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ON MIGMATITES AND ASSOCIATED PRE-CAMBRIAN ROCKS OF SOUTHWESTERN FINLAND

PART II. THE REGION AROUND THE BARÖSUNDSFJÄRD W. OF HELSINGFORS AND NEIGHBOURING AREAS

BY

J. J. SEDERHOLM

WITH ONE MAP, 57 FIGURES IN THE TEXT AND 44 FIGURES ON IX PLATES

HELSINKI - HELSINGFORS
DECEMBER 1926

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* Épuisés.

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TABLE OF THE CONTENTS.

GENERAL CHARACTER OF THE BARÖSUNDSFJÄRD REGION AND OUTLINE OF ITS PRE-CAMBRIAN GEOLOGY.

The *Barösundsfjärd* lies about 40 km W. of Helsingfors and is limited on the east by the forelands of Obbnäs and Porkkala, and on the west by an archipelago of innumerable islands some of which are justly renowned for their beauty. To the south the *fjärd* [fjärd (pr. fiærde) = firth; fjärden = the firth] widens towards the sea, while the northernmost part narrows into the *Pikkala viken* and other bays, which cut into the neighbouring coast-line of the province of Nyland.

The earliest mapping of this region was done in the years 1865—1878, and the result published by K. A. Moberg in 1880. At that time, however, the principles on which the study of the Archæan should be based, were still vaguely defined. Especially the discrimination between granites and gneisses was very uncertain. It was therefore not to be expected that this first mapping should give anything like an adequate idea of the extremely complicated geological structure of this region.

The writer has studied it on several visits especially in the years 1908 and 1911, He has devoted his main interest to the region near Bågaskär, and E. of the Barösundsfjärd; the region lying further to the west, north and northeast of the fjärd has not been studied in equal detail, but will also occasionally be treated here. As the present map is not based on a new detailed survey all over the region, it must be regarded as a sketch map, especially as to the northern parts. It only attempts to give a general idea of the complicated geological structure of the area.

In the year 1911 Dr. H. Hausen assisted the author in making drawings, and in the same year he independently surveyed a great part of the granitic area of Obbnäs, E. of the Barösundsfjärd, thereby also exactly determining its boundaries.

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[1] K. A. Moberg, Beskrifnng till kartbladet N:o 2. Finl. Geol. Unders. Helsingfors 1880.

In 1912 and 1916 the writer gave preliminary descriptions of part of the phenomena observed [1] and in 1911 he organized an excursion to show them to a number of visiting colleagues, representing different countries. In 1924 similar excursions were repeated, when among others Dr. Alfred Harker visited this region.

These visits of foreign colleagues have afforded the writer an agreeable opportunity of discussing many interesting questions connected with the phenomena and their interpretation. The suggestions which have been made have enabled him better to define the points which possess the greatest importance, and have shown him where additional evidence was most necessary. As this easily accessible region affords better opportunities than most others of studying some of the fundamental problems of petrology and especially what may be called »ultra-petrology», the writer hopes that these visits will be repeated.

The cordial thanks of the writer are due to Miss Kajanus, owner of a villa by the fjärd, and herself a student of geology, and to Mr Thure W. Lindeberg, of Pikkala, and Professor W. Wahl, of Störsvik, both residents on estates lying near to the Barösundsfjärd. Their kind aid and hospitality has also on many occasions facilitated the study of these regions for visiting foreign geologists.

The thanks of the writer are also due to Mr W. Poppius, Director General of the Customs, who kindly permitted him to travel in revenue vessels while surveying this region. The native fishermen and pilots inhabiting the islands of this area have also done everything in their power to facilitate the work of the writer and have shown him hospitality in their homes.

The writer is much obliged to Dr. V. Hackman for his kindness in aiding him with the calculation of the analyses, and to Professor P. Eskola for kindly analyzing a granite from the area.

OUTLINE OF THE PRE-CAMBRIAN GEOLOGY OF THE BARÖSUNDSFJÄRD REGION.

The oldest rocks of the region belong to the same formation as the oldest schists of the Pellinge region,[2] and are referred by the author

[1] J. J. Sederholm, Om palingenesen i den sydfinska skärgården etc. Geol. För. Stockholm Förh. Bd 34, 1912, pp. 285—316.

— — Ladogium Redivivum, 2d chapter: En serarkeisk granitgrupp i södra Finland och mellersta Sverige. Ibid. Bd 38. 1916, pp. 32—40.

[2] — — This series, Part I, Bull. Comm. géol. Finl. N:o 58.

to the Svionian (or Katarchæan) rocks which are common in middle Sweden and southern Finland. Among them fine grained »leptitic» schists prevail which often show a marked alternation of basic and more acid layers, and in many places are intercalated with thin layers of limestone.

The Rabbasö quartzite of the Pellinge area is not represented here. It still appears 25 km E. of Helsingfors in a highly metamorphic state, but is not visible further east.

Next in order in succession of the rocks of Pellinge follows the Stadsland gabbro. Along the Barösundsfjärd there occur, as constituents of eruptive breccias, metabasitic rocks which may be of equivalent age, and a little more to the east there is around Alglo, S.E. of Ekenäs, an area of gabbro, which is very similar to that of Stadslandet, and may possibly be correlated with it as to age. It is older than the gneissose granites of the region in question, but probably somewhat younger than the leptites.

Gneissose granites which seem to correspond to the Våtskär granite of the Pellinge region, here also penetrate the Svionian schists, and are often interwoven with them in an intricate manner, forming both eruptive breccias and arteritic migmatites. Some of these granites are porphyritic. These granites which are commonly rich in plagioclase, pass by gradations on the one hand into granodioritic rocks, on the other into granites richer in microcline, and connected with aplites and pegmatites.

The volcanic metabasalts of the Pellinge region are here represented only by numerous dykes which everywhere cut these older granites. They are penetrated by younger granites of Hangö type (also called Hangö-Ingå granite) which are rich in microcline and associated with pegmatite and aplite which often occur in great masses. These younger granites are never quite homophanous, but mostly migmatitic in character, and intimately interweave all the older rocks, forming migmatites.

The migmatites in the northern part of the area mapped contain mainly Hangö granite as their granitic constituent, but also more or less completely assimilated gneissose granites may occasionally occur. In the southwestern corner of the area mapped the gneissose granite predominates as constituent of the migmatites. However also veins of Hangö granite occur at many places. In the east, in the Porkkala region, polymigmatites, in which two granites interweave leptitic schists, are common.

