A somewhat different type of myrmekite is found in the case, where the coarser grains of plagioclase, sometimes over an extensive area, are intergrown with a great and, in some cases, exceptional quantity of worm-like quartz rods. These rods are sometimes thin, sometimes rather thick, and, in some cases, nearly parallel with each other, while in other cases again they have an oblique position to the others.

Also the idiomorphous plagioclase which is enclosed in microcline is sometimes surrounded by a narrow zone of myrmekite with slender worm-like rods of quartz.

The question referring to the origin of the myrmekite cannot yet be regarded as definitely decided, in spite of numerous observations and much accurate research concerning the myrmekite of many rocks.

— — My own observations on the myrmekite of the rapakivi of the Kanewski type have shown that there is actually a near relation between the composition of the plagioclase of the myrmekite and the quantity of quartz rods.

For andesine the relation was $i = 1.7 - 2$.

For acid oligoclase $i = 4 - 4.2$.

In some specimens it is possible to observe the immediate transition between the plagioclase of the myrmekite and plagioclase which forms perthitic inclusions.

All premisses are in favour of the conclusion that the myrmekite is a secondary product and is also most closely connected with the alteration and dissolution of the primary isomorphous mixture of potash-sodium-lime-felspar».

Luczizky thinks that it is not necessary hereby to assume the existence of the silicate postulated by Schwantke, and then concludes:

»On the other hand the occurrence of myrmekite not only in plutonic rocks but also in a great many crystalline schists, not seldom in such as cannot be referred to the orthogneisses, orthoamphibolites and similar groups, absolutely is at variance with the assumption of a connection between the structure now described and such typical magmatic structures as the micropegmatite. The occurrence of myrmekite in the rapakivi from the Kanewski area, far from the microcline, is not at variance with the theory here proposed, because the small grains of felspar may have been entirely changed into myrmekite».

Sustschinsky has observed myrmekite in several granites from southern Finland, and is inclined to regard it as a »magmatic-eutectic» structure.[1]

Geijer communicated, (1912) in his paper on basic »Schlieren» in some syenites from northern Sweden, very important observations concerning myrmekite and »myrmekite-perthite». With the latter name he designates a myrmekite-like structure, consisting of an acid oligoclase and vermicular microcline. I reprint here his communications *in extenso*, because of its great interest. Dr. Geijer has also kindly lent me a photograph of this myrmekite-perthite, which is reproduced in fig. 16, plate III.

Geijer's description reads as follows: [1]

Myrmekit und Myrmekiperthit. Wie oben angegeben, sind die kleineren Oligoklaskörner sehr oft myrmekitisch; dagegen sieht man nur sehr selten Myrmekit an der Grenze zwischen den grösseren Plagioklasen und Kalifeldspat. Der Myrmekit zeigt sonst in allen wesentlichen Hinsichten die Eigenschaften, die in Becke's Zusammenfassung als Charakteristika des Myrmekits angegeben sind. Dem sauren Charakter des Oligoklases entsprechend ist die Quarzmenge gering, die Stengel sind im allgemeinen fein. Zonalbau im gewöhnlichen Sinne kommt bisweilen vor, der Albitsaum ist dann quarzfrei. Der Myrmekit gehört in unseren Gesteinen hauptsächlich zu den wirklich quarzsyenitischen Typen, er ist spärlich oder fehlt gänzlich in den plagioklasreichen Gliedern, wo an seiner Stelle der später zu beschreibende Myrmekitperthit auftritt. Im ganzen genommen bildet er einen Reaktionssaum zwischen den grossen Perthitindividuen und der Oligoklassubstanz der Zwischenmasse. Dass aber nicht unbeträchtliche Stofftransporte stattgefunden haben, ergiebt sich aus dem gelegentlichen Auftreten von Myrmekitwarzen nicht nur inmitten der Perthitkristalle, sondern auch an der Grenze zwischen Perthit und Quarz. Fig. 2, Taf. 1 giebt ein typisches Bild von der »Angriffsmethode» der Myrmekitwarzen.

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[1] l. c. p. 266—267 and 431.

[2] Per Geijer, Basische Schlierengebilde in einigen nordschwedischen Syeniten. Geol. För. i Stockholm Förh. Bd. 34, 1912, p. 197—201.

Der Myrmekit ist also hauptsächlich an die perthitreichen Syenitphasen gebunden. Wenn wir zu den Varietäten übergehen, deren herrschender Feldspat Plagioklas (mit Orthoklas- oder Perthitdurchwachsungen) ist, so tritt ganz allmählich an die Stelle des Myrmekites ein Gebilde, das ich als ***Myrmekitperthit*** bezeichnen möchte. Dieser ist in Form und Auftreten dem Myrmekit ganz ähnlich, unterscheidet sich aber von ihm durch die Zusammensetzung, indem er aus Plagioklas mit Stengeln von ***Kalifeldspat*** besteht. Die beiden Feldspate in einer Myrmekitperthitwarze sind in kristallographischer Hinsicht parallel orientiert, wie in Perthit und Antiperthit. Dagegen tritt der (quantitativ immer untergeordnete) Kalifeldspat hier in keiner der in gewöhnlichen Feldspatverwachsungen vorkommenden Formen auf, sondern als Schläuche, die zuweilen verästelt sind und sich von den Quarzstengeln des Myrmekites nur durch ihre etwas gröbere Ausbildung unterscheiden (vgl. Tafel 1, Fig. 3; [= fig. 16, plate III, in this treatise] Tafel 2, Fig. 1). Diese Schläuche nehmen keine bestimmte Lage zu den Symmetrieelementen der Feldspate ein. Der Plagioklas ist immer ein saurer Oligoklas wie in dem hier vorkommenden Myrmekit, und zeigt bisweilen Albitlamellierung, die Spaltrisse sind meistens schlecht ausgebildet; Zonalbau habe ich nicht beobachtet. Der Kalifeldspat unterscheidet sich von dem Oligoklas durch seine schwächere Licht- und Doppelbrechung, auch ist bisweilen die charakteristische Kreuzlamellierung des Mikroklins sichtbar. In einigen Fällen enthält der Mikroklin zierliche perthitische Albitspindeln. Das Mengenverhältnis Oligoklas: Mikroklin in den verschiedenen Schnitten ist recht wechselnd, etwa zwischen 3 : 1 und 1 : 1; doch kan etwa 2.5 : 1 als das häufigste bezeichnet werden.

Hinsichtlich der Form und des Auftretens verhält sich der Myrmekitperthit, wie schon angegeben, dem Myrmekit ähnlich. Es zeigt sich das mit aller Deutlichkeit bei einem Vergleich der Taf. 1, Fig. 2 und Taf. 2, Fig. 2. Die Warzenform ist dieselbe, und die Warzen treten sowohl am Rande des Zentralfeldspates (mit diesem Ausdruck möchte ich den grossen angegriffenen Feldspat bezeichnen) als, wenn auch mehr spärlich, in seinem Inneren auf. Dagegen treten sie, häufiger als die Myrmekitwarzen, auch in der feinkörnigen Zwischenmasse auf, ohne sichtbaren Zusammenhang mit einem grossen Zentralfeldspat. Dieser Unterschied scheint jedoch von geringerer Bedeutung zu sein.

Die angegriffenen Zentralfeldspate sind am meistens die Durchdringungen von saurem Plagioklas und Kalifeldspat und die antiperthitischen Säume vieler Plagioklase, also Partien, wo Na-Ca- und

K-Feldspat unregelmässig wechseln. Nur selten findet man Myrmekitperthit, der in Perthit von dem gewöhnlichen Typus [1] eindringt, und in diesen Fällen scheint sein Auftreten mit dem Vorkommen kleiner Plagioklaseinwachsungen im Perthit verbunden zu sein. Zu den betreffenden Partien von abwechselnd Plagioklas und Kalifeldspat verhalten sich die Myrmekitperthitwarzen wie zu einem homogenen Medium, und es ist klar, dass sie nicht nur Kalifeldspat ersetzen, sondern auch z. T. Plagioklas. Zwischen dem Plagioklas einer Warze und dem angrenzenden Plagioklas des Zentralfeldspates ist nur selten ein deutlicher Lichtbrechungsunterschied bemerkbar, die chemische Zusammensetzung muss daher annähernd gleich sein. Wo mehrere Warzen einen Zentralfeldspat angreifen, sind die Mikroklinkomponenten der verschiedenen Warzen nur zufällig optisch gleich orientiert, sie können also nicht unverzehrte Reste des aufgefressenen Kalifeldspat darstellen. Der Oligoklas der Warzen nimmt auch keine bestimmte Lage zu dem Plagioklas des Zentralfeldspates ein.

Offenbar haben dieselben Faktoren, die die Bildung des Myrmekites im Hauptsyenit und den ihm nahestehenden Gesteinen am Erzschurf bewirkt haben, in den plagioklasreichen Gliedern zur Ausbildung von Myrmekitperthit geführt. Im ersteren Falle hat eine Reaktion zwischen K-Na-Feldspat (Perthit) und der anorthitreicheren Plagioklassubtanz der Zwischenmasse stattgefunden, in dem anderen sind nur an die Stelle des Perthites die Durchdringungen von Plagioklas und Orthoklas (oder Perthit) getreten. Der durchschnittliche Anorthitgehalt der Zwischenmasse ist in den myrmekitperthitführenden Gliedern kaum höher als in den myrmekitführenden Gesteinen. Übrigens hat ja Becke gezeigt, dass auch die Reaktion zwischen recht basischem Plagioklas (basischem Andesin) und Kalifeldspat zur Ausbildung von typischem Myrmekit führt, der sich nur durch den höheren Quarzgehalt von dem Myrmekit mit saurerem Plagioklas unterscheidet. Dem Anschein nach ist daher die Ursache der Myrmekitperthitbildung in der Natur des Zentralfeldspates zu suchen, der der angreifenden Plagioklassubstanz ein Gemisch von K- und Na-Ca-Feldspat entgegenstellte. Nichts deutet auf eine Zufuhr von Substanz, die nicht ursprünglich zu dem Gestein gehörte, es müssen sich also die Stabilitätsbedingungen für die drei Feldspatarten nach dem Ausscheiden der grossen Durchdringungsfeldspate geändert haben. Analog ist das Verhältnis bei dem

[1] In den Gesteinstypen, wo der Myrmekitperthit auftritt, sind ja solche Perthite viel seltener als die oben erwähnten Durchdringungen.

Myrmekit. Der Umstand, dass der Myrmekitperthit so offenbar ein Gemisch von Kalifeldspat *und Plagioklas* ersetzt, bezeichnet keinen Unterschied gegenüber dem Myrmekit, denn dieser greift ja eben perthitische Kalifeldspate an (vielleicht war damals der Zerfall des K-Na-Feldspates noch nicht eingetreten, was aber von geringer Bedeutung ist). Der grösste Unterschied zwischen den beiden Gebilden, Myrmekit und Myrmekitperthit liegt darin, dass bei jenem das Kali gänzlich entfernt ist, während es bei der Myrmekitperthitbildung in den neugebildeten Körper eingetreten ist, so dass dieser in seiner durchschnittlichen Zusammensetzung nicht merklich von der Substanz abweicht, die früher seinen Raum einnahm.

Wie aus dem oben citierten Aufsatz Becke's hervorgeht, können wohl einige Seiten des Problems der Myrmekitbildung als erklärt betrachtet werden, aber mehrere Fragen stehen noch offen. Die Struktur der Gesteine vom Rackberget deutet auf ziemlich bedeutende Umlagerungen, die nach dem Auskristallisieren der grossen Feldspate stattgefunden haben. Ausser Myrmekit findet man auch nicht selten Biotit, der in die Feldspate hineindringt, eine Erscheinung, die für Becke's Erklärung der Myrmekitbildung spricht. Die Feldspate zeigen ja, wie schon oben erörtert worden ist, deutliche Spuren von Druckwirkungen. Die Myrmekitbildung scheint aber nicht mit der mehr mechanischen Deformation in Zusammenhang zu stehen, denn die Struktur der Zwischenmasse einschl. der Aggregate von Myrmekitwarzen deutet vielmehr auf Kristallisation unter Bedingungen, die denen der Kontaktmetamorphose nahe stehen. Ähnliches ist schon von Sederholm mit Bezug auf die von ihm beschriebenen myrmekitführenden Gesteine hervorgehoben worden. Die äusseren Ursachen der Bildung von Myrmekit und Myrmekitperthit sind natürlich dieselben gewesen».

Gutzwiller has described (1912) a number of intergrowths of different minerals in his memoir on the »injection gneisses» of Tessin in Switzerland, among them also true myrmekite of quartz and plagioclase. Those which occur in the hornblende-biotite-gneiss of Madonna del Sasso in Locarno he describes in the following words: [1]

»Mit dem zwischen granoblastischen Quarz-Feldspatgewebe sich durchziehenden Quarzstreifen sind hin und wieder allerfeinste Myrmekite oder Mikropegmatite vergesellschaftet, oft von solcher Zartheit, dass sie erst bei stärkster Vergrösserung wahrnehmbar werden. Ferner fällt auf, dass mit diesen eckig verzahnten bis

[1] E. Gutzwiller, Injektionsgneise aus dem Kanton Tessin, Inaug.-Dissert. Lausanne, 1912, p. 29—31, 34—35, 37, 39, 44, 52 and 59.

streifenförmigen Quarzen die oben beschriebenen zerfetzten und zum Teil ausgegrünten Biotite verbunden sind und sich gemeinsam mit diesen zwischen den mehr isometrisch entwickelten Gemengteilen durchschlängeln, das mikroskopische Bild neigt daher zu lenticularer Textur.»

In the rock from the Tessin-bridge at Bellinzona he has found very typical myrmekite which he describes in the following way:

»Im mikroskopischen Bilde kommen vereinzelt gröbere myrmekitische Bildungen vor, bei welchen saurer Plagioklas von Quarz durchsetzt ist. Allerfeinste Verwachsungen dieser Mineralien treten sehr häufig auf. Ihre Quarzstengel entwickeln sich oft bäumchenartig, dringen vom Rande her in den Plagioklas ein; hier liegen somit echte Myrmekite vor. Vielfach verlaufen die Quarzstengel parallel, sind oft knieförmig gebogen und es entsteht dadurch eine schriftgranitähnliche Zeichnung, die an Mikropegmatit erinnert. Zwischen diesen beiden Ausbildungen gibt es auch Uebergänge, dermassen, dass in scheinbaren Mikropegmatiten wieder mehr wurmartige Quarzstengel sich vorfinden.

Die Plagioklase der Myrmekite sind vollkommen frisch, zeigen keine Spur von Zersetzungserscheinungen. Der Myrmekit findet sich wie im vorigen Gneis zum Teil da, wo Plagioklas an Kalifeldspat grenzt und erstreckt sich oft zapfenartig in diesen hinein; des weitern tritt er auch auf, wo der Plagioklas mit Quarz in Berührung steht, als ganz allein stehende Bildung. In diesem Punkte weicht der Myrmekit hier von der Becke'schen Prognose entschieden ab; doch wird dies wohl aus folgendem verständlich werden.

Die Quarzstengel und -Würmchen dieser *Myrmekite* löschen oft sämtlich, oft partienweise, einheitlich aus, ersteres besonders bei den allerfeinsten Verwachsungen, an welchen das Mengenverhältnis von Quarz zu Feldspat anscheinend konstant ist; sie dürften daher zum Teil eutektische Gebilde sein.

Die oben erwähnten gitterartig undulös auslöschenden Orthoklase treten meist in der Nähe der allerfeinsten Myrmekite auf, scheinen sogar an diese gebunden zu sein. Feinste Myrmekite finden sich auch in den streifigen Quarzaggregaten und drängen sich zusammen mit Quarz in feinen Zügen zwischen den gröbern Quarz-Feldspatkörnern durch.

Ueberhaupt kennzeichnen sich die salischen Lagen, welche die Dünnschliffe in Streifen durchziehen, durch den Reichtum an Myrmekiten, sowie durch die regellose Durchdringung der Quarz-Feldspatkörner und eine intensive gegenseitige Verzahnung der Quarzindividuen, wodurch ihre Struktur sich als eine fast ausschlesslich pegmatitische zu erkennen gibt. Im Gegensatz dazu finden sich in den Schliffen auch Partien, wo die Ausbildung der Quarze und Feldspäte durchaus kristalloblastisch ist; ihr entsprechen in der obigen Beschreibung die rundlich-polygonalen Körner».

About the myrmekite of the gneiss of Palasio and Pedevilla he makes the following statement:

›Der Schlüssel zu einer richtigen Deutung dieser Erscheinung gibt wohl die nächste Umgebung des Orthoklases. Sie besteht an einer Stelle, wo die Mikroklinstruktur ausgeprägt ist, aus Myrmekiten, deren Bildung nach Früherem auf Durchgasung zurückzuführen ist. Es mögen also Gase in den Feldspat eingedrungen sein und sich zu albitischen Schnüren abgesetzt haben. Infolge diese Stoffzufuhr in Dampfform würden im Feldspat Spannungen hervorgerufen worden sein».

Further he says, in the description of the maculated gneiss of the Verzasca tunnel, the following words about its myrmekite:

›Bei stärkerer Vergrösserung erkennt man aber, dass in diesen scheinbaren Mörtelkränzen sich sehr viele Myrmekite und mikroklinartige Feldspäte vorfinden, welche die grösseren Feldspatkörner umsäumen. Aus diesen eigenartigen Verhältnissen resultiert eine aplitische bis pegmatitische Struktur der salischen Komponenten.

Von den dunklen Gemengteilen zeigt der Biotit, wie oben erwähnt, durch seine fetzigen und zerstückelten Blättchen und Schüppchen im höchsten Masse auffallende Formen, die wiederum auf besondere Art und Weise und zwar nur durch pneumatolytische und magmatische Korrosion entstanden sein können; daneben kommen, wie oben erwähnt, seltener auch ganz normal ausgebildete Blättchen vor.

Eine solche Gestaltentwicklung der hellen und dunklen Gemengteile in ein und demselben Gestein gibt dem mikroskopischen Bilde ein ganz fremdartiges Gepräge. Es zeigt weder eine rein magmatische Struktur — dagegen spricht insbesondere das Auftreten des Biotits in zerstückelten Blättchen und Fetzen — noch eine rein kristalloblastische; denn jene feinsten Myrmekite, die oft erst bei stärkerer Vergrösserung wahrgenommen werden können und von ausgesprochener Frische sind, können unmöglich der gewöhnlichen Metamorphose entsprungen sein, um so weniger, als sie zum Teil echte Mikropegmatite zu sein scheinen».

In the following he speaks in several places about the myrmekitic and eutectic or micropegmatitic intergrowths of felspars and quartz.

About these he says on page 44:

»Aus der Vermischung dieser beiden Gesteinskörper in wechselnden Proportionen sind die Injektionsgneise entsprungen, welche bei schwacher Injektion sich zu erkennen gaben: durch die Zerfetzung der dunklen Gemengteile, den vielgestaltigen, stark verzahnten, oft streifenförmigen Quarz in Verbindung mit einzelnen Myrmekiten, neben einer vorherrschend kristalloblastischen Struktur des Gesteins. Bei Steigerung der Injektion war neben der Zerfetzung der femischen Komponenten eine Zunahme dieses besonders gestalteten Quarzes, eine Anreicherung der Myrmekite und das Erscheinen des Mikroklins zu konstatieren. Bei allerstärkster Injektion gelangte schliesslich die salische Quote mit ihrem aplitischen bis pegmatitischen Gefüge zur Vorherrschaft, während der sedimentäre Anteil mit den kristalloblastischen Ausbildungsformen bis auf spärliche Relikte verschwand und die dunklen Gemengteile immer mehr in den Hintergrund traten».

Further on page 59:

»Die *aplitisch-pegmatitischen* Partien kennzeichnen sich durch eine mehr oder weniger panxenomorphe oder sehr regellose Entwicklung ihrer Gemengteile bei Reichtum an Mikroklin, Myrmekiten und Mikropegmatiten. Letztere beiden Gebilde zeigen auch Uebergänge in einander; damit schlägt sich eine Brücke zwischen Erstarrungsstruktur und solchen, welche durch die Einwirkung von Gasen auf zum Teil schon vorhandene Mineralsubstanzen zurückzuführen sind.

— — Rückblickend auf die früher entwickelte Gesteinsreihe mit zunehmender Injektion (N:o 1—9) erkennt man, dass pneumatolytische Injektion zuerst an den femischen Gemengteilen wahrnehmbar wird, indem diese sich *pneumatophag* entwickeln. Die ersten stofflichen Additionen wurden strukturell an den eigenartig verzahnten Quarzkörnern und -Streifen, sowie an den feinsten Myrmekiten erkannt. Bei den stark injizierten Gneisen wird die Struktur vorherrschend aplitisch-pegmatitisch».

Gutzwiller also gives in the same publication very interesting communications about intergrowths between biotite and quartz, and brings their origin in connection with the myrmekite. On pages 28—29 he says the following:

»Wie in den obigen Gneisen erscheinen auch hier wieder die dunklen Komponenten zerlappt, zerstückelt und zerfetzt, nur noch in viel höherm Masse als dort und insbesondere der Glimmer, welcher infolge davon in seinem Aussehen geradezu an *von Insekten zerfressene Laubblätter* erinnert. — —

Bei stärkerer Vergrösserung erkennt man am ausgegrünten Biotit öfters eine feine Zerfetzung, oder Zernagung seines Randes und eine farblose Mineralsubstanz, die sich zwischen die zerfressenen Glimmerschüppchen schiebt. In andern Schnitten und andern Biotiten ist bei stärkster Vergrösserung ein dendriten-, fjord- oder bäumchenartig verzweigtes Hineindringen von farbloser Mineralsubstanz wahrzunehmen, womit die Ausgrünung des Glimmers verbunden zu sein scheint.

Die farblose Mineralsubstanz selbst ist im Innern des zerfetzten Glimmers der Feinheit der Fäserchen und Würzelchen wegen schwer sicher bestimmbar. Zwischen beiden Mineralsubstanzen ist meist eine deutliche Grenze vorhanden, wobei dann der Biotit stets das höhere Relief aufweist. Es kommt auch vor, das infolge des In- oder Uebereinandergreifens der farblosen Substanz und der Glimmerblättchen die Grenze zwischen beiden verschwommen ist; dabei sind dann die sonst farblosen Würzelchen schwach gelb bis braun, welche Farben nach und nach in diejenige des Biotit übergehen, oder der braune Glimmer ist, wie oben beschrieben, in grünen umgewandelt worden, der seinerseits wieder in braunen übergeht. Aber an mehreren Stellen ist zu beobachten, dass diese farblosen Aederchen und Bäumchen von polysynthetisch verzwillingten Plagioklasen ausgehen, weshalb sie wohl auch aus einer feldspatigen Substanz bestehen dürften.

Auch der *Amphibol* erscheint etwa ausgefranst und gegen die siebartig ihn durchdringende Feldspatsubstanz ausgebleicht; doch sind diese Erscheinungen lange nicht so ausgeprägt wie am Biotit».

Further on page 30—31:

»Ebenso sind die zerfressenen und zerfetzten Biotite und Hornblenden Gestalten, wie sie sich niemals durch Kristallisation aus einem Magma oder durch Umkristallisation im festen Zustande entwickeln; auch den gewöhnlichen Kontaktgesteinen sind sie fremd. Stellt man sich die Frage, unter welcher Einwirkung solche ausserordentlich komplizierten Formen sich etwa bilden könnten, so wird man am ehesten an das Eindringen äusserst dünnflüssiger, hochgepresster Lösungen oder heisser, ätzender Gase denken können, wie solche den pneumatolytischen Erscheinungen zu Grunde liegen. Wir kommen deshalb dazu, diese wurzelähnlichen und fjordartigen Gebilde am Biotit einer pneumatolytischen Injektion zuzuschreiben und ich möchte sie als Injektionsbäumchen oder Injektionsdendriten bezeichnen. Wohl müssen auch die feinen Myrmekite sowie die komplizierten Quarzgestalten als genetisch verwandte Bildungen aufgefasst werden».

On page 52 Gutzwiller says about the corroded hornblende:

»Vermutlich war die Hornblende vor der Intrusion des Aplits im Nebengestein echt kristalloblastisch entwickelt; durch die aplitische Injektion wurde sie angefressen, teilweise eingeschmolzen und umgewandelt, wodurch sie, wie auch der dabei entstehende Augit, ihre jetzigen Formen erlangt haben. Diese Ausbildungsart durch magmatische Korrosion könnte vielleicht als *phagomorph* bezeichnet werden».

Besborodko communicates, (1912) in his petrological paper on the basic differentiations in a granite occurring in the neighbourhood of Tchiriguin in the Province of Kiew, interesting observations concerning the myrmekite, which read as follows:

»Eine Myrmekitbildung ist hier auch überall zu beobachten. Der Myrmekit kommt in Plagioklas wieder in der Regel nur an der Grenze mit Mikroklin vor. Daraus ist eine Analogie zwischen dem Myrmekit und dem oben beschriebenen saureren Rande derselben Plagioklase an der Stelle ihrer Berührung mit Mikroklin ersichtlich. Besonders ist hervorzuheben, dass der Myrmekit und der sauere Rand überhaupt nicht aufeinander gelagert zu finden sind, sondern auf separaten Körnern vorkommen. Es war in manchen Fällen zu erkennen, dass auf einen und demselben Korne ein Myrmekit und ein saurer Rand miteinander abwechselten, als ob ein normal entwickelter Myrmekit plötzlich verschwunden und auf eine bestimmte Strecke von einem sauren Rande ersetzt würde. Ein solcher Plagioklas ist auf Taf. III, Fig. 7 dargestellt: man bemerkt hier in der Mitte des Gesichtsfeldes einen normalen Myrmekit auf der Berührungsstelle mit Mikroklin; etwas höher links an der Peripherie desselben Plagioklases erkennt man statt des Myrmekits einen helleren Streifen, der einen saureren Saum des Plagioklases darstellt; dieser saurere Rand schliesst sich an ein ganz kleines Körnchen des Mikroklines. Der übrige Teil des Plagioklases schliesst sich an den Quarz; hier bemerkt man weder Myrmekit, noch einen saureren Rand. Diese Abbildung überzeugt uns auch darin, dass die Menge der Mikroklinsubstanz keine wichtige Rolle bei Entstehung des saureren Randes spielt; ein und dasselbe Resultat erhält man bei kleinen, wie auch bei grossen Mengen des Mikroklins.

Alle aufgezählte Tatsachen beweisen uns, dass die beiden Erscheinungen — Myrmekit und der saurere Rand (Albitrand bei idiomorphen Plagioklaseinsprenglingen), durch dieselben Bedingungen ihrer Entstehung charakterisiert werden: beide lehnen sich an die Peripherie des Plagioklases und beide kommen ausschliesslich nur

[1] N. Besborodko, Zur Petrographie der Süd-Russischen kristallinischen Tafel. I. Ueber die basischen Schliere im Granit in der Umgebung der Stadt Tschigirin (Gouvernement Kiew). Deutsches Resumé. Inst. f. angew. Min. u. Geol. des Alex.-Donsch. Polyt. in Nowotscherkassk, 1912, p. 145.

dort vor, wo Plagioklas sich an den Mikroklin anstösst. Die Ähnlichkeit in den Entstehungsbedingungen gewährleistet noch nicht die volle Identität der beiden genannten Erscheinungen. Vorläufig kann man den Mikroklin selbst mit einer gewissen Sicherheit für einen sichtbaren Erreger beider Erscheinungen erklären: nur muss hier hinzugefügt werden, dass ein Zusammenhang zwischen dem Mikroklin und dem Myrmekit von den Gelehrten schon längst konstatiert worden ist, die der Frage über die Entstehung dieser rätselhaften Erscheinungen näher getreten sind».

Tronquoy gave (1912) in a very suggestive article in the Bulletin of the French Mineralogical Society a historical review of the different opinions which have been expressed with reference to the myrmekite and resumes several observations of his own, which he made upon his microscopical study of the granite of Villeder (Morbihan) in France[1]. Most of these facts are in accordance with the conclusions of Becke. He remarks however:

»J'ai pu constater que si ses bourgeons, qui penètrent toujours le microcline, sont rares lorsque ce feldspath n'est pas voisin d'un plagioclase, ils n'en existent pas moins quelquefois là où il touche au mica ou même au quartz.

Il n'y a d'ailleurs pas toujours relation d'orientation entre la myrmékite et l'oligoclase voisin, dans le granite cité ci-dessus, et l'on peut à cet égard distinguer deux cas bien distincts: tantôt la myrmékite apparaît sous forme d'une croûte plus ou moins irrégulière, entourant le plagioclase là ou il est moulé par le microcline; l'orientation de la croûte toujours plus acide que la plus péripherique des zones primitives de l'oligoclase, est alors la même que celle de ce dernier, bien que les extinctions ne coïncident naturellement pas (faces g^1 parallèles), mais les clivages sont communs.

— — Dans un second cas, il se produit dans le microcline des bourgeons arrondis; ils y pénètrent parfois profondement et se présentent soit isolés, soit réunis plusieurs ensemble. Tantôt il y a parfaite communauté d'orientation entre un bourgeon de myrmékite et le plagioclase voisin, et l'on peut même observer, sur des sections perpendiculaires à g^1, la continuation, de l'un des minéraux à l'autre, de la macle de l'albite; tantôt au contraire l'orientation de la myrmékite semble parfaitement quelconque, elle est différente dans les divers bourgeons voisins.

— — Je crois que dans bien de cas les émanations ou circulations alcalines ont produit, sur une roche déjà consolidée, des mo-

[1] M. R. Tronquoy, Origine de la myrmékite. Bulletin de la Soc. Franç. de Min. Tome 35, 1912, p. 214—223.

difications variées (Note: Ce sont là des phénomènes d'origine interne; peu après la cristallisation, les émanations peuvent provenir de la région même où les modifications s'accomplissent; plus tard les vapeurs ou eaux alcalines viennent de la profondeur où le refroidissement est moins avancé); la formation de la myrmékite me paraît être une manifestation de ces phénomènes d'autopneumatolyse qui sont si fréquents et dont les effets sont seulement plus ou moins nets. — — De plus petits cristaux pourront, dans certaines circonstances, se développer dans le microcline et s'orienter alors sur lui.

— — L'attaque du microcline paraît se faire sur des points de faible résistance notamment lorsqu'il n'y a pas contact avec les minéraux voisins, et qu'ainsi les émanations, soit liquides, soit gazeuzes, ont pu facilement pénétrer. — —

On peut aussi penser que le plagioclase primitif amorce la cristallisation de celui de nouvelle formation en jouant le rôle d'un germe au sein d'une solution. — —

La myrmekite se développe aussi facilement en partant d'une contact entre deux cristaux de microcline, mais plus particulièrement là où de petits cristaux de nature quelconque, de toute orientation, mal unis entre eux, laissant un passage facile aux imprégnations, touchent au microcline; plusieurs bourgeons d'orientations variées pourront alors prendre simultanément naissance.

La production de la *myrmékite* est donc une phénomène secondaire d'origine profonde et, sans doute, un mode special d'albitisation. Il est naturel que le broyage, à conditions qu'il n'ait pas été postérieur à l'époque où toute circulation alcaline eut cessé, et surtout les phénomènes dans lesquels M. Sederholm voit la cause de la production de la myrmékite aient pu, dans certains cas, favoriser son développement.

Tronquoy has also, in his memoir on the tin-bearing dykes of La Villeder in Morbihan, (1912) devoted much attention to the phenomenon in question. He says, about the granite de la Villeder: [1]

»Une particularité de ce granite est l'abondance du *quartz vermiculé* dans les feldspaths. C'est d'une façon presque constante qu'on voit dans les microclines des gouttelettes d'un feldspath plus réfringent et plus biréfringent remplies de fines veinules courbes de quartz. Très souvent, elles sont le prolongement de plagioclases voisins dont elles possèdent l'orientation; il est même parfois possible d'y suivre la continuation des clivages et des macles, mais on doit remarquer que leur biréfringence est, malgré la communauté d'orien-

[1] R. Tronquoy, Contribution à l'étude des gîtes d'étain. Ibid. Tome 35, 1912, p. 330--331.

tation, généralement plus élevée que celle de la partie principale, et l'ensemble de leurs propriétés permet de s'assurer qu'elles sont formées d'un feldspath acide voisin de l'albite. C'est ainsi qu'une section d'oligoclase perpendiculaire à n_g, s'éteignant sous un très petit angle avec le clivage p est entourée d'une bande dans laquelle l'angle d'extinction devient de plus en plus grand à mesure qu'on se rapproche du bord, pendant que l'angle des axes diminue, et qu'elle se continue en gouttelettes à quartz vermiculé qui s'éteignent sous des angles encore plus considérables.

On peut remarquer que ces portions de feldspath qui passent ainsi très souvent d'une façon tout à fait insensible à un cristal volumineux, paraissent greffées sur ce dernier postérieurement à sa formation. C'est en effet parfois sur une face originellement plane que ces bourgeons ont pris naissance, et leur production plus récente paraît surtout frappante lorsque, bien que de même orientation et en continuation parfaite avec le cristal qui les porte, ils sont beaucoup plus biréfringents et ne s'éteignent pas en même temps que lui, ce qui arrive lorsque ce dernier est resté assez basique jusqu'au bord. Il est possible d'ailleurs de reconnaître même en lumière naturelle la limite de ces bourgeons; ils contiennent en effet toujours en grande abondance ces aiguilles incolores très fines, très réfringentes, à biréfringence élevée et à allongement positif qui se recontrent dans le quartz. C'est un fait constant et que j'ai vérifié sur plusieurs préparations que, fréquentes dans le quartz, elles manquent, le plus souvent, dans le plagioclase, existent parfois en petite quantité dans le microcline, mais sont toujours très abondantes dans ces goulettes de plagioclase qui pénètrent les microclines, qu'elles présentent ou non du quartz vermiculé.

Ces observations prouvent que ces portions de plagioclase sont postérieures aus parties principales, elles sont également postérieures au microcline dans lequel elles se sont développées, et même à la consolidation parfaite du granite. Leur production est la conséquence d'une modification secondaire de la roche, modification dont on peut rechercher les causes et l'âge relatif à celui de la solidification complète du magma.»

Svitalsky has also, like so many other Russian petrologists, been interested in the myrmekite question. In his paper on the monzonites of the Tsipikan river system in Siberia (1913) he speaks about the myrmekite as follows (translated from the Russian):

»Another kind of newly formed minerals which occurs in our rocks is myrmekite, i. e. an intergrowth of plagioclase and quartz. They are obvious by their peculiar form, viz., incisions in the rounded contours of the plagioclases which are turned against the anorthoclase (cryptoperthite).

In two cases I have succeeded in determining the angle 2V for these plagioclases, it being (80—82) 2, which very nearly coincides with the angle 2V, but also at the same time argues in favour of the determination of the mineral as albite.

In some special cases the myrmekite occurs in a peculiar uncommon type, of a reverse character, viz., with the concave side turned against the plagioclase crystals, whereby these look as if they had been resorbed. — —

Concerning the orientation of the plagioclase of the myrmekite in relation to the neigbouring idiomorphous crystals of plagioclase the fact is to be noted that it is generally not conformable. — — Tronquoy's hypothesis — — which explains the formation of the myrmekite by a pneumatolytic action of the plutonic magma — — is too artificial and does not explain the invasion of the myrmekite substance into the idiomorphous crystals of plagioclase, nor its constant composition and analogy with the eutecticum Qu—Pl.

Tronquoy criticises the last mentioned hypothesis of Tschirwinsky on the basis of the occurrence of myrmekite also in metamorphic rocks (orthogneisses). But if so, why do we observe the myrmekite in acid and not in basic rocks, although the basic plagioclases are more easily decomposed than the albite?

If this be explained by the assumption that the changes have happened in such plagioclase that is adjacent to orthoclase, which is found only in acid rocks, how shall we then account for the fact that the plagioclase crystals have been resorbed and taken part in the composition of the myrmekite?

These facts convince me that we have to deal with a primary phenomenon which is most easily explained in accordance with Vogt's general conception regarding the processes which occur in magmas at their consolidation. The absence of a segregation of orthoclase, the relatively small amount of potash, as well as the facts mentioned above, allow me to conclude that the myrmekite is, in fact, a composite eutecticum Qu — (Ab + An) (quartz — plagioclase) which composition the magma had reached just at the time in question and which in acid rocks can be reached earlier than the triple eutecticum Qu — (Ab + An) — Or (quartz — plagioclase — orthoclase).

[1] Н. Свитальскій, Монцониты въ системѣ р. Ципикана. Explor. géol. dans les régions aurifères de la Sibérie. Région aurifère de la Léna. Livr. IX. 1913 p. 137—139.

The considerable amount of quartz in our rocks may serve as a confirmation of this assumption».