No rock corresponding to the Rysskär granite of the Pellinge area is known from this region. At a certain epoch some of the older gran-

Table I.

	Barösundsfjärd region	Pellinge region
Lower Jotnian	—	Rapakivi granite K
	»Trap» dyke J	—
Post-Kalevian? (or post-Jatulian?)	Obbnäs granite I	Onas granite J
Post-Bothnian (post-Pellinge)	Hangö—Ingå granites II	Hangö-Ingå granites II
	—	Pellinge formation of metabasalts and tuffs G
	—	Rysskär granite F
Bothnian?	Metabasaltic dykes E	Pernå formation of metabasalts and tuffs E
Post-Svionian	Older granites D	Våtskär granite D
	(Gabbro of Alglo C)	Stadsland gabbro C
	—	Rabbas quartzite B
Svionian	Leptites and limestones A	Sundarö formation of conglomerates, meta-andesites and tuffs, leptites and limestones A

ites were regarded by the writer as possibly belonging to this group, but no convincing evidence was ever found proving the existence of more than one granite older than the Hangö granite in this region, nor such in favour of a subdivision of the metabasalts into groups of different age. Most probably all the dykes of the present region correspond to the Pernå formation of metabasalts in the Pellinge area, while the Pellinge formation is here lacking.

The youngest of the rocks in this region which occur in greater masses is the coarse porphyritic granite which is known as the Obbnäs granite, as it forms the greatest part of the Obbnäs foreland. It is certainly of the same age as the Bodom granite which forms a similar area with rounded outlines 20 km more to the N.E. Both everywhere penetrate the Hangö granites and the migmatites associated with them.

For reasons which will be mentioned later, the writer thinks that these granites are to be correlated in age with the Onas granite of the Pellinge region.

Lastly there has been found, in the island of Vormö, a narrow dyke of fine-grained »trap». This rock, which has not undergone any stronger metamorphism, certainly belongs to the »trap» rocks which are common all over the southern coastal regions, and are later in age than the three older groups of granites, but older than the rapakivi granites.

The following table gives an outline of these different formations, and their probable correlation with the rocks of the Pellinge region.

LEPTITIC SCHISTS.

The leptitic schists which are the oldest rocks of the region, have almost everywhere been more or less intimately penetrated by granites of different age, and are therefore not only metamorphic, but often even ultrametamorphic in character. There are no zones which are so continuous and well preserved as the oldest schists of the Pellinge region,[1] or those of the Tammela region,[2] both described by the writer, or of the Kisko region, described in great detail, also petrologically, by Eskola,[3] or the Swedish coastal region near Stockholm, described by Holmquist.[4] We may therefore refer to these earlier descriptions of better preserved varieties of these leptites.

However, we find, also in the present regions, portions which still show the primary features better preserved and which seem to have been originally sediments. Their very distinct banding, which is caused by an alternation of lighter layers rich in felspar and quartz and darker ones in which biotite and hornblende predominate, is at least in part to be interpreted as bedding.

Bålaskär, S.W. of Bågaskär, is a good locality for studying these rocks. The alternation of darker and lighter bands visible here (figs. 1 and 2) is probably in most cases due to bedding, but an influence from the side of a penetrating gneissose granite is obvious in the rock shown in fig. 2, while the brecciation of the leptite shown in fig. 1 no doubt also took place at the time of the eruption of the same granite. It is therefore rather difficult here to discriminate between primary and secondary features.

[1] l. c.

[2] Beskrifning till kartbladet Tammela. Finl. Geol. Und. N:o 18.

[3] P. Eskola, On the Petrology of the Orijärvi Region. Bull. Comm. géol. Finl. N:o 40, 1914.

[4] P. J. Holmquist, The Archæan Geology of the Coast Regions of Stockholm. Geol. För. Stockholm Förh. Bd. 32, 1910, p. 806, and Guides des Excursions en Suède, XI Congr. géol. internat. Stockholm 1910.

Fig. 1. Bedded leptite at the N.W. shore of Bålaskär in Ingå. The diameter of the coin is 2.3 cm.

In the leptitic rocks of the present region primary minerals certainly recognisable as such have in general not been preserved. The rocks are entirely crystalline, and consist of plagioclase, microcline, quartz, hornblende, biotite, in some cases also muscovite. In most cases the original rocks seem to have been rich in plagioclase, while the microcline has generally been formed during the granitization of the schists in question. In some cases, however, microcline seems also to have been originally present. The plagioclase is in most varieties an oligoclase. The hornblende is of a character common among the crystalline schists of the Archæan, pleochroic in brownish-green to dark green colours. Some ore, apatite and titanite are also usually present. These rocks often exhibit the mosaic or cyclopic texture (Fig. 1, Plate I) which is common in strongly metamorphic crystalline schists. In other cases, again, part of the constituents form blastocrystals which grow through the other minerals like weeds in an overgrown field.

These leptites probably mainly consist of tufaceous material, often of andesitic composition. This material has, at least in many cases, been transported by water and possibly also undergone weathering. Effusive volcanic rocks which have been changed by shearing movements, may, however, possibly also be present.

In the Vormö region and W. of it, the leptites are lighter in colour than elsewhere, being rich in quartz and plagioclase.