In his classical treatise on the mineralogical composition and the structure of the crystalline schists Becke (1913) completed his observations and modified, in some minor points, his former opinions about the myrmekite:

Concerning N:o 3 of his former theses he says, in refutation of the hypothesis of Schwantke: »Man kann also den Myrmekit nicht auffassen als eine Ausscheidung von Substanzen, die im Kalifeldspat etwa nach Art einer festen Lösung vorhanden waren.»

Further he adds a new thesis:

»6. Die Myrmekitbildung scheint älter zu sein als die Bildung von Muscovit und Epidot aus Plagioklas. Denn man trifft bisweilen Gesteine, in denen die Myrmekitkörner ähnlich wie die Gesteinsplagioklase mit Schüppchen von Kaliglimmer und kleinen Epidotnadeln durchsetzt sind.

Wenn in einem Gestein, dessen Kalifeldspate mit Myrmekit umsäumt sind, sich um die Feldspate Gleitflasern von Muscovit entwickeln, so schneiden diese an den der Schieferung parallelen Flächen der Feldspatkörner den Myrmekit von seiner Unterlage ab. Die Myrmekitkörner bleiben im Feldspatauge sitzen. In den Streckungshöfen können sich die Myrmekitkörner wohl von dem zugehörigen Feldspatauge abtrennen und sich um mehreren anhäufen. — —

Nicht zu verkennen sind seine Beziehungen zur Krystallisationsschieferung. Mit dieser ist er durchaus verträglich; nur ist hervorzuheben, dass er auch in Gesteinen auftritt, die von Schieferung überhaupt frei sind.

Gesteine mit ganz reinen Erstarrungsstrukturen scheint er zu meiden, wie schon Sederholm für die Rapakiwigesteine hervorhebt. Ich kann angeben, dass ich ihn in Schliffen von Granit von Predazzo vergeblich gesucht habe. Auch in Schliffen des Granits vom Brocken habe ich ihn nicht finden können.

Die Myrmekitbildung ist wohl auf Tiefengesteine und krystallinische Schiefer beschränkt.

In eigentlich vulkanischen Gesteinen dürfte sie kaum vorkommen. In Kontaktgesteinen kann Myrmekit dann vorkommen, wenn sie Kalifeldspat führen.

Mit dem eigentlichen Mikropegmatit, dessen Natur als Eutektikum von Feldspat und Quarz zuerst von Teall auf Grund des Auftre-

[1] F. Becke, Über Mineralbestand und Struktur der krystallinischen Schiefer. Denkschriften der K. Akad. der Wissensch. Math.-naturwiss. Klasse. LXXV T., 1913, p. 134—140.

tens und der Beschaffenheit befürwortet, in neuerer Zeit von Vogt mit guten Gründen gestützt wird, hat der Myrmekit vieles gemeinsam. Es kann wohl aus der ganzen Beschaffenheit dieser Gebilde mit Recht gefolgert wurden, dass Plagioklas und Quarz sich gleichzeitig gebildet haben. Ein Unterschied liegt darin, dass im Mikropegmatit die Quarzstengel häufig geradlinige Umrisse zeigen, im Myrmekit dagegen gebogene runde Formen die Regel sind.

Mikropegmatit füllt Lücken im Gesteinsgewebe zwischen älteren Gemengteilen, die vom magmatischen Eutektikum eingenommen waren, hat daher keine selbständigen Grenzen; Myrmekit frisst sich in bereits vorhandene Kalifeldspate ein und ist gegen diesen durch konvexe, bisweilen etwas gekerbte oder gezähnelte scharfe Grenzen geschieden.

Wenn man aus diesen Tatsachen einen Schluss ziehen dürfte, so ist es der, dass die Myrmekitbildung sich in einer Phase der Gesteinsbildung zu vollziehen scheint, die sich unmittelbar an die Erstarrung anschliesst, also zu einer Zeit, wenn die Temperatur noch der Erstarrungstemperatur nahe steht und noch Lösungsmittel im Gestein vorhanden sind. — —

Nicht aufgeklärt ist, woher Na und Ca stammen, die dem Kalifeldspat zugeführt werden müssen, um Myrmekit zu erzeugen. Man könnte allenfalls an eine Lösung denken, die die Bestandteile der Plagioklase enthielte.»

Helge Backlund has (1913) found myrmekite in red gneisses from Olavarria (Buenos Aires). He says about the microcline of this rock: [1]

— — »Sus contornos son convexos, redondeados y rodeados por una microbrecha autígena. Alguna vez, elementos extraños, en forma de plagioclasa, toman parte en la formación de la microbrecha, y entonces entre el microclino y la plagioclasa se ha alojado la formación de mirmequita (Myrmekit)»

Georg Kalb has studied (1914) the myrmekite in the granite of Bornholm in the Baltic Sea, about which he says the following: [2]

»Die Zusammenstellung der Beobachtungen über Myrmekit von Becke hat auch für den Bornholmer Granit Gültigkeit, allerdings mit der Ausnahme, dass hier niemals Myrmekit oder ein Albitrand am Plagioklas gegen parallel angewachsenen Feldspat auftritt. Am

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[1] Helge Backlund, Algunas observaciones sobre rocas notables provenientes de Olavarria (Prov. de Bs. Aires). Min de Agric. Dir. Gen. de Minas, Geol. e Hydr. Bol. N:o 2. Sec. B, 1913, p. 8.

[2] Georg. Kalb, Petrographische Untersuchungen am Granit von Bornholm. Inaug.-Diss. Greifswald 1914, p. 45.

deutlichsten lässt sich dieses Verhalten im Knudsbackegranit feststellen, dessen Plagioklase fast durchweg von Kalifeldspat parallel umwachsen sind. Wird der Plagioklas an einer kleinen Stelle von einem anders gelagerten Kalifeldspat begrenzt, so zeigt er an dieser Stelle myrmekitische Ausbildung oder nur einen Albitsaum. Während der Albit stets scharf gegen den Plagioklas absetzt, ist an der Grenze des Myrmekit gegen den Plagioklas nur ein schnellerer Wechsel der chemischen Zusammensetzung aus der Auslöschung zu erkennen. In den anderen Bornholmer Granitarten tritt der Myrmekit meist als parallele Fortwachsung am Kalifeldspat auf.

Hervorzuheben ist noch die Erscheinung, dass auch vereinzelt im Kalifeldspat Quarzeinlagerungen sich finden, die sehr an Myrmekit erinnern, wie sie auch Schwenkel beobachtet hat.

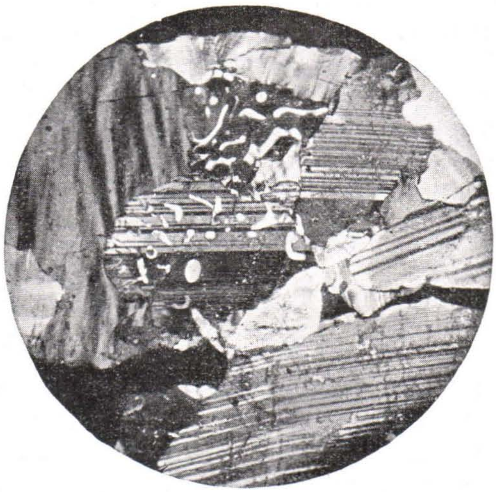

Fig. 11. Myrmekite in a granite from Välivaara by Lake Antinlampi in Rovaniemi. Polarized light. × about 10. Photo. Victor Hackman.

Während in allen Bornholmer Granitarten und Schlierenbildungen, die Quarze enthalten, Myrmekit beobachtet wurde, fehlt er in den grossen basischen Schliere im Haslegranit, in der kein Quarz ausgebildet ist; hier zeigt der Plagioklas gegen nicht parallel gelagerten Kalifeldspat stets reinen Albitsaum.

Alle diese Beobachtungen am Myrmekit von Bornholm lassen sich nur durch die Annahme einer primären Entstehung des Myrmekit erklären».

Hackman communicated (1914) in his description to the map of the Rovaniemi region in northern Finland a very good photograph of myrmekite in a granite from Välivaara in Rovaniemi [1] which I here reprint in fig. 11.

This myrmekite is remarkable because it so clearly shows the rounding of the quartz rods, a feature which is characteristical of most myrmekites and distinguishes them from primary micropegmatite.

At last I reprint from this bulletin, in order to make the collection of quotations as complete as possible, the theses of my colleague Eskola (1914) concerning the formation of myrmekite[2]:

»Myrmekite is present in abundance in this particular specimen as well as in many other samples which show fluxion structure in the Perniö-granite. As this suturelike implication of quartz and plagioclase at the boundaries of the potash feldspars is often regarded as a proof of metamorphism posterior to the consolidation of the rock, the writer's observations upon this subject, (which do not confirm this opinion) are summarized below. For the characteristics of ›myrmekite›, it suffices to refer to an article of Becke. Here I will only mention what new facts I have to add to this description.

1. Becke remarks as an important characteristic: der Myrmekitfeldspat grenzt sich gegen Kalifeldspat stets durch konvexe Flächen ab.» In the microcline-granites from south-western Finland a plagioclase-quartz mosaic with sutured boundary is frequently found with all the characteristics of the myrmekite, but with rectilinear boundaries against the microcline, i. e. the myrmekite feldspar apparently is idiomorphic (plate I, fig. 3). In the same rock there is also some myrmekite showing the usual curved outlines, and it seems that the former originated at a later period than the latter. The idiomorphic myrmekite-plagioclase is turbid like the average plagioclase of the rock. Generally such a myrmekite occurs where the microcline is bordered by somewhat large individuals of quartz or plagioclase, or where inclusions in the microline are developed as myrmekite. At times the myrmekite was seen to be bordered by a clear zone of albite, similar to that occurring around other plagioclases. No quartz imbrication having been found in the clear border-zone, it is probable that the separation of the albite from the microcline took place after the time when the myrmekite was formed. The myrmekite with curved outlines, on the other hand, is clear like the newly formed albite surrounding the plagioclase, and it occurs, as a rule, at places where the big microclines are bordered by the granulated mass.

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[1] Victor Hackman, Beskrivning till bergartskartan sekt. 66, Rovaniemi ett. av Geolog. översiktskarta över Finland, 1914, p. 35.

[2] Pentti Eskola, Petrology of the Orijärvi Region. Bull. Comm. géol. de Finl. N:o 40, 1914, p. 27—28.

2. ›Gesteine mit ganz reinen Erstarrungsstrukturen scheint er zu meiden, wie schon Sederholm für die Rapakivigesteine hervorhebt›. I have, however, observed true myrmekite in several rapakivi-granites, e. g. in a specinen from Kavantsaari, in eastern Finland, and also in small amounts in a »typical› rapakivi from Luumäki, district of Wiborg. In both cases the myrmekite was formed as a continuation of idiomorphic plagioclase bordered by the potash feldspar.

3. ›Nicht zu verkennen sind seine Beziehungen zur Krystallisationsschieferung. Mit dieser ist er durchaus verträglich; nur ist hervorzuheben, dass er auch in Gesteinen auftritt, die von Schieferung überhaupt frei sind.» Besides this I wish to point out that granitic rocks of partly granoblastic structure may be devoid of myrmekite. Thus in the oligoclase-granites from the Orijärvi area, described later on, the myrmekite is of rare occurrence. It is seen that an advanced metamorphism was not able to produce any myrmekite.

As to the origin of the myrmekite, the conclusion of Becke is as follows: »Wenn man aus diesen Tatsachen einen Schluss ziehen dürfte, so ist er der, dass die Myrmekitbildung sich in einer Phase der Gesteinsbildung zu vollziehen scheint, die sich unmittelbar an die Erstarrung anschliesst, also zu einer Zeit, wenn die Temperatur noch der Erstarrungstemperatur nahe steht und noch Lösungsmittel im Gestein vorhanden sind.› This conclusion is in accordance also with the facts mentioned above, only it seems probable that the myrmekite in part may have originated already during the process of consolidation. In any case, the presence of the myrmekite cannot be regarded as a sign of regional metamorphism»

Observations of the Author on Myrmekite and Similar Structures.

I will here give an account of some of my own observations which throw light upon this subject, discussing at the same time the ideas of the different authors concerning the nature and origin of myrmekite, and related phenomena. Finally, I will give a summary of the conclusions reached.

In my first communication on this subject, in a lecture »Om mikropegmatitstrukturer i eruptiva bergarter›, at the meeting of the Geological Society of Helsingfors the 16th of February 1896, I pointed out that the myrmekite ›was a structure of comparatively late date which either belonged to the last stage of crystallization, or was metamorphic».

It is this difficult discrimination between primary and secondary which has been the great problem to most petrologists who have tried to explain the origin of myrmekite, and related structures. They have taken position on different sides, and sometimes also shifted their opinions, in proportion to the added material of evidence which they have gathered.

MYRMEKITE AND SIMILAR STRUCTURES IN RAPAKIVI GRANITES AND FEEBLY METAMORPHIC YOUNGER ARCHÆAN GRANITES OF FINLAND AND SWEDEN.

When studying the primary structures of the Fenno-Scandian granites we are always accustomed to resort to the late-pre-Cambrian rapakivi granites, because these are entirely exempt from all signs of a metamorphism posterior to the consolidation of the rock. Let us also try the myrmekite on this touchstone.

The structures in question are certainly much less common in the rapakivi granites than in the earlier granites of the same region. Especially in those rapakivi rocks which are fine-grained and in their structure nearly related to quartzporphyrites no myrmekite can be found, but also the coarse-grained ones may often be devoid of this structure, as has been emphasized by myself and by Holmquist. I remarked in my first-printed communication on the subject that the cases where myrmekite was found in rapakivi rocks, could be accounted for by the presence of inclusions of foreign rocks which had undergone contact metamorphism or refusion. Later observations of Luczizky and Eskola seemed to indicate that myrmekite might occur in the rapakivi granites, also where no foreign rock fragments were visible.

I will here give a detailed account of the observations on myrmekite and similar phenomena which I have made upon studying the rapakivi granites, comparing them with some observations on other rocks.

Of special interest is a rapakivi granite from Säkkijärvi which has been regarded for a long time as one of the best types of the Wiborg rapakivi, a coarse granitic rock characterized by the presence of ovoid orthoclase crystals surrounded by a mantle of plagioclase. The rock in question occurs as boulders at the mouth of Vilajoki in Säkkijärvi, west from Wiborg. It is this rock of whose structure in thin sections Holmquist has given a figure in natural size in Fig. 1 in his work on the Swedish granites. From an analysis of this rapakivi, made by Dr. Rob. Mauzelius in Stockholm, which I have received by the courtesy of Professor Holmquist, Dr. E. Mäkinen has kindly calculated its norm and determined its place in the American system. It is a *Toscanose*, containing 26,46 percent quartz, 65,46 percent felspar (perthite and plagioclase), and 6,07 percent biotite, while the rest is composed of ore, apatite and titanite. The individualized plagioclase is an oligoclase with 23 percent An, while the perthite-plagioclase is an albite (An_{10}).

The rock contains ovoids of pale red orthoclase, measuring 2—4 cm in diameter, which are surrounded by a broad mantle of green oligoclase which often shows better crystal forms than the orthoclase. Between the ovoids lies a rather coarse aggregate of orthoclase, plagioclase, grey quartz, partly in idiomorphic crystals, measuring up to 0,5 cm, partly allotriomorphic, and biotite.

This biotite is of the greatest interest because it is associated with vermicular quartz and typical myrmekite. It is, as is usually the case in the rapakivi rocks, a very strongly pleochroic biotite; $\mathfrak{a}$ and $\mathfrak{c}$ are yellowish brown, $\mathfrak{b}$ very dark brownish green, almost black.

In some cases it is rather idiomorphic, but commonly entirely allotriomorphic also against the quartz crystals. Against the felspar it generally shows fringed borders, and it often contains, in the core, quartz and fluorite, forming, with these minerals, intergrowths of symplektitic character. Fig. 17, plate III, shows a crystal of this biotite which has rather rectilinear boundaries against the surrounding quartz crystals, while there are fringes everywhere when it touches felspar. It has certainly begun as a primary crystal, whose growth has continued afterwards as a blastocrystal. The transparent grains which fill a bay-like concavity on the left side consist partly of fluorite, which predominates, partly of quartz. Fig. 18, plate III, shows another crystal of biotite which contains several cores of ore. From one of them projects a slender lamella of biotite into the surrounding felspar which follows one of its cleavage directions. Everywhere in the same felspar there are thin lamellae of a green, chlorite-like mineral arranged along three distinct crystallographical planes, one of them parallel with the slender mica lamella protruding from the larger biotite. This contains in the midst quartz and fluorite in almost equal quantities, whose outlines suggest that they have partly corroded the mica.

At another place there is biotite in groups of crystals measuring together about 5 mm in diameter. The biotite is also here in part more continuous at the borders, while the interior portions are filled with quartz and fluorite. At some sides, however, the biotite is more continuous in the midst, while it shows a border-zone consisting of an intergrowth of quartz and biotite. (fig. 19, plate IV).

This intergrowth shows in part dactylitic structure, while another part is myrmekite-like: biotite lamellae which are irregular in form, and look as if they were bent, are interwoven with vermicular quartz. Here grains of true myrmekite occur at the outer side of this dactylitic and myrmekite-like intergrowth of biotite and quartz, forming seemingly its continuation. Fig. 20, plate IV, shows in greater enlargement these »warts» of myrmekite in which the quartz forms extremely slender vermicular rods.

On several places outliers from the dactylitic or myrmekite-like biotite-quartz intergrowth protrude through the myrmekite, penetrating several grains of it.

How shall we interpret these puzzling phenomena?

In general the biotite is a late constituent in the rapakivi rocks, where most of it is entirely allotriomorphic. Especially in the fine-grained granophyric rapakivi rocks of the Åland islands this is very conspicuous. In these rocks the fine-grained granophyric portions form grains with a diameter of a few millimeters, between which lies an aggregate of later crystallized, coarser minerals which contains open cavities. The biotite crystals often project into these cavities which are partly filled with fluorite. The orthoclase crystals which occur in the cavities often show a thin coating of albite on the clinopinacoidal surfaces. Thus we find that in these rocks the last rest of the magma, together with the bulk of the femic elements, also contained some salic material, whose last part crystallized as albite, as well as some fluor.

Also in the rapakivi granite from the Wiborg area now in question the crystallization of the biotite has begun towards the end of the consolidation of the magma. The larger and more continuous biotite crystals must be regarded as primary in the fullest sense of the word, but another part of the biotite is certainly crystalloblastic. It has encroached upon the earlier crystallized felspars, both microcline and plagioclase. That it hereby also has been deposited along certain crystallographical planes, forming regularly shaped inclusions, is most easily explained by the assumption that the cavities have been hollowed out by gases. And in fact fluorite is present also here, together with quartz filling the interior of the biotite crystals and intergrown with the minerals mentioned. The forms of these intergrowths suggest the idea that the fluor, and probably also the silica, have corroded those portions of the biotite which have crystallized earlier. Thus the idea of a »quartz de corrosion» does not lack its foundation, although the forms of the symplektites certainly depend more on a skeleton crystallization of the felspar, or biotite, than on a later corrosion.

The fluorite has obviously acted as an »agent minéralisateur» at the formation of the biotite. The quartz may, in part, be derived from the orthoclase which has been replaced by myrmekite and biotite. But in this particular case, part of it at least may be regarded as magmatic quartz.

The myrmekite seems to be of somewhat earlier formation than the biotite-quartz-symplektite. Flakes of biotite penetrate the spindles of myrmekite and the arrangement of the symplektitic parts of the biotite often suggests the idea, that they have replaced certain grains of myrmekite. We shall return to this question later on, when discussing another similar case.

In conclusion may be said that the occurrence now described shows that myrmekite and biotite-symplektite may originate in rocks which have not undergone any later metamorphism, at the end of their consolidation, and that fluor in certain cases may have acted as an »agent minéralisateur» at their formation.

In a rapakivi from Kousalampi near Kouvola, in the most easterly part of the Wiborg rapakivi area, I have seen hornblende which contains cores of quartz and fluorite, and seems to have been corroded by the fluoric gases, and, perhaps, by the silica.

Intergrowths between quartz and plagioclase, or biotite, are very common in the rapakivi granites of the Wiborg area at such places where this rock is in contact with basic rocks, especially where these occur as fragments included by the granite. My colleague, Dr. Frosterus, has studied these interesting phenomena, and partly described them in the pamphlets accompanying the geological maps of our survey.[1] I have later studied his slides which exhibit in many cases very typical symplektitic structures.

A specimen of rapakivi granite, or rather monzonite, from Uotila in Mäntyharju, collected by Frosterus in the immediate neighbourhood of a fragment of labradorite, is of considerable interest. The rock is very rich in quartz which seems to be the last of all the minerals of the rock. In part it is even later than the myrmekite. The felspar is predominantly oligoclase; orthoclase is

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[1] Benj. Frosterus, Beskrifning till bergartskartan af sektionen C 2, S:t Michel. Geol. Komm. Helsingfors, 1902, p. 67 sequ.

also present. Biotite occurs in a considerable quantity. It has fringed borders and often ends in typical dactylite or symplektite.

Myrmekite is also abundant, especially in the neighbourhood of the biotite-symplektite, but even then a plagioclase is often found behind it in the immediate vicinity. This plagioclase seems to have formed the starting point at the formation of the secondary plagioclase in the myrmekite. (fig. 21, plate IV). Biotite has also here crystallized posterior to the myrmekite. Where it has invaded other felspar crystals it may occasionally have fringed borders but has often also an even edge. Where it enters a myrmekite spindle, replacing its plagioclase, it often leaves the earlier structure more or less intact. Myrmekite spindles may only in part be changed into biotite-symplektite (fig. 22, plate IV. Here the biotite projects as slender fingers also a little beyond the myrmekite; this biotite has the same orientation as the adjacent solid crystal) while the neighbouring spindles are entirely unchanged). The myrmekitization and the formation of the biotite are here obviously independent phenomena, the biotite having superseded the former structure. At other places in the same rock the quartz has corroded all the other constituents, especially the oligoclase, but also the myrmekite, (fig. 23, plate IV) which occurs partly swimming in quartz, being, however, even then in company with some fragments of potash felspar. This quartz has partly the same optical orientation as the quartz of the neighbouring myrmekite. This occurrence is of great interest because it shows so clearly that the myrmekite in this case has been formed before the end of the consolidation of the rock, although also here as a crystalloblastic (synantetic) mineral.

Fig. 24, plate IV, shows a place where the primary plagioclase is continued partly by myrmekite, partly by plagioclase which intergrows in patches with the orthoclase, but contains almost no quartz.

The rapakivi granite from Simola, a railway station not far west of Wiborg, is known to be of interest in several respects. The granite here contains large fragments of diabase, sometimes measuring several hundred meters in diameter, which it has assimilated more or less completely. Some portions still retain their basic composition and show very typical contact-metamorphic structures, while, in other cases, the rock may be called granitic, or rather monzonitic, because it contains an unusual quantity of plagioclase, and frequently femic minerals as well. It has often a dark colour, in which case the felspar contains a great quantity of small inclusions. The hornblende is green and often very patchy, especially at the margins, where it contains a multitude of quartz and felspar grains. It has cores of light green pyroxene, which seem to be augite, in part diallage, and often also olivine. Ore grains occur as well, from which radiate tufts of dactylitic or symplektitic biotite, containing extremely fine vermicular rods of quartz. Myrmekite is also present. This structure occurs here, as is the rule, where orthoclase and plagioclase (oligoclase with about 20 % An) meet. There are also suture-like boundaries between orthoclase and plagioclase where quartz occurs only in very scarce quantities and not so very intimately interwoven with the plagioclase (fig. 25, plate V). It sooner conveys the impression that orthoclase has encroached upon the plagioclase. However it is very likely that here, as usual, the case has been the reverse.

The composition and structure of the rock show that its material has been derived from the neighbouring basic rock by refusion or resolution and that there has been a continuous adjustment of its composition, whereby reactions have also taken place between the neighbouring minerals.

It is a striking fact that quite similar phenomena occur in the younger Archæan (so called post-Bothnian) granites of central Finland where they contain assimilated fragments of basic rocks. These rocks have also been studied before by Frosterus.

E. g. in a dark greenish granite which occurs at Huhtajärvi in Petäjävesi, S.W. from Jyväskylä in central Finland, I have found quite analogous phenomena in the vicinity of masses of diabase which the granite has penetrated and in a great measure assimilated.

The fact that the rock has derived so much basic material from without, accounts for its peculiar character. It may be designated as a monzonite, and contains very much plagioclase with a maximum extinction on 010 of a few degrees; hence it is an oligoclase. It sometimes shows a zonar structure. Furthermore, potash felspar which shows no cross-twinning is also common. In spite of the abundance of quartz, the rock also contains augite and diallage, green, compact hornblende, often surrounding the pyroxene. In the same way as in the rock from Simola, some ore is also observed, and, often in the immediate vicinity of the ore, biotite occurs, forming with quartz dactylitic and symplektitic intergrowths which radiate from the ore and the femic minerals in every direction. Especially around these tufts of biotite, myrmekite of the most typical character occurs in abundance, but it is found also independent of the biotite, at the boundaries of the plagioclase and the adjacent allotriomorphic potash felspar (fig. 26, plate V).

Also here the biotite seems to have crystallized posterior to the myrmekite, having replaced it in part, whereby it has formed with quartz, which in this case is not a relict from the myrmekitic structure, dactylitic intergrowths (fig. 27, plate V). It is obvious that these structures are also here independent, although closely connected in age.

There is also in the same rock an antiperthitic intergrowth of plagioclase with patches of potash felspar (fig. 28, plate V), which I think is due to a replacement of the former, by material carried in solution at the end of the crystallization.

Frosterus has also described gabbros and diabases older than the younger Archæan (»post-Bothninan») granites of southern Finland, occurring north-west of St. Michel in Kangasniemi and neighbouring parishes. Close to lake Kutemajärvi, the basic rock is penetrated by veins of granite and frequently very much changed by refusion. In a thin section of a specimen from the contact of a fragment with a neighbouring more acid rock, which also here is monzonitic in character, I have observed a quartz, forming myrmekite-like intergrowths with plagioclase. This quartz is certainly to be designated a »quartz de corrosion».

The greater plagioclases consist of oligoclase with about 21 % An (max. ext. 5°). The biotite seems in part to have crystallized earlier than the plagioclase, while, partly, it is crystalloblastic, having replaced the neighbouring plagioclase. The quartz has corroded both the biotite and the oligoclase which have then re-crystallized, forming with the quartz myrmekite-like intergrowths (fig. 29, plate V). It is not to be assumed, however, that the forms are due mainly to corrosion, since if such were the case, the felspar should have the same optical orientation as the surrounding uncorroded felspar, while here, on the contrary, the felspar of the myrmekite has almost the same orientation as the largest felspar crystal, thus obviously forming a continuation of the same which has protruded into the portion which shows a transversal twinning lamellation.

The felspar has been solved by corrosion and has afterwards re-crystallized as a skeleton crystal before the quartz was consolidated which fills its interstices.

I have not observed any potash felspar in this large thin section. It is therefore not probable that this mineral has existed here in the immediate neighbourhood of the structure in question. We have thus a proof that myrmekitic intergrowths may occasionally originate like the minerals crystallizing in a molten magma, not as crystalloblastic minerals. But also here it has happened through the resolution of the earlier crystallized minerals, and the myrmekite cannot be regarded as a primary constituent in the strictest sense of the word. The phenomenon in question seems to be analogous to that described by Osann (cf. p. 77).

Symplektitic intergrowths of various kinds occur in the dark coarsely porphyritic pyroxene-granite from Grafversfors near Norrköping in Sweden which is known as a monumental stone. I have been able to study this rock in large thin sections thanks to the courtesy of Dr. A. Gavelin. Prof. P. J. Holmquist has called my attention to this granite and has kindly lent me the beautiful photograph rendered in fig. 31, plate VI.

The larger felspars in this granite have a size of $0{,}5 - 1 \times 1 - 2$ cm. Most of them consist of microcline, part of oligoclase (21 % An) which often shows bent, or broken lamellæ. It appears decidedly to have crystallized earlier than the microcline into which it protrudes. The space between the felspars is occupied by bronzitic pyroxene, connected with ore, and by hornblende which is highly pleochroic, in greenish-brown to greenish black colours.

These minerals are allotriomorphic, and so also is the quartz which occurs in rather large crystals and always shows undulatory extinction, being sometimes also divided into portions which extinguish differently. Besides these primary constituents, biotite and myrmekite occur, both of which are crystalloblastic.

The myrmekite forms crusts at the borders of the plagioclases where these meet microcline. Its plagioclase is somewhat more acid than the primary oligoclase. At the oligoclase crystal shown in fig. 30, plate V, the myrmekite is most abundant on the surfaces of the prismatic zone. The left end of the oligoclase crystal is surrounded by plagioclases at the right end, where it meets microcline, there is also a rim of myrmekite, although thinner. One of these end surfaces is probably the basis. The myrmekite often exhibits the most graceful forms. It may be coarser on the inner side, while its fibres are of the utmost delicacy where it touches the microcline (fig. 31, plate VI). Here the quartz forms an allotriomorphous cement between the felspar branches which suggests that the felspar has been formed as a skeleton crystal.

The biotite occurs mostly as tufts which protrude into the felspar, often in such an irregular way as to prove of its being a crystalloblastic product which has replaced felspar. It has generally a dactylitic character, being mostly interlocked with quartz. Occasionally the mass between the biotite »fingers» also consist of plagioclase, or of myrmekite. In general, the relations between the dactylitic biotite and the myrmekite are very intimate. Myrmekite crusts or spindles often surround the ends of the biotite tufts (fig. 32, plate VI) in an arrangement which suggests that they form continuations of these tufts. In several cases *the rods of vermicular quartz continue directly from the biotite-dactylite into the myrmekite.* (figs. 33 and 34, plate VI), or a finger of biotite extends farther along a certain portion of the myrmekite. In the case shown in fig. 34, plate VI, this portion is richer in quartz while the biotite in the continuation is very compact, containing but little quartz. The general case, however, is the reverse, viz. that the biotite follows the plagioclase fingers of the myrmekite, leaving the vermicular quartz, between them, intact. Fig. 33, plate VI, presents a particularly clear picture of the instance in point. Fig. 35, plate VI, is also of great interest. Here the biotite shows a symplektitic structure with quartz worms directed *normally against the cleavage of the mineral* only in one restricted place where this structure continues into the neighbouring myrmekite. Here I think, it is obvious, that this structure is a relict from the myrmekite whose plagioclase the biotite has replaced.

The biotite may protrude from myrmekite into the surrounding microcline, or penetrate hornblende, microcline and plagioclase, or myrmekite by turns. As it is certainly not a primary constituent older than all these minerals, this also seems to prove that it is of later date.

My first impression upon studying this rock, which took place before I had examined the rapakivi specimens mentioned above, was that which probably would suggest itself to every observer, viz. that the biotite-dactylite was of earlier origin, and that the myrmekite formed its continuation.

However, upon a closer scrutiny of the occurrence of the myrmekite, I always found microcline and plagioclase, as usual, on either side of it, even where it was in close connection with biotite, in such an arrangement as to prove that also here it is synantetic between plagioclase and microcline.

Obviously the invasions of myrmekite and mica-dactylite have also here been very near to each other in age, but the latter was however, as already said, generally of a somewhat later date; quite in the same way as with the troops of an invading army: those being in the rear arriving later than those which are at the front, even thus enabling them to fill the gaps in the ranks of the former.

My study of the slides of Finnish granites, described above, was pursued in such a way that I looked through a great number of thin sections of rapakivi granites and other granites with well preserved primary structures in our collections, whereupon I laid aside the slides, in which I found the mineral intergrowths in question in a more characteristic form. Having done so, I became aware that almost all of them originated from places, where the granite contained inclusions of foreign basic rocks. In many cases the specimens, as results from the foregoing statements, were taken from the immediate neighbourhood of the inclusions. Many of the specimens which contained myrmekite in abundance were from Simola, where the rapakivi granite is so intimately mixed with more or less completely digested fragments of basic rocks, others were from analogous places in the same rapakivi area, while, as already remarked, also the granites of younger Archæan (post-Bothnian) age which contained inclusions of diabases and gabbros showed the same phenomena. The rapakivi from Vilajoki in Simola is taken from great boulders, and thus nothing is known about its relations to other rocks. But more or less completely assimilated fragments of basic rocks are, in this area, of such common occurrence, that it seems possible that also this rock may have contained such inclusions.

The granite from Grafversfors has the peculiar dark colour which often characterizes granites which have digested basic fragments, and its content of pyroxene is rather unusual for a normal granite. It is very probable that also this rock, which in many respects resembles the granite from Petäjävesi, has the same origin as the other rocks in question. The same seems probable as regards such rapakivi granites of southern Russia in which Luczizky has found myrmekitic structures in abundance. They have, as a rule, a much darker colour than our rapakivi granites and contain an unusual quantity of femic minerals.

It cannot be by mere chance that the puzzling phenomena in question are so much more common in those parts of the granites which are adjacent to included fragments of basic rocks (or, in some cases, perhaps, to more basic parts of the same rockmasses). If the formation of the synantetic minerals, as seems to me beyond doubt, is caused, not only by an interchange of material between the neighbouring minerals, but also of material carried in from without in solution, then a difference in the mineralogical composition of the neighbouring rocks must have been of great influence. Rocks, rich in plagioclase, have delivered solutions rich in the constituents of this mineral, which have reacted on the minerals of the neighbouring granite rocks, resolving some of them, and in the same way the femic constituents of the basic rocks have reacted on the granitic parts, during the processes of assimilation and crystallization going on in the rockmasses.

SOME OBSERVATIONS CONCERNING THE FORMS OF MYRMEKITE, IN DIFFERENT GRANITES OF FENNO-SCANDIA.

In a granite from Lake Oksjärvi in Tammela, S.W. of Tavastehus, I have observed a myrmekite which is shown in fig. 36, plate VI. It lies at the boundary of microcline and biotite, but on the opposite side of the mica plagioclase occurs (visible in the lower left-hand corner of the photograph) which has almost the same optical orientation as the plagioclase of the myrmekite. Probably the biotite also here is of a later date than the myrmekite which has originated at the boundary of oligoclase and microcline. The inner portions of the myrmekite show broader canals, filled with quartz, partly straight, partly curved, while the borders consist of a very delicate and more irregular intergrowth of plagioclase and quartz. The average diameter of this myrmekite spindle is about 0,33 mm.

Thanks to the courtesy of my friend, Professor P. J. Holmquist in Stockholm, I am able here to publish two beautiful microphotographs, taken by him, of myrmekite from the granite of Lysekil, Bohuslän, in Sweden. This is a late Archæan granite with an often well-preserved primary texture, rich in microcline and often also in oligoclase. Fig. 37, plate III, shows a myrmekitic rim of a felspar from this granite magnified by 30 diameters which exhibits characters similar to the myrmekites in fig. 31 and 36, plate VI. Also here the inner part contains greater cavities filled with quartz, while the border consists of thin leaves which appear bent, and are separated by quartz. Fig. 38, plate VII shows a portion of myrmekite in the same section which is of special interest, because it shows how the twinning lamellae of the plagioclase project into the quartz. This seems to prove that the latter mineral has crystallized at a later date than the plagioclase, allowing the latter to continue its crystallization in the cavities containing silicic acid in solution.

Fig. 39, plate VII, again shows an example of myrmekite in a Finnish granite of post-Bothnian age, from Rajala in Kankaanpää, N.E. of Björneborg.

This rock occurs close to the boundary of basic schists, and is very rich in plagioclase. A plagioclase crystal of this granite contains myrmekite in abundance, apparently also the inner part of the crystal. One receives the impression that the felspar has been corroded in a large measure by quartz. It is, however, possible that the boundary of the plagioclase and an adjacent microcline may be parallel to the section, so that it mainly cuts the myrmekitic border of the plagioclase.

I have observed, however, an instance where the occurrence of myrmekite in the centre of a plagioclase crystal seems indubitable. Fig. 40, plate VII, shows a thin section of a granite from Bergholm in Pernå which is also of much interest geologically. It occurs in a contact zone between an old gneissose granite and an intersecting dyke of fine-grained rapakivi granite. At this place no sharp contact is found, but the young granite grades imperceptibly into the old one. Petrologically, the rock of the section shows most affinity to the rapakivi, although there are still traces in the character of some minerals suggestive of the gneissose granite. The figure shows an oligoclase from this rock whose core consists of myrmekite, while the outer portions which have, in part, a slightly different chemical constitution, contain no quartz. I regard this as a sign of a re-crystallization of the older rock.

BIOTITE-QUARTZ-SYMPLEKTITE, MYRMEKITE AND MYRMEKITE-PERTHITE IN A QUARTZ-NORITE FROM NEDER-TORNEÅ IN NORTHERN FINLAND.