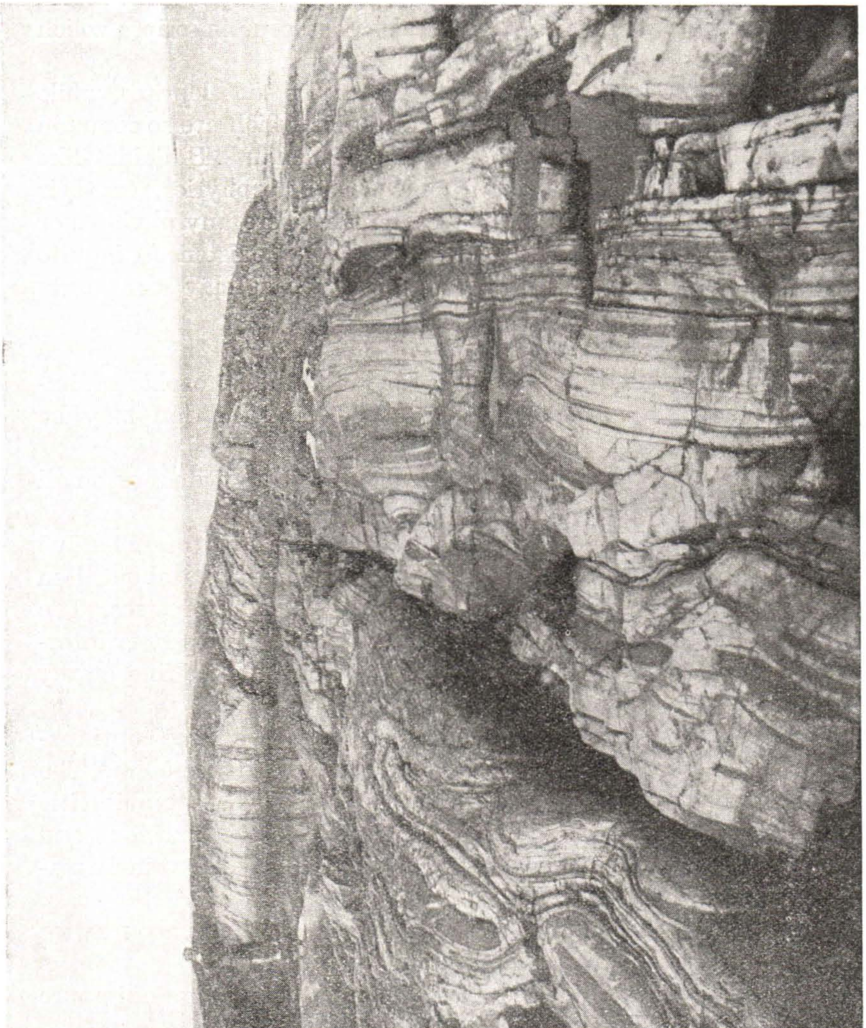

Fig. 2. Leptite containing granitic stripes. N.W. shore of Bålaskär in Ingå.

Where the leptites have been penetrated by granitic veins which are often very intimately intermingled, the darker varieties also contain microcline and quartz. These minerals also occur in stripes which may be due to injection or a metasomatic action.

All leptites of the present region seem to be soda-leptites, while the corresponding rocks rich in potash-felspar, which are so common in Sweden, have not yet been discovered in Finland. Hälleflint-like rocks such as strongly metamorphic quartz-porphyries, or their tuffs, have not been observed here. Nor are there any phyllites or mica-schists which would indicate the former existence of quite normal sediments formed by weathering, such as clay or quartz sand.

Crystalline limestones, however, occur at many places intercalated with leptites and are certainly metamorphic sedimentary rocks, although their exact mode of formation may be somewhat uncertain.

They form very thin layers intercalated with leptites, or on all sides surrounded by granite.

Thus we find, on the northern shore of the island of Lill Lövö in Ingå, a layer of crystalline limestone which measures about 1 m in breadth and can be followed to a length of a hundred metres. The limestone is middle- to coarse-grained and rather pure. It is intercalated with basic leptites, but on both sides of them we find a grey gneissose granite.

On the northwestern shore of the island mentioned, the continuation of the same limestone can be followed to a length of 50 m. The layer has a breadth of 1—2 m and is intercalated with an amphibolitic schist, a leptitic rock containing scapolite next to the limestone and a quartzitic rock which either may belong to the granitic vein formation, or be of sedimentary origin.

On the N. W. shore of Lövö the leptite is also intercalated with thin layers of limestone containing grains of pyroxene.

On two places on the island of Orslandet thin layers of impure limestone have been found.

On the N. E.-shore of Lövgrund in Ingå the migmatite contains fragments of leptite intercalated with thin layers of limestone and of »skarn» rich in idocrase and garnet.

In the easternmost parts of the islands of Bågaskär, the leptitic fragments in the migmatite are intercalated with thin layers of limestone.

On the northern shore of Påvskär in Ingå, the gneissose granite contains a fragment of crystalline limestone which is several metres in length. The rock is rather pure, and does not contain any contact minerals in greater quantity, although it is on all sides surrounded by granite.

At Rörörn in Ingå the leptitic portions of the migmatite contain some thin layers of limestone.

In Lingonsö (W. of the area mapped) the leptite contains several thin intercalations of limestone and of skarn rich in calciferous minerals.

Att Rönnskär, S. of Porkkala Udd, a thin layer of limestone also occurs.

All these layers of limestone are too inconsiderable to be shown on the map. In the neighbouring regions the layers of limestone occasionally attain greater size.

At Vinikby in Helsinge, N. of Helsingfors, a crystalline limestone has been quarried which has formed a zone measuring several decametres. Also in Kyrkslätt and Sjundeå at several places outcrops of similar limestone occur, but are in most cases very impure. They have not been studied in greater detail in connection with this investigation.

Lastly, similar crystalline limestone occurs in greater masses in the Lohja (Lojo) region, northwest of the area sbown on the coloured map. They are often very pure. This region, where the Svionian rocks, although also here mixed with granitic veins, are much better preserved, so that even certain stratigraphical features may be recognized, introduces special geological problems which will not be treated here.[1]

OLDER GNEISSOSE GRANITES AND ASSOCIATED ROCKS.

DESCRIPTION OF THE NON-MIGMATITIC VARIETIES

The oldest granites have generally a grey colour. In a few instances the surface colour may be reddish, but even then the freshly chipped specimens have a more greyish tint. These granites are mineralogically characterized by the rather high amount of ferromagnesian constituents, usually also by the preponderance of plagioclase (oligoclase) over potash felspar. Biotite usually prevails over hornblende, when that mineral is present. A gneissose texture, marked by parallel rows of black mica, is common, especially in those varieties

[1] Cf. P. Eskola, V. Hackman, A. Laitakari and W. W. Wilkman, Suomen kalkkikivi. Engl. Summ. Suomen Geol. Toim. Geotekn. Tiedonantoja N:o 21, 1919.

which pass over into migmatitic rocks. The minerals of the rocks studied microscopically generally show the influence of strong mechanical crushing. We find also the intimate interweaving of the minerals which is common to »gneissose» rocks, not the regular textures characteristic of such granites as have crystallized nearer to the surface in one casting, and have never suffered any subsequent changes.