Hackman has described dactylitic intergrowths of biotite and quartz occurring in a quartz-norite from Laivaniemi in Neder-Torneå, on the northern shore of the Gulf of Bothnia.

The rock, which is of Archæan age, is, in itself rather peculiar. It consists of plagioclase (andesine) and pyroxene, which is highly pleochroic, with reddish colours, and contains a great number of small inclusions of hematite. It is, in part, orthorhombic (hypersthene), in part monoclinic. Magnetite, ilmenite and apatite occur in small quantities, while biotite is more frequent. Besides plagioclase, also potash felspar is present, as well as quartz. At the boundary between the potash felspar and the plagioclase, myrmekite occurs, and is often very typical. Also in this rock the plagioclase of the myrmekite has partly been replaced by biotite in which the vermicular quartz of the myrmekite is still preserved in the border-zone.

The biotite is certainly secondary, and has in part fringed borders, also where it has not replaced myrmekite. Sometimes it forms very typical dactylitic intergrowths with quartz of which structures Hackman has communicated an interesting figure (fig. 12).

He says in his description that the biotite and the quartz form a kind of micropegmatitic intergrowth, and have obviously originated at the expense of a hypersthene crystal which has undergone resorption.

The potash felspar occurs in this rock in two different varieties. One of them contains plagioclase, possibly albite, in an extremely minute microscopical intergrowth, while in the other the potash-felspar is also intergrown with plagioclase, although in quite a dif-

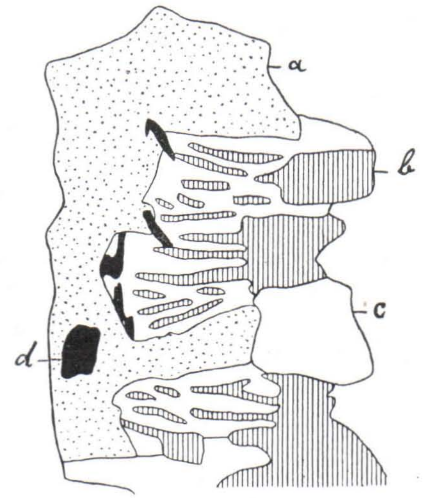


Fig. 12. Crystal of hypersthene (a) which has been corroded and penetrated by an intergrowth of biotite (b) and quartz (c), in a quartz-gabbro from Herajärvenkalliot in Neder-Torneå. (d = iron ore) × about 50. From Hackman's memoir.

ferent fashion. It includes, in some places, sparsely scattered rounded grains of a plagioclase which has the same character, and sometimes also the same orientation as the neighbouring primary andesine. Furthermore, it contains very small rounded inclusions, as well as numerous vermicular rods of plagioclase. This mineral has a much higher index of refraction than the surrounding potash felspar, and belongs to the series oligoclase-andesine. The intergrowth has often a decidedly myrmekite-like appearance (fig. 41, plate VIII). The rounded inclusions occasionally seem to grade into the vermicular rods, i. e. they appear to be only shorter portions of the rods. But there are also places (fig. 42, plate VIII) where they seem to grade into the larger rounded inclusions which seem to be remnants of partly corroded primary plagioclase. Moreover, the latter are also

[1] V. Hackman, Beskrifning till bergartskartan af sektionen C 6, Rovaniemi, etc. af Geologisk Öfversiktskarta öfver Finland, 1914, p. 8.

sometimes nearly connected with the vermicular rods of plagioclase, which circumstance points to the possibility of an origin in common.

The boundary of the primary andesine and the potash felspar is often sinuous, sometimes very irregular, and it seems certain that the andesine has been corroded when the formation of the potash felspar took place. Probably the potash felspar has replaced the primary plagioclase, much in the same way as myrmekite replaces microcline. Also in the case now in question, a part of the corroded mineral has probably remained nearly »in situ», re-crystallizing together with the potash felspar. These phenomena seem to throw much light upon the manner in which secondary intergrowths of minerals originate.

The structure in question merits, equally as much, and perhaps with more right, than the structure described by Geijer, to be designated as myrmekite-perthite, considering that the former is a microperthite of myrmekite-like character. The latter also bears much likeness both to myrmekite and perthite. However, as an intergrowth of predominant plagioclase with potash felspar, its character is sooner antiperthitic than perthitic.

The rock from Laivaniemi is well worth a continued study by means of which it might also be determined whether the phenomena in question are of a truly metamorphic origin, or have been formed in the continuation of the crystallization processes of the original magma of the rock.

MYRMEKITE IN GRANITES SHOWING SIGNS OF MECHANICAL METAMORPHISM.

Like several earlier authors, I have found that myrmekite may be of an earlier date than the mechanical metamorphism of the rocks.

Thus I have observed in a little vein of granite in an arteritic schist of St. Andreæ in eastern Finland, a myrmekite which has been crushed and partly destroyed (fig. 43, plate VII) because it lies in the trituration zones which intersect the rock.

On the other hand, I have observed a number of cases where the formation of the myrmekite is of a later date than the trituration of the rock.

At the railway station of Matku (formerly Forssa) in southern Finland (on section Tammela of the detailed geological map of Finland)[1] there occurs a porphyritic granite which shows signs of a

[1] J. J. Sederholm, Beskr. till kartbl. N:o 18 Tammela, 1890, p. 29—30.

strong mechanical metamorphism visible also to the naked eye. The rock is schistose, but some of the trituration zones intersect the schistority, almost at right angles. In connection with the formation of the cleavage, the microcline phenocrysts have been triturated, and in these zones also a number of small myrmekite spindles has been formed (fig. 44, plate VII). In this case it seems obvious that the mortar structure is due to the crushing of a solid rock and cannot be regarded as a »protoclastic» structure, and also that the myrmekite has originated posterior to the trituration, or is about of the same age.

Also the red microcline-granites from the same region, which commonly show no signs of crushing visible to the naked eye, and which belong to the so-called post-Bothnian granites, often exhibit a very typical mortar structure. I have long been doubtful as to whether it has originated during the consolidation of the rock or after it, but am now inclined to think that in several cases, at least, the crushing has taken place when the rock was solid.

Fig. 45, plate VIII, shows a thin section of one of these granites, from Keihäsjärvi in Kalvola, where trituration zones intersect a microcline crystal, and are themselves cut by zones of granulated quartz. The former trituration zones are marked by the deposition of an acid plagioclase and a great number of small spindles of myrmekite. It looks as if a crystal of albite should have been faulted at the formation of the myrmekite vein. If this be correct, it should prove that the formation of albite and myrmekite were almost contemporaneous with the crushing of the rock.

Fig. 46, plate VIII, shows a similar case from a granite occurring on the island of Bogskär in the Baltic between Åbo and the Åland islands. Here the microclines are very much crushed, and the cracks are, in some cases, filled only with quartz or biotite, in others again with small spindles of myrmekite which seems beyond doubt to be a secondary structure.

Fig. 47, plate VIII, shows a portion of a thin section of a granite from Keijärvi in Ylöjärvi, near Tammerfors, where the mortar-structure is very typical. The felspar of the rock, both the oligoclase and, especially, the microcline, which predominates, are intersected by a number of cracks. The quartz is entirely granulated. Also the greater crystals of biotite show bent and broken lamellæ. Obviously the cataclasis has taken place at a date when the rock was already entirely consolidated. The mortar between the pieces of microcline consist of smaller bits of felspar, but also, in some places, (e. g. on the right side of the photograph) of biotite.

Myrmekite grains are very common among the constituents of this mortar.

In another granite from Keihäsjärvi in Kalvola, (fig. 13) the myrmekite grains have, in some places, accumulated in heaps which entirely fill out the interstices between the pieces of a larger microcline. They have probably originated successively. At first a crack may have been filled up by small grains of myrmekite whereupon merely a slight movement has been necessary to loosen these myrmekite grains from the microcline. If this has been the case, a new series may have been formed, whereby fragments which lay close to the border of the microcline could act as centra for the cystallization. These new myrmekites have again been scaled off,

Fig. 13. Heaps of myrmekite grains which fill out the interstices between the pieces of a broken microcline, in a granite from Keihäsjärvi in Kalvola. Polarized light. × 13.

and thus the process has continued till the heap was finally formed.

These examples, which might easily be multiplied, suffice as proofs of the fact, that myrmekite may also be formed at an epoch much later than the consolidation of the rock.

FRINGES OF BLASTOCRYSTALLINE BIOTITE FORMED AS CONTINUATIONS OF PRIMARY BIOTITE IN DIORITIC, MONZONITIC OR GRANITIC ROCKS FROM NORTHWESTERN FINLAND.

The earlier mentioned basic rocks of north-western Finland which have been studied by Dr. Mäkinen grade into rocks containing potash felspar which he designates as quartz-diorites and monzonites, &c. A microcline-bearing quartz-diorite from the railway station

Sievi contains a considerable quantity of primary quartz which fills the interstices between the plagioclase and pyroxene crystals. In close connection with the quartz, mostly surrounded by it, occur idiomorphic crystals of biotite which certainly belong to the latest crystallizations (fig. 14). However, they have grown over the neighbouring plagioclases in the shape of irregularly formed fringes, which include remaining patches of plagioclase that have the same orientation as the greater crystals. Where the biotite borders to quartz or to microcline, which is also a lately crystallized constituent, it has sharp outlines. It often includes grains of magnetite which seem to have been formed in close connection with the mica.

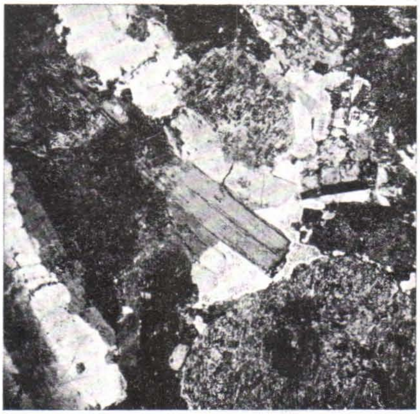


Fig. 14. Biotite crystal which is idiomorphic when lying in quartz but has a fringed border where it is surrounded by plagioclase. Quartz diorite 0,5 km S. of railway station Sievi, S.W. of Uleåborg. Polarized light. × 14.

Another rock of the same series from Tuomikoski in Ylivieska, which Mäkinen also designates as a microcline-quartz-diorite, contains biotite in great quantities. It lies partly in the microcline between the plagioclase crystals, together with pyroxene and secondary green hornblende, but has also partly encroached upon the plagioclase crystals, upon which it generally shows suture-like or fringed borders. In some of these fringes the individual tags are straight and oriented like the main part of the crystal, and then the fringed biotites can be regarded as skeleton crystals. In other cases, the individual fringes look as if they were bent and twisted. The interstices between them are filled with quartz. In some cases, also bundles of biotite lie irregularly interspersed in the plagioclase.

Around the fringes of biotite and quartz sometimes nodules of typical plagioclase-quartz-myrmekite also occur which is another proof of the close genetical connection between these different phenomena.

The more continuous biotite crystals contain cores of magnetite, either as rounded grains or skeleton crystals.

I regard this biotite as partly primary, formed at the end of the crystallization of the magma, partly »autometamorphic», formed, after the consolidation of the greatest part of the constituents, as a blastocrystalline replacement product of the plagioclase. Although it is not exactly a »reaction rim» or a synantetic mineral in the truest sense of the word, it shows much similarity to the phenomena already described. The occurrence of cores of ore is very analogous to the first case described, but if there has been a reaction between this ore and the plagioclase in the neighbourhood, it seems to have happened partly before the magma was entirely consolidated.

SYMPLEKTITE OF MUSCOVITE AND QUARTZ AS A CRYSTALLOBLASTIC STRUCTURE IN FELSPAR.

Also muscovite may occur intergrown with quartz in myrmekite-like forms. Thus a microcline granite from Saari on the southern shore of Lake Pyhäjärvi in Tammela in Finland contains a number of muscovite flakes, some of them in connection with biotite, some independent of it and apparently of a later date. Several of them show fringed borders (fig. 48, plate VIII) in which the interstices are filled with quartz. They face microcline, but there seems to be no mineral on the other side which could have delivered material to the mica.

Conclusions Drawn from the Foregoing Statements on the Nature and Origin of Myrmekite and Myrmekite-like Structures.

DIFFERENT KINDS OF MYRMEKITE-LIKE STRUCTURES.

As we are aware from the descriptions given above, many different phenomena have been described as myrmekite or myrmekite-like structures. We have, in the first place, the true myrmekite which is an intergrowth of plagioclase and vermicular quartz, and which has originated as a crystalloblastic product replacing potash felspar. There seems furthermore to be another variety of myrmekite-like intergrowths which possesses the same mineralogical character as the true myrmekite, being, however, a re-crystallization product of plagioclase and which might be designated either as myrmekite or myrmekite-like plagioclase-micropegmatite.

Under the name myrmekite-perthite, Geijer has described myrmekite-like intergrowths of plagioclase and orthoclase.

Lacroix, Shand and Brouwer have observed myrmekite-like intergrowths of orthoclase and sodalite, and also of the former with another mono-refringent mineral. These may be designated, according to the nomenclature here proposed, as myrmekite-like orthoclase-sodalite-symplektite etc.

Finally we have, as Michel Lévy, also in this case, has been the first to point out, an intergrowth between biotite and vermicular quartz. This displays both as to its structure and origin a close analogy to the myrmekite. I designate it as myrmekite-like biotite-quartz-symplektite.

MYRMEKITE-LIKE ORTHOCLASE-SODALITE-SYMPLEKTITE AND NEARLY RELATED STRUCTURES.

The phenomena which are nearest to us in age, and probably also most easily explained, are the intergrowths of orthoclase and zeolites, in most cases, as it seems, sodalite. The last mentioned structure is synantetic in the strictest sense of the word, occurring at the boundary of orthoclase and leucite (Somma) and showing a very typical symplektitic structure. Shand has described similar phenomena from the borolanites where they occur both in the so-called pseudoleucites as well as in the groundmass. Because of the great changes which these rocks have undergone it is difficult to determine which among the minerals have reacted on each other, but it seems probable that also here one of them has been orthoclase.

As to the symplektite which is synantetic between leucite and orthoclase, it is evident that it cannot be due merely to a reaction between these minerals, because none of them contain the soda necessary for the formation of natrolite. In this case, no doubt material has been transported from without and added to the leucite. Moreover, it is uncertain whether natrolite substance in solution may simply have reacted upon the orthoclase, solving part of it which has re-crystallized together with natrolite, or, whether also the substance of the leucite, $K_4Al_4Si_4O_{12}$, which has less silica and more alumina and potash than the orthoclase, has taken part in the reactions. In this case a compound containing more silica than the natrolite $Na_2Al_2Si_3O_{12}$ must have been added, presumably a combination of the analcime silicate $Na_2Al_2Si_4O_{12}$ and the albite silicate $Na_2Al_2Si_6O_{16}$.

Possibly also chlorine derived from sodalite has been present, acting as a mineralizer. The existence of crystal water in the natrolite shows that the reactions have taken place in solutions.

As to the date of these structures, it is obvions that they are not due to any later metamorphism, but belong to the end of the consolidation of the rock magma itself.

MYRMEKITE-LIKE PLAGIOCLASE-MICROPEGMATITE.

In one case observed by me, (in the rock from Kutemajärvi) a myrmekite-like intergrowth has been formed simply by the solution of plagioclase and its re-crystallization together with the quartz which has acted as a solvent. This rock is a monzonite which originated at a syntexis of diabase and granite. Osann has described a similar case in a Canadian anorthosite where it is quite obvious that quartz has corroded the plagioclase; later on, the cavities thus formed have been filled by an intergrowth of felspar and quartz. He leaves it undecided whether the felspar is plagioclase or orthoclase, but considers the latter more probable. If this be correct the phenomenon in question, thus far, stands isolated.

These observations seem to prove beyond doubt that in certain cases a corrosion caused by silicic acid may have taken place at the formation of the myrmekite-like structures. The present forms of the felspars, however, are not due to corrosion, but to an intergrowth of felspar, forming skeleton crystals, and quartz, which fills out their interstices.

MYRMEKITE-PERTHITE AND MYRMEKITE-ANTIPERTHITE.

Of very great importance is the observation of Geijer, according to which myrmekite-like structures may consist of an intergrowth of predominating plagioclase, and orthoclase, showing wormlike forms, being, however, broader, as a rule, than the quartz of the typical myrmekite. This »myrmekite-perthite» occurs in rocks rich in plagioclase, while the neighbouring quartz-syenitic rocks contain common myrmekite. The former is, in the main, synantetic between greater individuals of perthite and surrounding oligoclase crystals belonging to the groundmass. Geijer also observed this phenomenon at the boundary between quartz and perthite. This may, however, be explained in the same way as the similar occurrence of common myrmekite. »Myrmekite-perthite» also occurs, according to Geijer, more frequently than the common myrmekite, in the fine-grained groundmass without any visible connection with larger »central felspars».

Geijer finds it evident that the cause of the formation of »myrmekite-perthite» lies in the chemical character of the »central felspar». This consists, in this instance, of an intergrowth of potash and soda-lime-felspar which was invaded by plagioclase. Thus all material in the intergrowth was derived from the same rock. The crystallization of the »myrmekite-perthite» took place after that of the larger felspars, as Geijer assumes, under conditions which were nearly related to those prevalent during the contact metamorphism. The remark that biotite has, also in this case, often invaded the larger felspars as a crystalloblastic mineral is interesting.

I think that it would be preferable to call the structure described by Geijer *myrmekite-antiperthite,* and reserve the name myrmekite-perthite for the intergrowths of microcline and vermicular plagioclase, such as the structure which I have described above, occurring in the quartz-norite from Neder-Torneå (p. 126). Or, if we shall continue to use the latter term in the meaning proposed by Geijer, we ought to emphasize that there are different kinds of myrmekite-perthite.

The myrmekite-like intergrowth of two different felspars in the rock from Neder-Torneå is therefore of great interest insomuch that we here observe all stages of the gradual destruction of the primary felspar, as well as the re-crystallization of its substance, together with that of the potash felspar which has acted as a solvent.

TYPICAL MYRMEKITE.

The common myrmekite is an intergrowth of plagioclase and vermicular quartz. The statements of earlier authors, according to which also potash felspar should occur, intergrown with quartz, as a constituent of the typical myrmekite, were all due to errors. I have myself committed the same mistake, but stated already in my first communication that the felspar was generally plagioclase. This is always the case, commonly a felspar of the series oligoclase-albite. The refined methods of petrological research, which have been introduced especially by Michel Lévy and Becke, allow us hereafter, in most cases, unfailingly to determine the character of the felspar.

As we are aware from the foregoing quotations, the opinions of petrologists who have studied the puzzling structure in question, still differ very much in their conclusions. I shall now discuss them point by point, referring also to my own observations.

1. Is the myrmekite always invasive into microcline or orthoclase? Most of the observers agree as to this point. The few cases in which myrmekite has been observed at the boundary of plagioclase and quartz may be explained by the fact that potash felspar

has earlier existed at the boundary, although it has been entirely replaced by myrmekite. I have observed a number of cases where such a succession of events has very likely taken place. The seeming exceptions from the general rule are so few as not to invalidate it. But if the myrmekite has always replaced earlier crystallized potash felspar, then it is a crystalloblastic product and cannot be regarded as primary in the strictest sense of the word.

In general the myrmekite shows, as pointed out by Becke, convex outlines against the potash felspar. The opposite cases are so few as not to invalidate the conclusion that it has its front turned against this felspar into which it has grown. Moreover, the myrmekite possesses, in some cases, a border-zone next to the microcline in which the lace-like intergrowth shows the utmost delicacy (figs. 31 and 36, plate VI, and 37, plate VII). The shape reminds one of a leaf or of some other multilobate, or multiramose, growing organic structure.

2. Is there always a core of plagioclase? In a great many cases the myrmekite is synantetic between primary crystals of plagioclase and potash felspar, forming fringes around the former at the contact with the latter which are analogous to the phenomena that have been called coronas or reaction rims. Several authors, however, have also observed cases which seem to deviate from this general rule. Hovever, it is very difficult to prove that plagioclase cannot have existed as a core, at least not in small quantities. As Becke has pointed out, the myrmekite may be a rim surrounding a plagioclase core which lies immediately below or above the thin section and has been removed at the grinding of it. Moreover, the potash felspar so generally contains plagioclase in microperthitic intergrowth that it is always possible to assume that a minute core of such material may have existed.

There is also a type of myrmekite, whose origin seems to be somewhat different from that of the fringe-like rims around plagioclase. It occurs in its most typical form in granites showing mortar structure (cf. figs. 45—47, plate VIII). The myrmekite then forms small irregular grains, or elongated spindles whose quartz worms radiate from a point near to one of the ends, or otherwise start from a short line. These spindles occur around the margins of the microcline grains and have grown against their centres, or along cracks in the larger felspars, also then pointing inwards.

If there has been in these cases a core of primary plagioclase, it has certainly been very small. It has played a rôle similar to that of a germ crystal. But it is also possible to assume that, in certain cases, secondary plagioclase which has been deposited directly on the margin of the potash felspar, may have formed the core of the myrmekite.

In general, the occurrence of the myrmekite, also in rocks where it is common, is very irregular. Becke points out that it has a predilection for some of the surfaces of the plagioclase crystals, and rarely occurs on the basis. However, I have also noted a case where it seems to occur on this surface.

It is further very probable, as Tronquoy assumes, that the microcline has been attacked with preference on surfaces where percolating waters or gases have gained access with greater facility than elsewhere. I have, myself, observed that those plagioclases which are entirely surrounded by microcline, as far as can be judged from the slides, may show no myrmekitic rims while such rims, on the other hand, occur at all other contacts between the two minerals in the same slide.

It is a striking fact that the formation of the myrmekite never extends very far from the core, the diameters of the spindles or crusts never, in the cases known to me, exceeding 1 mm. This shows that it is really a structure which is synantetic between potash felspar and plagioclase, primary or secondary, which was adjacent. But if the size of the individual grains is always minute, myrmekite may, in some cases, form a not inconsiderable part of the granite. In a porphyritic granite from Orivesi I have found not less than 15 percent myrmekite (measured according to the Rosiwal method).

3. From where has the material of the myrmekite been derived? The myrmekite like other synantetic minerals has not originated simply as a »reaction rim» by an exchange of material between the adjacent minerals. The plagioclase of the core has generally not been attacked, but has grown outwards by addition of material, and it was often, as just remarked, present in but very small quantities, at the moment when the crystallization of the myrmekite began. It is also impossible to think that its material was entirely derived from the potash felspar which it has invaded. Schwantke's hypothesis, very interesting in itself, seems to me to be untenable. The postulated silicate $Ca\,Al_2\,Si_6\,O_{16}$ is a purely hypothetical one whose existence is not warranted by the fact that there are a few analyses of potash felspar which do not agree with the rest. But even if such a silicate should exist, it would hardly be possible to account for the formation of the myrmekite by re-crystallization in a solid state of a compound felspar. It often occurs in such great

quantities that the potash felspar, or the plagioclase included in it in microperthitic intergrowth, cannot have contained such great amounts of soda and lime. Material must have been carried in from without, and other material, especially potash, removed.

This is also the opinion of Becke. He thinks, however, that all Al_2O_3 and SiO_2 were derived from the potash felspar. When Ca was substituted for K, part of the SiO_2 became free and the myrmekite must, therefore, be richer in quartz in the same proportion as its plagioclase is richer in anorthite. Now it is very difficult, as Becke remarks, to measure the quantity of the quartz vermiculé, which has such irregular outlines, but his preliminary results seem to speak in favour of the theory.

This is certainly very ingenious and suggestive, and merits to be tried by the aid of continued research. Very probably it holds good in many cases. The conditions, however, seem to be more complicated than Becke assumes. I have myself observed many cases where certain portions of myrmekite rims contain much more quartz than neighbouring parts, in which the felspar certainly has the same composition (cf. figs. 24, plate IV, 34 and 35, plate VI). Moreover, the quartz of the myrmekite sometimes has the same optical orientation as the surrounding quartz which occurs in a greater quantity, independently of the felspar, (cf. fig. 23, plate IV) and in these cases there seems to be no regular proportions of the amounts of quartz and plagioclase of the myrmekite.

4. Has the quartz and felspar crystallized simultaneously? It is generally believed that the quartz and felspar of the myrmekite have crystallized at the same time, in analogy with the primary micropegmatite. Several authors have even thought that the analogy was complete, thus regarding the structure in question simply as a plagioclase-micropegmatite which originated at the primary crystallization of an eutectic or anchieutectic magma. I will return to this question later on. But also the petrologists who think that the myrmekite is secondary, seem to regard the quartz and the plagioclase as contemporaneous crystallizations.

Entirely different was the earlier conception of Michel Lévy and other French petrologists who regarded the quartz as a »quartz de corrosion», and thought that the forms of the felspar were due to that corrosion.

The latter idea was no doubt erroneous. The forms of the plagioclase are mainly due to a skeleton crystallization whereby the quartz has filled the interstices. But in several cases its final crystallization seems to have taken place so much later than that of the felspar, that it was able to change the forms of the latter mineral by corroding it, (fig. 23, plate IV) or that the felspar could continue its growth in certain lamellæ (fig. 38, plate VII).

That such corrosion may have happened becomes still more evident, when we take into consideration the analogous intergrowths of biotite, quartz and fluorite in which the latter minerals have no doubt corroded the biotite (figs. 17 and 18, plate III).

5. Primary or secondary origin of the myrmekite. The authors who have discussed the petrogenetical question have arrived to widely different conclusions. In several cases they have also changed their opinions in the measure as they have gathered more evidence.

It has already been emphasized that myrmekite cannot be regarded as primary in the strictest sense of the word, since it has crystallized within the borders of another mineral, replacing its substance.

Another question is whether the myrmekite is a product of the plutonic activity connected with the consolidation of the magma of the rock in which it occurs, or a formation of later date.

I have here accounted for a number of observations which seem to prove beyond doubt that the myrmekite of certain rapakivi granites, and also of older pre-Cambrian rocks, has been formed before the final consolidation of all the mineral constituents of the magma in question.

The greatest part of the magma itself had crystallized, but solutions and gases, derived from the neighbourhood, or from more distant parts of the same rockmasses, still circulated within them. The same opinion has already been expressed by Becke, Reinhardt, Tronquoy, Luczizky, Gutzwiller, Eskola and others. Some of the cases studied by me seem to indicate that these reactions have been favoured by the existence in the vicinity of semi-molten basic rocks. These contained more plagioclase than the granites, and the lack of harmony in the chemical composition caused a lively transfer of material.

But even if a great part of the myrmekite is a product of the plutonic activity which gave rise to the rock itself, it is not thereby proved that it should not in other instances be due to a later metamorphism. On the contrary, it is in itself very likely that similar conditions which prevailed at the end of the consolidation of the rock masses may have set in at the beginning of a new period of plutonic activity. The observation of Beck, quoted by Trüstedt, (p. 87) concerning the occurrence of myrmekite in a narrow zone of greisen which lies next to a vein of quartz intersecting a granitic gneiss at Pitkäranta in eastern Finland, is in this respect of much interest, because, under the circumstances, no other explanation seems possible than that of a mainly pneumatolytic contact action.

Becke, Reinhardt, Gutzwiller and myself have also assumed that the formation of myrmekite may be due to contact metamorphism. Hereby is not necessarily meant the restricted metamorphism in an aureole around a small magma basin. To me, regional metamorphism and plutonic contact metamorphism are, in many cases, synonymous processes. When mentioning the former in this connection, I have not meant mainly a mechanical metamorphism.

It is evident that the formation of myrmekite is not compatible with very strong metamorphism, irrespective of its cause. Such delicate structures, where the different rods of quartz often have a thickness of less than 0,01 mm, in some cases less than 0,001 mm, are easily destroyed as soon as stronger metamorphosing influences set in. They are therefore rather uncommon in rocks with true gneissose texture.

The formation of the myrmekite may be either earlier, contemporaneous with, or later than the mechanical crushing of the rock, depending on the succession of the events at its metamorphism.

THE BIOTITE-QUARTZ-SYMPLEKTITE AND ITS RELATIONS TO THE MYRMEKITE.

Becke has pointed out that the great amounts of potash which are discharged when the myrmekite is formed, at the expense of the potash felspar, may possibly supply the material for the formation of secondary mica in plutonic rocks, or in their contact aureoles. These presumptive theoretical conclusions of a genetic relation between myrmekite and mica are entirely corroborated by observations of Gutzwiller and myself which show that in many cases the formation of biotite, often intergrown with quartz, directly follows the invasion of the myrmekite, like the second rank of an invading troop following the first one.

The study of the biotite-quartz-symplektites throws much light upon the mode of formation of these structures, in general. Although also here, a part of the quartz may be a rest of the felspar which has been replaced by the symplektite, this quartz seems to be connected, in some cases, with such quartz that belongs to the last rest of the magma. The presence of fluorite shows that also material brought from without has been present. The peculiar forms of the intergrowths seem to be due, also in ths case, mainly to a skeleton crystallization (this is especially true of the dactylitic parts), but is influenced sometimes by a corroding action of the silicic acid. The fluorite may have acted as mineralizer at the crystallization of the biotite, and may also have been concomitant at the dissolution of the primary potash felspar. However, I should not call the whole process pneumatolytic, considering that materials have, no doubt, also been carried in aqueous solutions.

CONCLUDING REMARKS.

In general the processes which have now been discussed, both the formation of the biotite-quartz-symplektite and the myrmekite, are much more complicated than earlier authors have admitted. At first acquaintance they frequently appear to render an explanation easy enough. It may then seem obvious that they are primary or secondary, that they are due to the action of gases or solutions or to a re-crystallization in a solid state, that corrosion has either played a rôle, or been absent, or that they have all been of a more recent, or later date than the mechanical crushing of the rock. But the closer we scrutinize these puzzling things, the more difficult will it be to apply one of these theories as an explanation of all these phenomena.

As to the myrmekitization, most of the different theories are of some value, at least in the elucidation of some minor points, though none of them give a complete explanation of the whole process. This is, as Tronquoy has remarked, a special case of albitization. But the latter process, again, is only one of the special cases of the changes which rocks undergo when they are percolated by superheated water, carrying in solution a number of different matters, many of which are extracted from adjacent rock masses, and by gases. These processes may either belong to the waning phase of the plutonic activity, connected with the eruption of the rock in question, or, to the beginning of a later period of metamorphism. In both of these cases, it may be inferred that agents of a nearly identical character have been active, in consequence of which the minerals formed also show so much analogy.

These processes must necessarily be of a very complicated character, because they depend on the nature and quantity of the solvent, of the composition of the rock itself, and of the adjacent rock masses, as well as the changes in pressure, temperature, etc.

Petrologists so often speak about »juices», percolating the rock masses, but generally in a very vague and indefinite fashion. Here, we have been able to study the work of such juices, being thus in a position to supply a contribution to the determination of their nature.

Also the term minéralisateurs is often used in a very vague manner. As Morozevicz justly remarks, these agencies are evoked as a deus ex machina every time when phenomena of crystallization meet which are otherwise difficult to explain in a satisfactory way. The experimental researches of the investigator mentioned show that minerals of the same character as those of the eruptive rocks originate, without any aid of mineralizers, in artificially fused rocks. But it would be going too far entirely to deny the existence of mineralizers in rock magmas, especially of such occurring at the end of the consolidation of the magma. On the contrary, there are many proofs of the existence of such gases and liquids, and we will, by studying especially such phases of the process in question where the rocks have not been more completely changed, learn to know more thoroughly the real nature of these agencies.

As to the synantetic structures of the basic rocks, they seem to differ from those of the granites, in so far that most of them are truly metamorphic.

Of course it is possible theoretically to imagine that also in these rocks changes of the minerals may have taken place in a large measure during the waning phase of the eruptive activity by which the rock was originally formed. In fact we have learnt to know, also from the basic rocks, some examples of metasomatic changes of such a character. However, it is obvious that these rocks in general have been percolated by gases and liquids, belonging to the magma of the rock itself, in a much more restricted quantity than the acid rocks. The comparative scarcity in the former, of veins analogous to the pegmatites and aplites of the granites is already a fact pointing in this direction. Although we will probably learn to know, by farther micropetrological research, also in the basic rocks, new cases of metasomatic changes of the character in question, I do not think that such studies will reveal anything in quantity and importance comparable to the »late-primary» albitization and myrmekitization &c. of the granitic rocks.

I think that it would be advisable to discriminate between such metasomatic changes which belong to a later period of metamorphism, i. e. are secondary in the strictest sense of the word, and

[1] J. Morozewicz, Experimentelle Untersuchungen über die Bildung der Minerale im Magma. Tschermak's Min. u. Petr. Mitt. XVIII, 1899, p. 8.

those which have taken place in direct continuation of the consolidation of the magma of the rock itself. I propose to call the latter deuteric, as distinct from secondary changes. The word deuterogene, which would perhaps be preferable, has been used before by Naumann as a designation of the clastic rocks.

The great chemical interest of all the synantetic minerals lies in the fact that they seem to be chemical formulæ written in stone. Often their interpretations seem to lie so close at hand, that it appears only necessary to grasp a pen and write them down on paper. But, as we have found, it becomes evident later, that the reactions between the mineral substances derived from the adjacent minerals have been complicated by transfer of material from greater distances, thus increasing the difficulty of an interpretation.

The ancient rocks, especially the granites, often appear to the petrologists as monotonous and dead. However, we observe among their minerals structures which almost give the impression of something living and growing. One is often reminded, while studying the beautiful phenomena here in question, of the words of the poet about things which do not fade, but »suffer a change into something rich and strange». It seems to us as if we were able here to grasp the formation of metamorphic minerals almost in statu nascenti. The value of the synantetic minerals is herein equal, if not superior, to that of the pseudomorphs which have furnished so much elucidation on the subject of metamorphic processes. Their study further helps to bridge the chasm which exists, according to the orthodox petrology, between the phenomena connected with the primary crystallization of magmatic rocks and that of the later metamorphism which they have undergone.

The purpose of this memoir has mainly been to show that these structures are well worth a continued and very detailed study and to develop the *method* of such research. Where there are legible signs, we are certain that they will be sooner or later interpreted, even if the first interpretatien would not prove entirely successful.

In spite of this great interest of the synantetic minerals I have often felt the futility of such a purely theoretical study of microscopical structures, at a time when the world's fate is at stake. It has sometimes occurred to me that if one had to repeat, in a modernized form, the famous dictum of Archimedes: ne disturbe circulos meos, it would not sound quite as well to say: please do not disturb my study of myrmekite, &c. But, after all, if one is not able, in some way or other, to fight for Mankind, or Fatherland, or some similar lofty ideal, what can one do better than to work, in a modest way, for Science.

Explanation of the Figures.

Where not otherwise mentioned, all photographs have been taken by Mr. W. W. Wilkman.

PLATE I.

Fig. 1. Ilmenite surrounded by a corona-like rim of biotite when bordering on andesine. Olivine-diabase from Kiperjärvi in Eura, near Björneborg. Specimen taken by Hj. Gylling, Eura 53, 1886. Ordinary light. × 53.

Fig. 2. »Porcupinitic» biotite, protruding from hypersthene into andesine. Norite from Tuulasoja in Merijoki, S.W. of Uleåborg. Specimen taken by E. Mäkinen 23, 1911. Ordinary light. × 22.

Fig. 3. Olivine crystals surrounded by rims of primary augite, brown hornblende and ilmenite. Gabbro E. of Salmela, Ylivieska, S.W. of Uleåborg. Specimen taken by J. J. Sederholm 12, 1887. Ordinary light. × 18.

Fig. 4. Olivine crystal surrounded by coronas of tremolite and green hornblende, which also occur as pseudomorphs after andesine laths projecting into the olivine. Hyperite (gabbro) from Ölme, N. E. of Lake Wenern, Sweden. Specimen taken by J. J. Sederholm, 1896. Ordinary light. × 16.

Fig. 5. Olivine crystal surrounded by coronas of tremolite and green hornblende, when bordering on plagioclase. To the left below augite; at the contact of the latter mineral and the olivine no coronites occur. Old Archæan olivine-gabbro from a small island S.E. of Tunnholm, Borgå. Specimen taken by J. J. Sederholm 72, 1914. Ordinary light. × 40.

Fig. 6. Olivine crystal surrounded by a primary coating of augite. Old Archæan diabase from the eastern part of the island Virskär, Pernå, S.E. of Borgå. Specimen taken by J. J. Sederholm 23, 1911. Polarized light. × about 50.

PLATE II.

Fig. 7. Myrmekite-like intergrowth of plagioclase and vermicular hornblende, encroaching upon primary plagioclase. The same rock as fig. 6. Ordinary light. × 55.

Fig. 8. Myrmekite-like intergrowth of plagioclase and vermicular hornblende in a plagioclase lath surrounded by augite. To

the left of the intergrowth flakes of biotite occur. The same rock as fig. 2. Ordinary light. × 57.