Both equigranular and porphyritic rocks occur. Among the latter a very typical variety is that outcropping in the island of Strömsö, W. of Barösund, and on some adjacent islands. Varieties with a similar texture occur within a zone stretching from this region to the S.E., e. g. on the island of Manngrund, N. of Bågaskär. The porphyritic crystals which measure 1—2 cm in length and are surrounded by a mass of middle grain, mainly consist of microcline, while some of them are oligoclases. In general, the porphyritic rocks seem to be richer in potash felspar than the equigranular varieties. In a rock from Strömsö the felspar constituents were found, measured by the Rosiwal method, to form about 50 per cent (by weight) of the whole rock, while the plagioclase had a slight preponderance over microcline (26 against 23 %). Quartz was found to form about 40 per cent of the whole, while biotite constituted a little above 10 per cent. In the determination of the amount of the constituents in a rock such as this, much depends on the direction in which the thin section cuts the rock, and it seems therefore possible that the amount of quartz has been overrated.

By microscopic study of this rock we ascertain the fact that both the microcline and the oligoclase of the bigger crystals show the influence of mechanical pressure. The twinning lamellation of the latter indicates a strong fracturing and faulting. At other places, again, the oligoclase crystals are better preserved and surrounded by xenomorphic quartz. The quartz is generally strongly crushed, often drawn out into narrow stringers. (Fig. 2, Plate I). The biotite forms small flakes which mainly lie along certain lines that indicate fractures intersecting the other minerals, especially the bigger quartz grains. The biotite of these shearing zones is associated with small crystals of oligoclase, and, at places where they intersect crystals of microcline, with myrmekite. The biotite flakes are not to be regarded as fragments of bigger crystals that have been shattered, but obviously crystallized, or re-crystallized, at the time of the formation of the shearing zones. The biotite occasionally occurs in fissures formed along the cleavage planes of the felspars, especially the plagioclases. In some cases it is xenomorphic towards the quartz. Also the existence of myrmekite which has encroached, in these shearing zones, upon the potash felspar, is a fact proving that they were formed at a time when granitic material existed in solution, either under primary (resp. deuteric) or secondary conditions.

In many cases, the bigger felspar crystals have been left almost intact by the shearing action. The rows of mica wind between the felspars, sometimes enveloping them, so that a rather typical »meshing» originates.

However, the formation of the parallel texture has taken place at a time when the greatest part of the minerals had already solidified. The crushing of the quartz in these granites, as well as in some of the younger granites of the same area, still to be described, has entirely the same character as the crushing of the porphyritic quartz crystals in certain quartz-porphyries, e. g. that of Karvia described by the writer [1], or of the quartz grains of quartzitic sediments which have undergone mechanical metamorphism. The changes cannot be explained as merely due to strains originated by an unequal crystallization. The quartz was crushed when it was already solid and brittle, and has only in part been healed by subsequent crystallization processes.

Mylonitic zones intersecting the granite of Strömsö may be seen even with the naked eye. In these zones the mechanical changes of the minerals are still more obvious than in the cases already described.

In a porphyritic granite from Flakholm, near Strömsö, we are able to make interesting observations on the formation of the m y r m e k i t e which occurs in the trituration zones, and elsewhere in the rock. Those oligoclase crystals which are entirely surrounded by microcline do not often show any fringes of myrmekite, while those lying nearer to the margin of the microcline crystals, show broad myrmekitic border zones. In fig. 4, Plate I, we observe a microcline crystal which includes two smaller crystals of oligoclase. One of them is isolated, and shows no myrmekitic border zones. The other one was obviously entirely surrounded by microcline originally, but later cracks have been formed in that crystal, reaching the oligoclase crystal, partly separating it from the neighbouring microcline, and radiating to all sides from the oligoclase. These cracks have been mainly filled up with quartz, and along these minute quartz veins grains of myrmekite have been formed, partly as a direct continuation of the bigger crystal of oligoclase. At those places, however, where this mineral is still in

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[1] J. J. Sederholm, Ueber einen metamorphosierten präcambrischen Quarzporphyr etc. Bull. Comm. géol. Finl. N:o 2, 1918.

immediate contact with the microcline (to the left in the figure), no myrmekite is visible. These facts, as well as others already stated, seem to suggest that the solutions which contained the material necessary for the formation of the myrmekite, which was formed at a time when all microcline, as well as probably also the biotite, had already crystallized, acted principally at such places where minute cracks had originated. These cracks gave access to solutions carrying soda and probably also containing a surplus of silica.

These facts give additional evidence in favour of the conclusion arrived at by the writer previously, according to which the myrmekite has not, as little as other »synantetic» minerals, been formed merely by an interchange of material between the minerals lying in contact with each other. But if even such changes at the boundaries of two adjacent minerals cannot be explained without assuming the intervention of solutions, then it is still more probable that the reactions by other metamorphic changes follow the old rule: corpora non reagunt nisi fluida.

In some varieties of these porphyritic granites, e. g. in that of Manngrund, the chemical changes have been preponderant over the mechanical, which therefore have been in part again obliterated. In this case, however, it is possible to assume that an influence of a later granitization has taken place, because Hangö granite is abundant in the same island.

The equigranular granites which are more common than the porphyritic varieties already described, are in general much poorer in potash felspar than the former. In some of them, crystals of the latter mentioned mineral are even almost lacking, as is indicated already by the absence of myrmekite which is often, in abyssal granitic rocks, such a good indicator of the co-existence of both felspars.

These equigranular granites have often somewhat dark surface colours in freshly chipped specimens, and as they also contain biotite and hornblende in rather large quantities, one would be inclined to regard them as dioritic rocks. Microscopically, however, we find that they are generally very rich in quartz, and most of them may therefore better be described as oligoclase granites, or as granodiorites. There are, anyhow, among these rocks both here and especially in adjacent regions such as pass over into diorites and even into more basic rocks. As smaller masses we also find, e. g. on Granö and Manngrund, in the region of Bågäskär, very dark gabbroid rocks which either are genetically connected with the gneissose granite or immediately preceding it in age. They consist mainly of hornblende, which has greenish colours in microscopical sections, together with varying amounts of plagioclase, biotite and ore.

The prevailing rock in the island of Påvskär, which is situated in the Barösundsfjärd E. of Bågaskär, may be regarded as a rather typical example of these equigranular gneissose granites. It is a middle-grained rock of a greenish-grey surface colour, and consists of oligoclase, quartz, microcline, biotite and some pyroxene, together with small amounts of apatite, epidote etc. Ore and titanite seem to be very sparse in this granite.