Fig. 9. Myrmekite-like intergrowth of plagioclase and vermicular hornblende; in the midst of the intergrowth two flakes of biotite occur. The same rock as figs. 2 and 8. Ordinary light. × 150.

Fig. 10. Biotite with dactylitic fringes surrounded by intergrowths of plagioclase and vermicular hornblende (or pyroxene). Below, to the left, is seen a corner of a big olivine crystal. Anorthosite N. of Nurma in Mäntyharju, S.E. of Heinola. Specimen taken by A. Pönnelin, 1893, n:o 86. Ordinary light. × 43. Photo. Benj. Frosterus.

Fig. 11. Myrmekite-like intergrowths of plagioclase and vermicular hornblende, or augite, encroaching upon primary plagioclase. To the right biotite which sends out smaller flakes into the intergrowth. The same rock as fig. 10. Ordinary light. × 65. Photo. Benj. Frosterus.

Fig. 12. Intergrowths of plagioclase and hornblende, encroaching upon primary plagioclase. In the midst a zone of uralite, biotite &c. (cf. fig. 3 in the text). Anorthosite from Kousa in Mäntyharju. Specimen taken by Benj. Frosterus, 1895. N:o 184. Polarized light. × 20.

Fig. 13. Intergrowth of epidote and quartz which shows, in part, vermicular forms. The grain to the right of the epidote, which shows three light twinning lamellae, is calcite. Below this calcite there is a grain of quartz (white). On most sides of the epidote, grains of microcline occur; below, to the left, a grain of plagioclase (light, showing an indistinct twinning lamellation). Contact-rock at the boundary between crystalline limestone and granite. Western shore of Swatoï Nos, Lake Baïkal, Siberia. Specimen taken by Pentti Eskola, 1914. Polarized light. × 23.

Fig. 14. Uralitic web which has replaced pyroxene and is surrounded by a rim of zoisite, when bordering on plagioclase. In the midst a rounded grain of quartz. Quartz-diorite from Iknonvaara in Pielisjärvi, N.E. of Joensuu. Specimen taken by U. Makkonen 59, 1901. Polarized light. × 35.

Fig. 15. Intergrowth of scapolite and vermicular quartz, surrounded by grains of quartz (showing undulatory extinction), microcline, scapolite and calcite (some of the last-mentioned lying next to the intergrowth.) Calcitic gneiss, alternating with crystalline limestone. Kirmoudd on Ovensor (Ahvensaari), Korpo, archipel of Åbo. Specimen taken by A. Laitakari, 20, 1912. Polarized light. × 20.

Fig. 16. »Myrmekite-perthite», consisting of oligoclase (white) and vermicular microcline. The grey mineral to the left is quartz, but the slender rods which seem to project from it, and extend into the oligoclase, consist of microcline. Syenite from Rackberget in northern Sweden. Specimen taken by Per Geijer. Polarized light. × 45. Photo. Per Geijer.

Fig. 17. Biotite crystal showing straight contours when bordering on quartz, but fringed contours when in contact with felspar. In the upper left hand corner, grains of quartz and fluorite next to the biotite. Rapakivi from Vilajärvi in Säkkijärvi, W. of Wiborg. Specimen taken by H. Berghell. Ordinary light. × 22.

Fig. 18. Biotite crystal containing several grains of ore, and, in the centre, quartz and fluorite. A slender mica lamella projects from an ore grain in the adjacent felspar. The same rock as fig. 17. Ordinary light. × 20.

PLATE IV.

Fig. 19. Biotite intergrown with quartz, and, on the upper side of this intergrowth, spindles of myrmekite. The same rock as fig. 17 and 18. Ordinary light. × 20.

Fig. 20. Spindles of myrmekite at the border of an intergrowth of biotite and quartz. Portion of the section shown in fig. 19. Polarized light. × 45.

Fig. 21. Myrmekite invading the corner of an orthoclase crystal; the plagioclase has later in part been replaced by biotite. In the lower portion of the photograph, plagioclase mainly occurs. Rapakivi granite (monzonite), next to an included fragment of anorthosite from Uotila, Mäntyharju, S.E. of Heinola. Specimen taken by Benj. Frosterus, 1893, N:o 208. Polarized light. × 55.

PLATE III.

Fig. 22. Spindles of myrmekite at the boundary of a crystal of microcline. Behind them lies biotite which has almost entirely replaced the plagioclase of the myrmekite spindle most to the left. This biotite has the same orientation as the adjacent solid biotite crystal. The same rock as fig. 21. Polarized light. × 23.

Fig. 23. Plagioclase crystal corroded by quartz which has in part the same orientation as the vermicular quartz in the myrmekite which forms a rim at the contact of the plagioclase and adjacent microcline. The same rock as fig. 21. Polarized light. × 20.

Fig. 24. Plagioclase continued by a myrmekitic rim, containing, in some places, but very little quartz. The mineral in the

upper part of the photograph is microcline. The same rock as fig. 21. Polarized light. × 52.

PLATE V.

Fig. 25. Suture-like boundary between plagioclase and microcline, with some quartz at the contact. Rapakivi granite from Simola, W. of Wiborg. Specimen taken by Benj. Frosterus 1891, 24. Polarized light. × 44.

Fig. 26. Microcline crystal bordered by rims of myrmekite, at the contact with adjacent oligoclase crystals. Porphyritic granite from Hautajärvi in Petäjävesi, S.E. of Jyväskylä. Specimen taken by T. Hirn, 1895, N:o 260. Polarized light. × 16.

Fig. 27. Myrmekite, in part intergrown with dactylitic biotite. The same rock as fig. 26. Polarized light. × 24.

Fig. 28. Oligoclase crystal containing microcline in antiperthitic intergrowth. The same rock as fig. 26. Polarized light. × 24.

Fig. 29. Micropegmatitic intergrowth of oligoclase and quartz which has replaced primary oligoclase. Archæan granite from Kutemajärvi, Kangasniemi, N.W. of St. Michel. Specimen taken by Benj. Frosterus, N:o 272. Polarized light. × 45.

Fig. 30. Oligoclase crystal surrounded by a myrmekitic rim when bordering on microcline. Pyroxene-granite from Grafversfors near Norrköping in Sweden. S. G. U., large thin section N:o 17. Polarized light. × 13.

PLATE VI.

Fig. 31. Myrmekite with a lace-like border-zone. The same rock as fig. 30. Polarized light. × 140. Photo. P. J. Holmquist.

Fig. 32. Tufts of dactylitic biotite and myrmekite. The same rock as fig. 30. Polarized light. × 22.

Fig. 33. Myrmekite in which the plagioclase has been in part replaced by biotite. The same rock as fig. 30. Ordinary light. × 50.

Fig. 34. Dactylitic biotite encroaching upon myrmekite. The same rock as fig. 30. Polarized light. × 20.

Fig. 35. Myrmekite spindle upon which a biotite crystal has encroached, leaving in part the vermicular quartz intact. The same rocks as fig. 30. Polarized light. × 45.

Fig. 36. Myrmekite, resembling in part graphic granite, at the boundary of microcline and biotite, behind which lies, in the lower lefthand corner of the photograph, oligoclase. Microcline granite from Nummela, N.W. of Oksjärvi, Tammela, S.W. of Tavastehus. Specimen taken by J. J. Sederholm, M. 52, 1888. Polarized light. × 60.

PLATE VII.

Fig. 37. Myrmekite with fringed border-zones. Granite from Lysekil in Sweden. S. G. U., large thin section N:o 28. Polarized light. × 30. Photo. P. J. Holmquist.

Fig. 38. A portion of myrmekite from the same thin section as, fig. 37, showing how certain twinning lamellae of the plagioclase project into the quartz. Polarized light. × 140. Photo. P. J. Holmquist.

Fig. 39. Oligoclase crystal and myrmekite. Microcline granite from Rajala, Kankaanpää, N.E. of Björneborg. Specimen taken by J. J. Sederholm, K. 78, 1892. Polarized light. × 45.

Fig. 40. Oligoclase with a core of myrmekite. Old Archæan granite, re-crystallized at the contact with a dyke of rapakivi granite. Northern shore of Bergholm, Pernå. Specimen taken by J. J. Sederholm 29, 1912. Polarized light. × 45.

Fig. 41. Potash felspar containing vermicular plagioclase and small drop-like inclusions of the same mineral. The larger grains showing twinning lamellation consist of primary plagioclase. Quartz-gabbro from Kuivaniemi, Neder-Torneå in northern Finland. Specimen taken by J. Illukka. J. 22, 1899. Polarized light. × 52.

Fig. 42. Potash felspar containing rounded inclusions of plagioclase of varying sizes. In the upper right hand corner allotriomorphous perthitic potash felspar occurs which is free from inclusions and vermicular rods of plagioclase. Around this potash felspar lie crystals of pyroxene. The primary plagioclase shows corrosion phenomena when bordering on that potash felspar which contains rounded inclusions. The same rock as fig. 46. Polarized light. × 52.

PLATE VIII.

Fig. 43. Distortion induced by pressure on myrmekite. Granite occurring as a small lense in mica-schist from St. Andreæ, E. of Wiborg. Specimen taken by Benj. Frosterus. N:o 58, 1893. Polarized light. × 18.

Fig. 44. Porphyritic granite intersected by trituration zones which are partly filled out by myrmekite. From a railway cutting near Matku, Urjala, E. of Tavastehus. Specimen taken by J. J. Sederholm, 1888. Polarized light. × 18.

Fig. 45. Spindles of myrmekite on trituration zones intersecting microcline and a crystal of secondary albite. Microcline granite from Keihäsjärvi in Kalvola. Specimen taken by H. Buss 32, 1887. Polarized light. × 13.

Fig. 46. Microcline intersected by trituration zones which are mainly filled out by myrmekite spindles. Granite from Bogskär. S.W. from Åbo. Specimen taken by Benj. Frosterus, 1890. Polarized light. × 12.

Fig. 47. Microcline crystals intersected by trituration zones which are partly filled out by myrmekite. In the crack subdividing the largest felspar, to the right, also biotite occurs. Granite from Keijärvi, Ylöjärvi, N.W. of Tammerfors. Specimen taken by J. J. Sederholm, K. 24, 1890. Polarized light. × 16.

Fig. 48. Muscovite showing fringed border-zones where the mica is intergrown with vermicular quartz. In the midst biotite, to the left microcline, to the right oligoclase. Southern shore of Lake Pyhäjärvi, Tammela, S.W. of Tavastehus. Specimen taken by J. J. Sederholm, M. 59, 1888. Polarized light. × 45.

PLATE I.

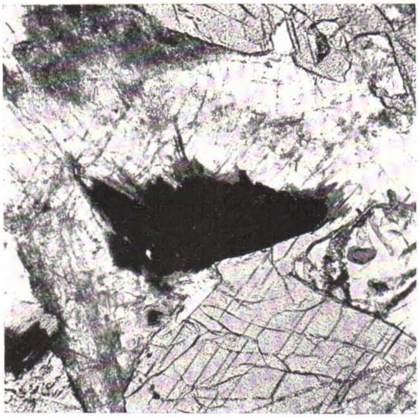


Fig. 1.

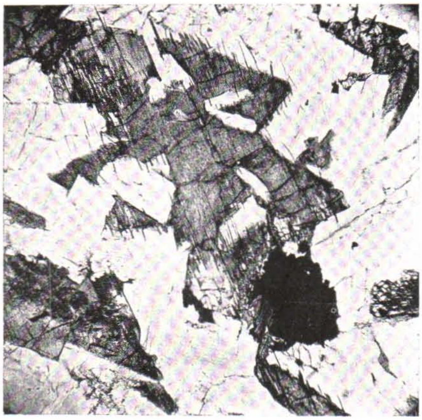
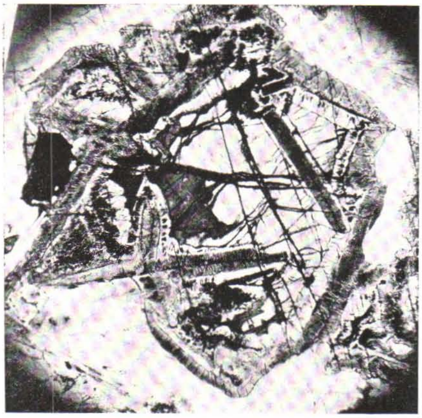


Fig. 2.

Fig. 3.



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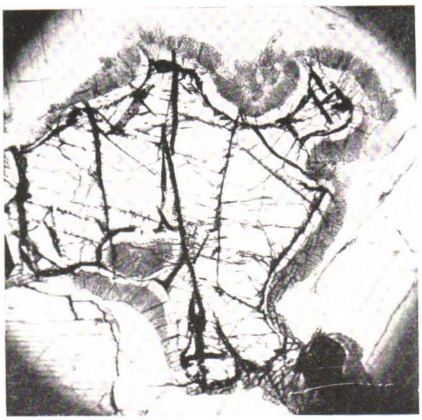

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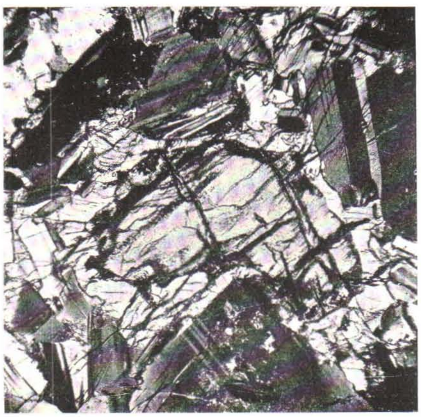


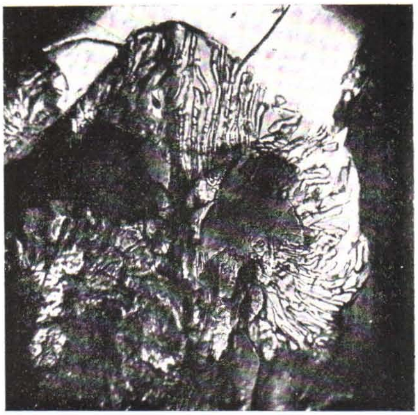
Fig. 6.

J. J. Sederholm: On Synantetic Minerals.

PLATE II.

Fig. 7.

Fig. 8.



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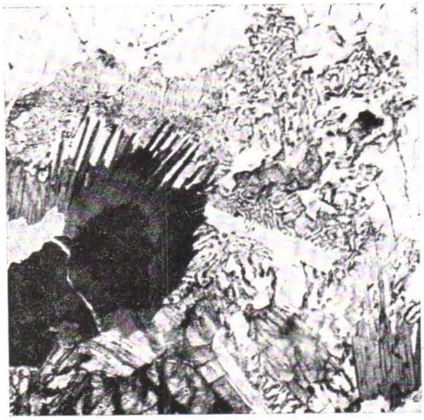

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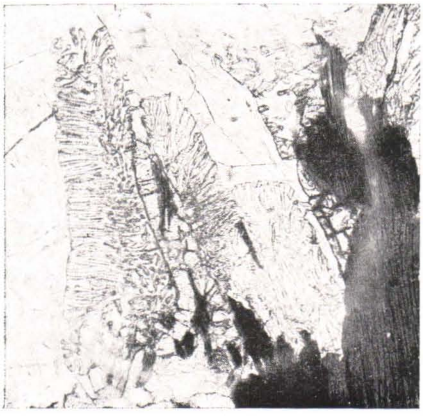
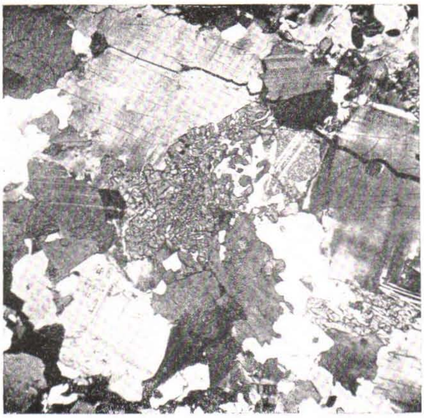


Fig. 11.

Fig. 12.

J. J. Sederholm: On Synantetic Minerals.

PLATE III.



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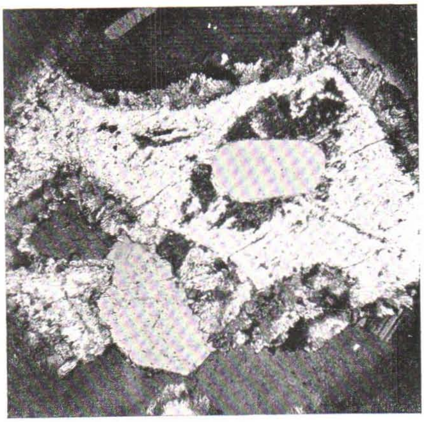


Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

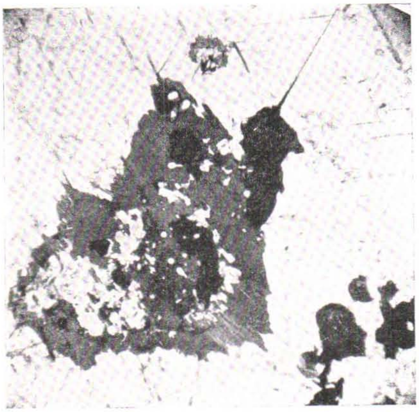


Fig. 18.

J. J. Sederholm: On Synantetic Minerals.

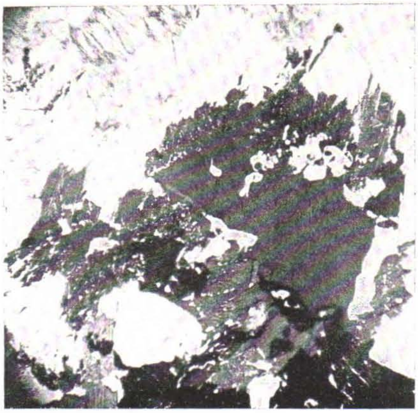


Fig. 19.

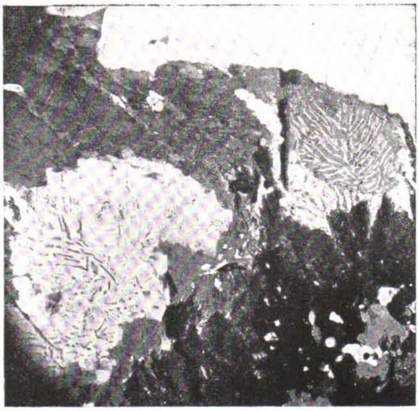
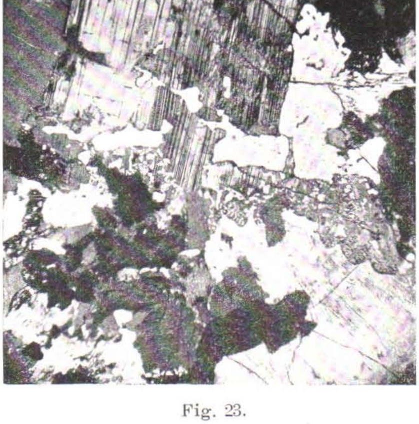


Fig. 20.