By a volumetric determination in a typical variety there was found about 21 per cent (weight) of quartz and 71 of felspar. The chemical analysis (Table II) gave a larger amount of quartz, and less of felspar, in the norm. Oligoclase (An 26) seems to be preponderant. Only a small percentage consists of distinctly recognizable potash felspar, but the analysis shows that it occurs in a greater amount, although it is intimately intermingled with the plagioclase.

One part of the microcline seems to be an early constituent of the rock, and shows signs of having been changed during a later metamorphism. Towards it, the neighbouring plagioclase has a fringe of myrmekite. Most of the microcline, however, occurs in regular antiperthitic intergrowth with the oligoclase, and at least part of it seems to be of secondary origin. In some cases those portions of the oligoclase which have been strongly bent or broken, contain more numerous microcline lamellæ than the other parts (Fig. 5, Plate I). This microcline often shows no twinning lamellation. In some cases, however, the lattice lamellation is distinctly visible.

The bigger oligoclase crystals, which measure 1.5—3 mm in length, are often very much broken, whereby the twinning lamellæ show conspicuous faults (Fig. 6, Plate I). In other cases, again, the oligoclase crystals show well preserved idiomorphic forms, and are surrounded by xenomorphic quartz.

Most of this mineral is strongly crushed, especially in certain narrow zones. These do not only intersect the quartz grains, but in part also the bigger felspars, while they leave, in other cases, the latter entirely intact, winding around them. These zones, which indicate fractures, are filled with small flakes of biotite, together with grains of oligoclase, measuring 0.05—0.5 mm. Where they are in contact with primary microcline, the latter is as usual in part replaced by myrmekite.

The biotite forms 6 to 7 per cent of the rock. There is still 1 to 2 per cent of pyroxene which has a diallagic character.

There are also varieties of the same rock, in the western part of Påvskär, which have a much lighter surface colour and are poorer in femic minerals. By microscopic determination, these minerals have been found in some cases to form only 3—4 per cent (weight). These lighter, more acid rocks are also very rich in oligoclase, and their general character is not very different from that of the main rock. They include fragments of the darker varieties, forming with them a kind of eruptive breccia.

In the S. W. part of Påvskär a narrow vein of a lamprophyric[1] rock (Fig. 4, Plate II) intersects this light variety of the Påvskär granite, an indication of differentiation processes going on at the time when it crystallized.

Its composition, as far as it can be judged from microscopical observations, is not far from that of a metabasalt. The higher amount of potash, which is usually characteristic of the lamprophyric rocks, can often be detected only by chemical analysis. If this narrow vein belonged to the metabasaltic dyke formation, one might expect to find the same black, almost aphanitic rock that forms the narrowest veins and which, no doubt, was originally glassy, while the present rock is middle-grained and very similar to other vein rocks which will be described below and which are certainly lamprophyric, being genetically connected with aplites.

The present vein rock is, according to a determination by the Rosiwal method, composed of about 56.6 per cent of plagioclase, 16.6 per cent of diopside, 12.5 per cent of hornblende, 8.4 per cent of magnetite and 5.9 per cent of biotite, together with some apatite, occurring as slender needles (Fig. 4, Plate II). Most of the constituents form rounded grains. Only the biotite occurs as bigger flakes which are to be regarded as blastocrystals. It is dark brown and strongly pleochroic. The green hornblende and the diopside are closely associated, often occurring in parallel orientation. The plagioclase is an andesine (An 42).

The granite surrounding this vein is uncommonly light, and poor in femic minerals.

Typical pegmatites and aplites (Fig. 2, Plate II) occur connected with the older granites. Their age is also in this case determined by

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[1] It is only with a reservation that the author uses the term lamprophyre, to which strong objections have been raised by Zirkel, Brögger and others. The »lamprophyres» of Finland are neither bright (λαμπρός) nor porphyritic rocks. Another name for those rocks would be preferable, but the use of this older term is so firmly established that it seems to be difficult to replace it by a new. If that would be possible, the author would favour the term epibasite.

the intersecting metabasaltic dykes. The minerals of these older pegmatites are very strongly crushed (Fig. 1, Plate II). These dyke rocks connected with the plagioclase granites are also in general rather rich in plagioclase, while the younger pegmatites show the large amount of microcline which is characteristic of the Hangö granites.

While there are now, on the one hand, more acid differentiation products of these granites, there are also, on the other hand, more basic varieties. One of them, from Påvskär, microscopically resembles a diorite (Fig. 3, Plate II), but is still rather acid. It contains some green hornblende, but here, too, the biotite is preponderant.

In Påvskär some varieties of these granites do not macroscopically show any distinct parallel texture, but microscopically they have generally a gneissose character. In one of the more acid varieties, however, the quartz, which is abundant and has corroded the other minerals, shows but a very feeble influence of mechanical changes.

Where a more distinct foliation exists, fragments of older, leptitic rocks always occur. They are abundant in some places, and as usual more or less strongly changed by assimilation processes. Inclusions of crystalline limestone also occur which sometimes are astonishingly poor in contact minerals.

Similar to the examples described are the older granites at many other places in the same region. The variation which they display depends in part on differences in the chemical composition, in part, and mainly, on the varying extent to which they are mixed with older rocks, mainly leptites.

The chemical character of these older granites has already been elucidated by chemical analyses published by the author and by Eskola.

From the present region, a very typical granite of this group from the western shore of Påvskär (cf. the description p. 13) has been analyzed by Mr. Allan Zilliacus (Table II).

It is a susquehannose according to the C.I.P.W. classification.

The parametric figures according to Niggli are as follows:

si = 336, al = 40.5, fm = 17, c = 20, alk = 22.5, k = .26, mg = .40 ti = 1.14, qz = + 146.

The composition approximates to the plagioclase-granitic type of Niggli.

Another rock belonging to the same series, from Ändö in Ingå has also been analyzed (Table III). This rock (Fig. 3, Plate I) is much richer in potash felspar than the rock of Påvskär.

It is an Amiatose, near a Riesenose.

The place in Niggli's system is determined by the following values.

Table II.

Gneissose granite from the western shore of Påvskär in Ingå.
Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm:	
SiO_2	70.75	1 179	Q	33.60
TiO_2	0.32	4	Or	11.68
Al_2O_2	14.54	142	Ab	30.92
Fe_2O_3	0.48	3	An	12.79
FeO	2.15	30	C	1.63
MnO	—	—	Sal	90.62
MgO	0.98	24		
CaO	3.86	69	Hy	5.44
Na_2O	3.64	59	Mt	0.70
K_2O	2.03	21	Il	0.61
P_2O_3	0.88	7	Ap	2.35
H_2O	0.53		Fem	9.10
	100.16		S:a	99.72

1, 2, 3, 4, Susquehannose.

Table III.

Gneissose granite from Ändö in Ingå.
Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm:	
SiO_2	71.73	1 195	Q	34.38
TiO_2	0.15	2	Or	25.02
Al_2O_3	13.74	134	Ab	17.29
Fe_2O_3	0.64	4	An	15.29
FeO	2.95	41	C	0.10
MnO	0.03	—	Sal	92.08
MgO	0.75	12		
CaO	3.03	55		
Na_2O	2.05	33	Hy	5.42
K_2O	4.25	45	Mt	0.93
P_2O_5	0.11	1	Il	0.30
S	0.03	1	Ap	0.34
H_2O	0.53		Fem	6.99
	99.99		S:a	99.07

I, 4, 3, 3, Amiatose (near Riesenose).

si = 365, al = 41, fm = 18, c = 17, alk = 24, k = .58, mg = .10 ti = .61, p = .30, qz = + 169.

The main difference from the Påvskär rock lies in the greater amount of microcline and the somewhat lesser of femic minerals.

Table IV gives the average of 7 analyses of the oldest granites of southwestern Finland, 4 of them made by Eskola, and 3 communicated by the present writer. As we are aware, the average is very near to the plagioclase-granite type of Niggli. The analyses also agree with the fact that the plagioclase in these granites is commonly an oligoclase. Only in very rare cases potash prevails over soda, indicating a larger amount of microcline. The amounts of iron, especially FeO, and lime are uncommonly high for granites, while the average percentage of MgO is a trifle above one per cent.

Tab. IV.

Average of seven analyses of older gneissose granites from southwestern Finland.

SiO_2	71.31
TiO_2	0.34
Al_2O_3	13.78
Fe_2O_3	0.67
FeO	2.58
MnO	0.06
MgO	1.11
CaO	3.10
Na_2O	3.91
K_2O	2.10
P_2O_5	0.20
H_2O	0.75
S:a	99.92

MIGMATITES OF LEPTITES AND OLDER GRANITES.

These granites, which are older than the metabasaltic dykes, form very typical migmatites with the leptites. These mixed rocks are in part eruptive breccias (agmatites) in part veined gneisses (arterites). Both groups are connected by gradual transitions, and in many cases it is difficult to say whether the rock shall be designated as an eruptive breccia or an arterite.

Very typical agmatites may be studied in the Bågaskär islands in Ingå. Especially in the S.W. part of the E. island of Bågaskär, and the adjacent part of the western island, the eruptive breccias are as well developed as at any place in the world. The granite is full of inclusions of leptite of varying forms and sizes and in different degrees of assimilation. Some of them are angular, others rounded by absorption, they partly show rectilinear boundaries, and partly they are bent and folded, or in the process of splitting up into a greater number of smaller fragments. Fig. 3 and the figures immediately

Fig. 3. Eruptive breccia (agmatite) of leptite, metabasite, and gneissose granite. S.W. shore of E. Bågaskär in Ingå.

following give a better idea of these rocks than any written description.

Most of the fragments are leptitic, but they show a great variation because of the varying degree of their penetration by the granite. Moreover, basic rocks also occur, which are metagabbros or metadiabases.

Some of the fragments seen in fig. 3 are long and narrow, those visible in the left upper corner of the photograph to such a degree even as to resemble veins. In fact some lamprophyric stripes in such rocks may be rather difficult to distinguish from drawn out fragments.

In some portions of the rock shown in fig. 3 we observe leptitic fragments which have been intimately permeated by the granite and in great part dissolved in it, so that these portions may be designated as a nebulitic gneissose granite. But as to the origin, there is no essential difference between these parts of the migmatite and those which may be designated as typical breccias.

The above-mentioned phenomenon is still more evident in another place in the same islands, lying between the sound which separates them, and the pilot's pier on western Bågaskär (at the innermost part of the harbour of both islands). This rock surface is shown in fig. 4.

As we are aware, one part of the rock surface shown in the photograph is a very typical »eruptive breccia», or agmatite, containing

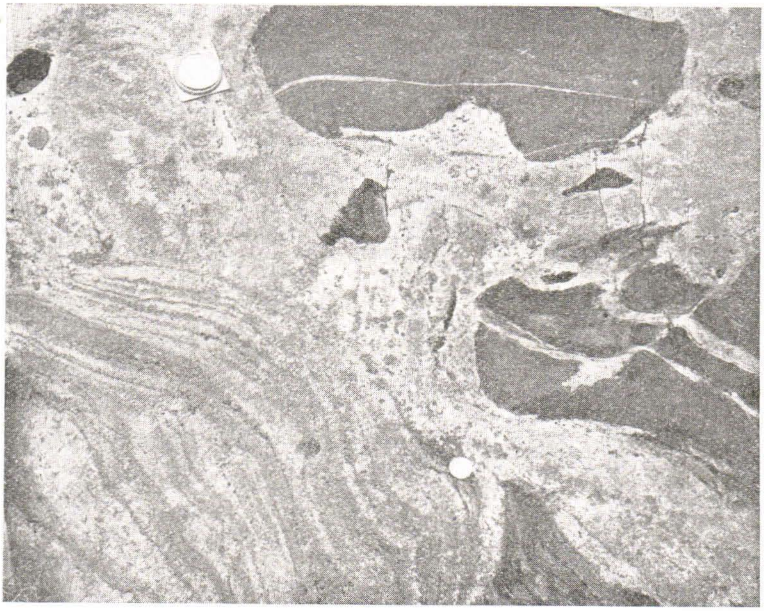

Fig. 4. Eruptive breccia (agmatite) grading into a »gneissose granite» (nebulitic arterite) whose parallel texture intersects that of other parts of the rock. W. Bågaskär in Ingå. C:a 1: 7 natural size.

angular fissured fragments of a massive metabasitic rock, surrounded by a non-gneissose homophanous granite. In the lower part of fig. 4, again, the rock is a striped granite, where the stripes indicated by rows of mica are nothing more than remnants of almost completely absorbed fragments of highly granitized leptites. By closely examining this rock surface, we notice that the foliation of this gneissose rock intersects the parallel texture of another portion of likewise gneissose granite (that where the compass is lying) belonging to the same rock masses. The striping is not quite so distinct here, but anyhow visible. Thus we find that striped portions originated at different epochs during the formation of these migmatitic masses,

Fig. 5. Eruptive breccia (agmatite) with lamprophyric veins. Horizontal surface at W. Bågaskär in Ingå. 1: 40. North is to the right in the figure.

and that the gneissose granite has been in a flowing motion in which the rows of mica have participated.