Fig. 21.

Fig. 22.



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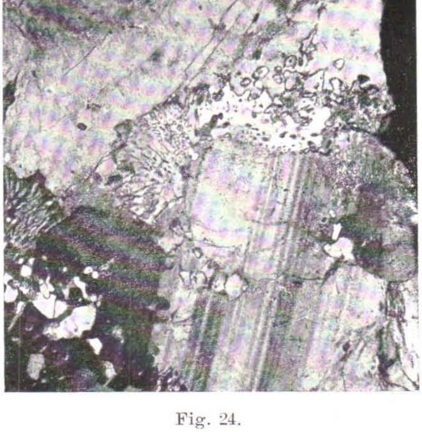

Fig. 24.

J. J. Sederholm; On Synantetic Minerals.

PLATE V.

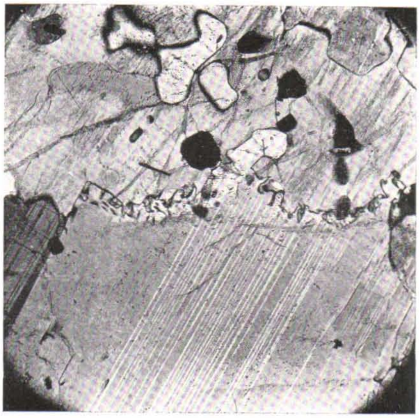

Fig. 25.

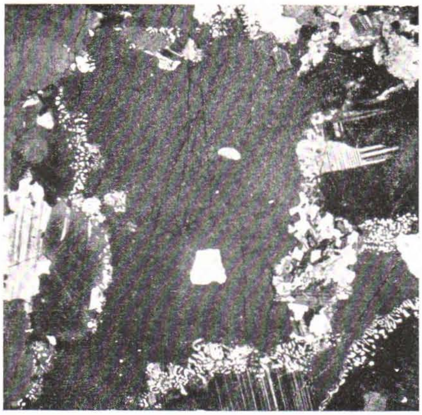

Fig. 26.

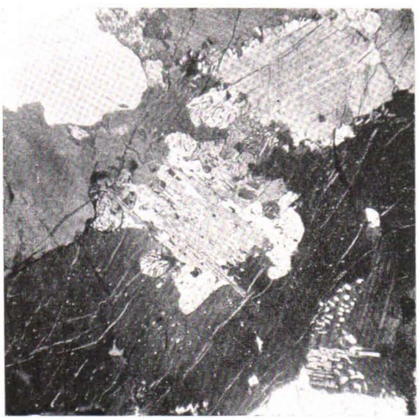

Fig. 27.

Fig. 28.

Fig. 29.

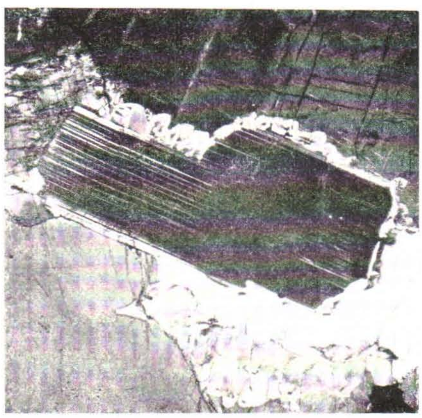

Fig. 30.

J. J. Sederholm: On Synantetic Minerals.

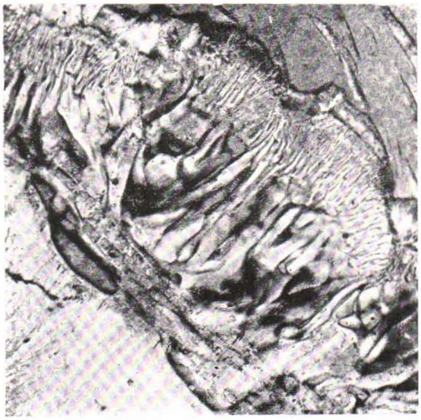

Fig. 31.

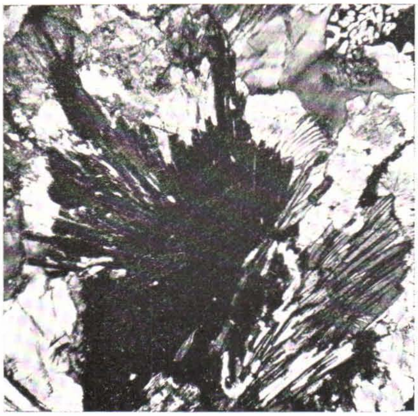

Fig. 32.

Fig. 33.

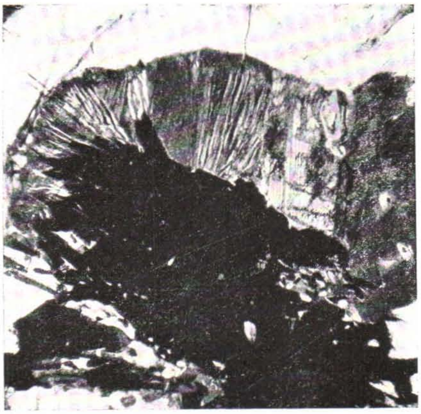

Fig. 34.

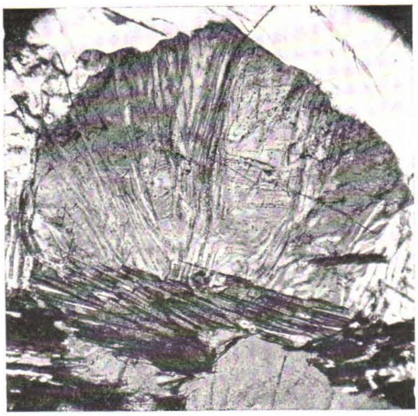

Fig. 35.

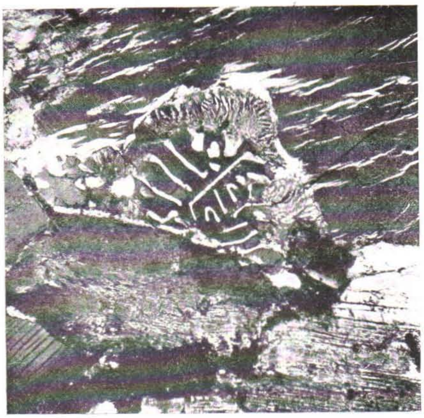

Fig. 36.

J. J. Sederholm; On Synantetic Minerals.

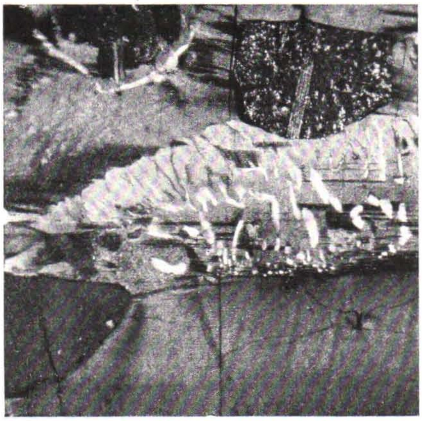

Fig. 37.

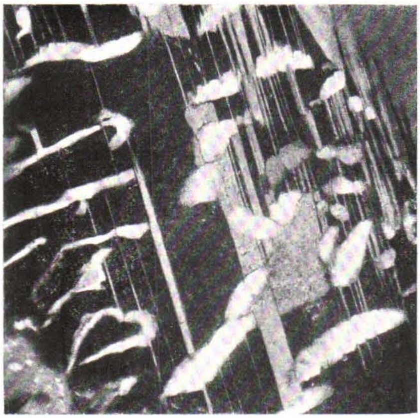

Fig. 38.

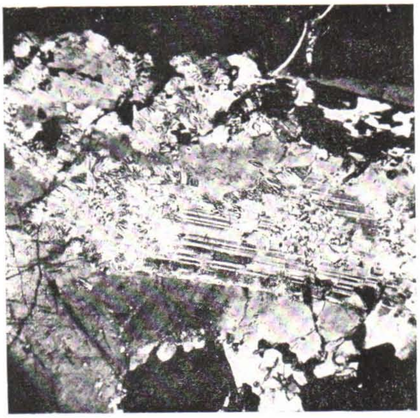

Fig. 39.

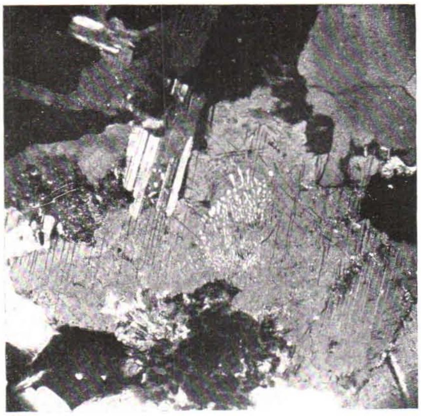

Fig. 40.

Fig. 41.

Fig. 42.

J. J. Sederholm: On Synantetic Minerals.

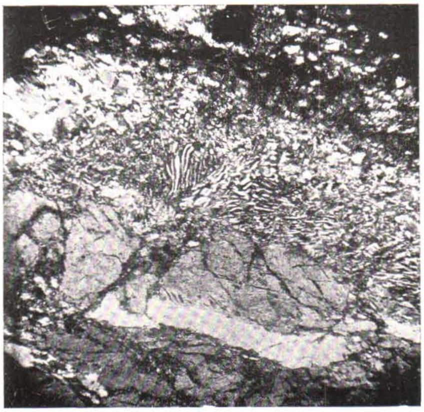

Fig. 43.

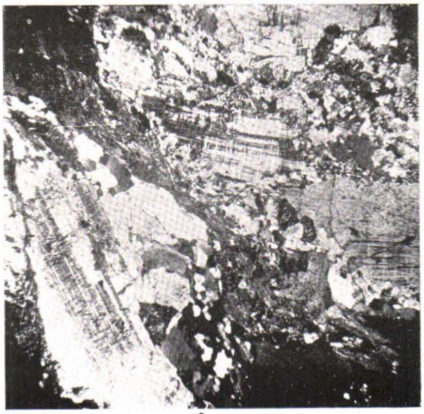

Fig. 44.

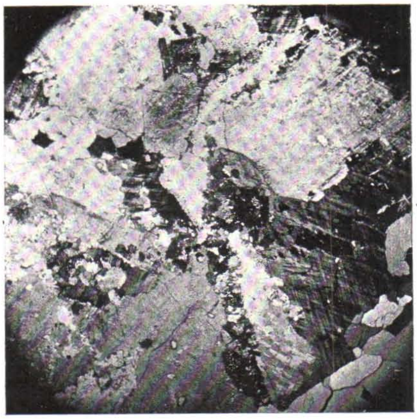

Fig. 45.

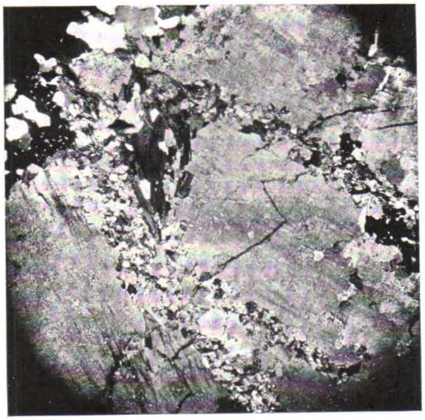

Fig. 46.

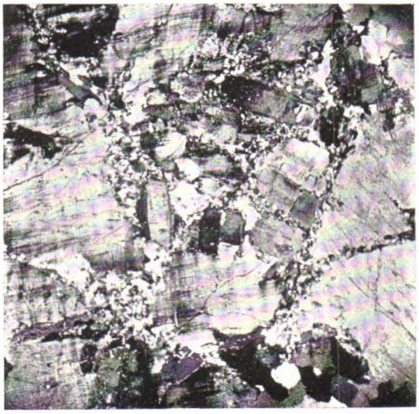

Fig. 47.

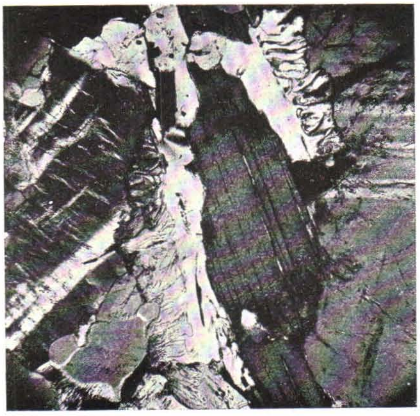

Fig. 48.

J. J. Sederholm; On Synantetic Minerals.

N:o 17. On the occurrence of Gold in Finnish Lapland, by CURT FIRCKS. With one map, 15 figures and frontispiece. Nov. 1906 .... 1:25

N:o 18. Studier öfver Kvartärsystemet i Fennoskandias nordliga delar. I. Till frågan om Ost-Finmarkens glaciation och nivåförändringar, af V. TANNER. Med 23 bilder i texten och 6 taflor. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. I. Sur la glaciation et les changements de niveau du Finmark oriental. Mars 1907.. 4:—

N:o 19. Die Erzlagerstätten von Pitkäranta am Ladoga-See, von OTTO TRÜSTEDT. Mit 1 Karte, 19 Tafeln und 76 Figuren im Text 7:50

N:o 20. Zur geologischen Geschichte des Kilpisjärvi-Sees in Lappland, von V. TANNER. Mit einer Karte und zwei Tafeln. April 1907.......... 1:—

N:o 21. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. II. Nya bidrag till frågan om Finmarkens glaciation och nivåförändringar, af V. TANNER. Med 6 taflor. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. II. Nouvelles recherches sur la glaciation et les changements de niveau du Finmark. Juin 1907.... 3:50

N:o 22. Granitporphyr von Östersundom, von L. H. BORGSTRÖM. Mit 3 Figuren im Text und einer Tafel. Juni 1907 .... 1:—

N:o 23. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia, af J. J. SEDERHOLM. Med 8 taflor, en planteckning, en geologisk öfversiktskarta öfver Fennoskandia och 11 figurer i texten. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. With 8 plates, a coloured plan, a geological sketch-map of Fenno-Scandia and 11 figures. Juli 1907.......... 3:—

N:o 24. Les roches préquaternaires de la Fenno-Scandia, par J. J. SEDERHOLM. Avec 20 figures dans le texte et une carte. Juillet 1910 .... 1:50

N:o 25. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-Öjen im Kirchspiel Saltvik, Åland-Inseln. von V. TANNER. Mit 2 Tafeln und 5 Fig. im Text. Mai 1911 .... 1:25

N:o 26. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium, von EERO MÄKINEN. Mai 1911.......... —:50

N:o 27. Esquisse hypsométrique de la Finlande, par J. J. SEDERHOLM. Avec une carte et 5 figures dans le texte. Juillet 1911.......... 1:50

N:o 28. Les roches préquaternaires de la Finlande, par J. J. SEDERHOLM. Avec une carte. Juillet 1911 .... 1:50

N:o 29. Les dépôts quaternaires de la Finlande, par J. J. SEDERHOLM. Avec une carte et 5 figures dans le texte. Juillet 1911.......... 1:50

N:o 30. Sur la géologie quaternaire et la géomorphologie de la Fenno-Scandia, par J. J. SEDERHOLM. Avec 13 figures dans le texte et 6 cartes. Juillet 1911.... 1:50

N:o 31. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar, af H. HAUSEN. Mit deutschem Referat. Mars 1912 .... 1:—

N:o 32. Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor, af H. HAUSEN. Mit deutschem Referat. Mars 1912.......... 1:—

N:o 33. Kvartära nivåförändringar i östra Finland, af W. W. WILKMAN. Med 9 figurer i texten. Deutsches Referat. April 1912.......... 1:—

N:o 34. Der Meteorit von St. Michel, von L. H. BORGSTRÖM. Mit 3 Tafeln und 1 Fig. im Text. August 1912 .... 1:50

N:o 35. Die Granitpegmatite von Tammela in Finnland, von EERO MÄKINEN. Mit 23 Figuren und 13 Tabellen im Text. Januari 1913 .... 1:50

N:o 36. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities, by PENTTI ESKOLA. With 15 Figures in the Text. Februari 1913.. 1:50

N:o 37. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia, von J. J. SEDERHOLM. Mit einer Tafel und 27 Figuren im Text. Juni 1913 .... 1:50

N:o 38. Studier öfver Kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter, af V. TANNER. Med 139 figurer i texten och 16 taflor. Résumé en français: Etudes sur le système quaternaire dans les parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. Oktober 1915 .... 7:50

N:o 39. Der gemischte Gang von Tuutijärvi im nördlichen Finland, von VICTOR HACKMAN. Mit. 4 Tabellen und 9 Figuren im Text. Mai 1914 .... 1:50

N:o 40. On the Petrology of the Orijärvi region in Southwestern Finland, by PENTTI ESKOLA. Oktober 1914 .... 4:—

N:o 41. Die Skapolithlagerstätte von Laurinkari, von L. H. BORGSTRÖM. Augusti 1914. 1:50

N:o 42. Über Camptonitgänge im mittleren Finnland, von VICTOR HACKMAN. Aug. 1914. 1:50

N:o 43. Kaleviska bottenbildningar vid Mölönjärvi, af W. W. WILKMAN. Med 11 figurer i texten. Résumé en français. Januari 1915 .... 1:50

N:o 44. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter, af PENTTI ESKOLA. En train de paraître ....

N:o 45. En train de paraître..................................

N:o 46. Le gisement de calcaire cristallin de Kirmonniemi à Korpo en Finlande par AARNE LAITAKARI. Avec 14 figures dans le texte. Janvier 1916........ 1:50

N:o 47. Översikt av de prekambriska bildningarna i mellersta Österbotten, av EERO MÄKINEN. Med en översiktskarta och 25 fig. i texten. English Summary of the Contents. Juli 1916 .... 2:50

N:o 48. On Synantetic Minerals and Related Phenomena (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, &c., by J. J. SEDERHOLM, with 14 Figures in the text and 48 figures on 8 plates. July 1916 .... 3:—