On a surface immediately to the west of that shown in fig. 4, a very peculiar phenomenon is seen which is shown by the drawing in fig. 5, while the photographs in figs. 6—7 reproduce parts of it.

As we see from these figures, the eruptive breccia is also here very typical, and contains fragments which are mostly angular, while some of them are bent or folded. In the middle of the rock surface shown in fig. 5, we notice a big fragment which has been divided into several parts lying near to each other, separated only by narrow veins of granite. These veins all anastomose with the granite which surrounds the fragments, and it becomes evident that the granite has gradually filled up the interstices between the fragments, in the same measure as they have been separated by fissures from the adjacent portions and drifted away from them. At the western end of the middle granitic vein, there is a darker stripe at the junction between a vein and the neighbouring main portion of the granite, vaguely indicating a kind of boundary (cf. also fig. 5), but at the opposite eastern end of that vein, shown in the left upper corner of fig. 7, there is not the slightest trace of a boundary.

The fragments consisting of bedded leptite are intersected by narrow veins of a very dark rock rich in hornblende and biotite and possessing a lamprophyric character. There is one broader and several narrow veins partly parallel with the former, partly branching out from it. These lamprophyric veins intersect both the fragments of leptite and some of the granitic veins separating them (fig. 7). One of the latter-mentioned veins, however, intersects equally distinctly the lamprophyric vein, while finally we observe, in a third granitic vein subdividing the fragments, a fragmentlike portion of a lamprophyric vein (visible in the upper part of fig. 6 and the lower part of fig. 7) which obviously originally intersected the granitic vein, but later took part in an eastward movement of the granite in this vein. This movement caused a faulting of the lamprophyric vein, so that it now forms a fragment included in the granitic vein.

Lastly we find also at some places an aplitic vein material which partly fills the same narrow vein as the lamprophyre, partly intersects the basic veins (see especially fig. 7).

The lamprophyric veins are thus partly younger, partly older than the broader granitic veins, and at one place they are younger than the formation of a granitic vein, but older than the last movements of its magma. Finally they seem also to be of almost the same age as some aplitic portions of the same granitic masses.

These apparently contradictory phenomena seemed to the writer very difficult to explain for a long time, but after making observations on similar things in other granitic areas in the coastal regions of southern Finland, he thinks that he has been able to find a satisfactory explanation.

The subdivision of the leptitic fragments of the eruptive breccia obviously did not occur in one brief period, but during a protracted lapse of time, in which the granite surrounding them retained its

Fig. 6. Photograph of the middle part of the rock surface shown in fig. 4. The dark lamprophyric veins are seen cutting several granitic veins, but have themselves been faulted by movements in the granitic vein seen in the upper part of the photograph. About 1: 11 natural size.

capability of moving like a fluid, or a plastic solid, gradually filling every fissure which was formed. But the state of aggregation of the granite has been such as also to allow fissures to originate in it, and these have been filled with femic exudates from the granitic masses. In this way lamprophyric veins have been formed. By later movements of the granite these narrow fissure veins were at places faulted and in part even obliterated. Also acid exudates were formed almost simultaneously, or a little later than the lamprophyric veins, giving origin to the last, aplitic veins.

All these processes took place during the time of the consolidation of the older granites. Then, the eruptive breccia is, in the same islands, intersected by the most typical volcanic fissure dykes (fig. 12). These

Fig. 7. Continuation of the left photograph, showing the faulting of the broadest lamprophyric vein and the connection of lamprophyric and aplitic veins. About 1: 11 natural size.

dykes can be followed for more than fifty metres and will be described in detail later on. They show slight deflections which were caused by the influence of the Hangö granite which is younger than these dykes and occurs also on the same island. In most cases, however, the dykes are here devoid of any granitic veins, and still entirely retain the character of true fissure dykes which were originally rectilinear, and they sharply intersect both the fragments and the cement of the eruptive breccia.

The rock of the lamprophyric vein has in general a more basic character than that of the narrow lamprophyric vein of Påvskär, and the metabasaltic dykes of the present region. It consists of green hornblende which prevails, forming more than half of the weight of the rock, while the rest is plagioclase (about An 40), biotite, ore and apatite (cf. fig. 5, Plate II).

This rock has been analyzed with the following result.

Table V.
Lamprophyre from W. Bågaskär in Ingå.
Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm:		
SiO_2	49.26	821	Or		17.79
TiO_2	0.63	8	Ab		9.43
Al_2O_3	11.87	117	An		18.63
Fe_2O_3	0.88	5		Sal	45.85
FeO	8.12	113			
MnO	1.56	22	Di		28.95
MgO	11.16	279	Ol		21.60
CaO	11.14	199	Mt		1.16
Na_2O	1.11	18	Il		1.22
K_2O	2.99	32	Ap		0.34
P_2O_5	0.24	1		Fem	53.27
S	0.09	1		Sa:	99.12
H_2O	1.89	—			
	100.94				

III, 5, 3, 2, Absarakose

The molecular parameters according to Niggli are:
si = 105, al = 15, fm = 54, c = 25, alk = 6, k = .64, mg = .63
p = .13 ti = 1.0; qz = — 19 c/fm = 0.47

It is a gabbro-noritic magma type.

While in any case in those portions of the migmatites of the Bågaskär which we have now described, the character of an eruptive breccia prevails, we observe, close to the rock surfaces described, near to the Pilot's pier at western Bågaskär, other varieties which pass by gradations into migmatites that possess, taken as a whole, a more arteritic character. The only difference, however, is that in them the fragments of leptite have been split up along the bedding, and injected by numerous granitic veins. The alternation of femic and salic layers has obviously favoured this process, the latter portions having in large measure been changed in such a degree as to acquire the character of a granite. But here also some of these arteritic portions which obviously were formed during the same continuous process, were again broken into pieces after their consolidation, and intersected by veins of a granite which is gneissose, showing a distinct parallel texture that runs along the walls of the veins (fig. 8).

Fig. 8. Arteritic portions forming fragments in the eruptive breccia of W. Bågaskär. The parallel texture of the intersecting veins follows their directions. About 1: 8 natural size.

On the island of Lövgrund, one kilometre W. of Bågaskär, we find other varieties of the same migmatites in which the older components and the granitic constituents are still more intimately connected. The lighter portions of these banded rocks do here probably in large measure consist of salic beds of leptites, which alternate with thinner basic beds, but these bedded rocks have been fractured and faulted (fig. 9) and intimately mixed up with granite, or granitic juices, transforming them metasomatically into a granite-like rock. Some portions, again, show better separated aplitic veins injected »lit par lit», whereby the mixture has become plastic and shows a strong ptygmatic folding (fig. 10).

Although at these places the granite of the migmatite is richer in microcline than is usual with the older granites, there is no doubt

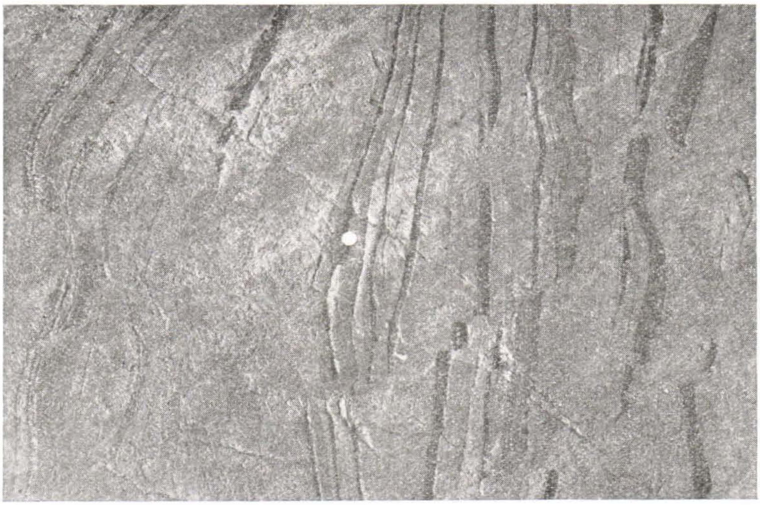

Fig. 9. Migmatite formed out of bedded leptite whose basic parts have been faulted at the final stage of the granitization. Lövgrund near Bågaskär, Ingå. C:a 1: 12 nat. size.

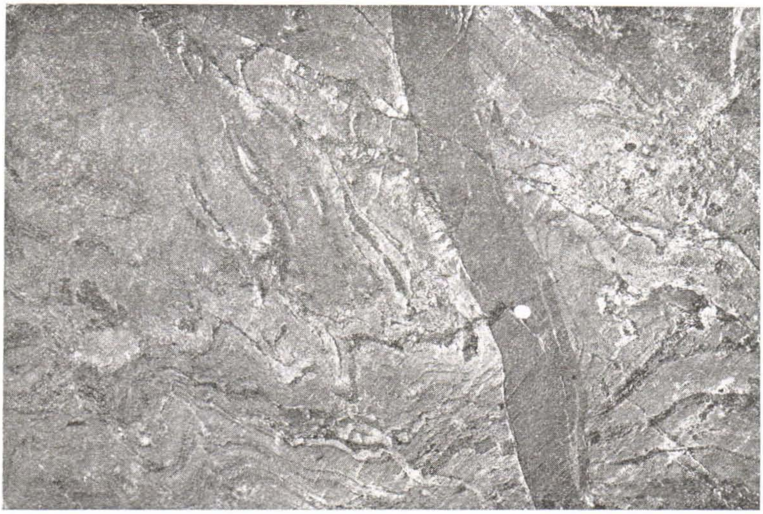

Fig. 10. Migmatite of leptite and older granite, showing ptygmatic folding and cut by a dyke of metabasite. Lövgrund near Bågaskär, Ingå. C:a 1: 10 nat. size.

that most of the veins belong to them and not to the Hangö granite. Then, the metabasaltic dykes which everywhere in this region furnish such a distinct demarcation line between the older granites and the Hangö—Ingå granites, occur also here (figs. 12—13). We will account in detail for these phenomena later on, in the chapter describing the basic dykes, and their changes by the action of the younger granite.

The migmatites of the Bågaskär region offer the most convincing evidence in favour of the assumption that eruptive breccias, what the author calls agmatites, and veined gneisses, or arterites, are formed by the same processes, and ought to be united in one group of rocks and under a common designation. It is not practical to include the former in the same group as volcanic breccias, originated e. g. by the splitting up of a sandstone, and the cementation of its fragments by a volcanic basalt, while we include the arterite in the all-comprising group of gneisses (to which lately even limestones injected by granitic veins have been added, and which is in fact the widest of all »sack designations»). All these deep-seated rocks characterized by a mixture of granite and crystalline rocks of different character ought to be classed together and under one designation, migmatites, and not separated into divisions of very different genetical signification.

CHANGE OF LEPTITES BY PALINGENESIS INTO GNEISSOSE GRANITES.

In the migmatites of Bågaskär and Lövgrund we were able to study the change of the lighter portions of the bedded leptites, by metasomatic changes caused by the eruption of the oldest granite, into rocks of a more and more granitic character. It is obvious that this change of certain parts of the bedded rocks into rocks of granitic character, a process which may be described as palingenesis, will make the relations of sedimentary and eruptive rocks still more confused than they otherwise are in these migmatites. A renowned foreign petrologist, when visiting this coastal region together with the writer, used jestingly to call them »mishmashitic», instead of migmatitic rocks. This »mish mash» is most perplexing at such places where the whole mass of the leptite is on the verge of being more completely re-fused, or, in other words, is undergoing palingenesis, and at the same time has been mixed up with eruptive granitic magma.

Thus we find, e. g., in the island of Bålaskär, S.W. of Bågaskär, a bedded leptite which is in part very typical (cf. fig. 1) although broken up into numerous fragments, in which, however, also the salic portions still retain the character of a strongly metamorphic leptite. In other parts of the same island veins of a typical grey gneissose granite are seen distinctly intersecting the leptite, while we again observe, in the eastern part of the island, an apparently bedded rock (cf. fig. 2) concerning which it is difficult to say whether the salic bands should be regarded as strongly metamorphic parts of the leptite or as granitic layers formed by injection (eventually metasomatically changed).

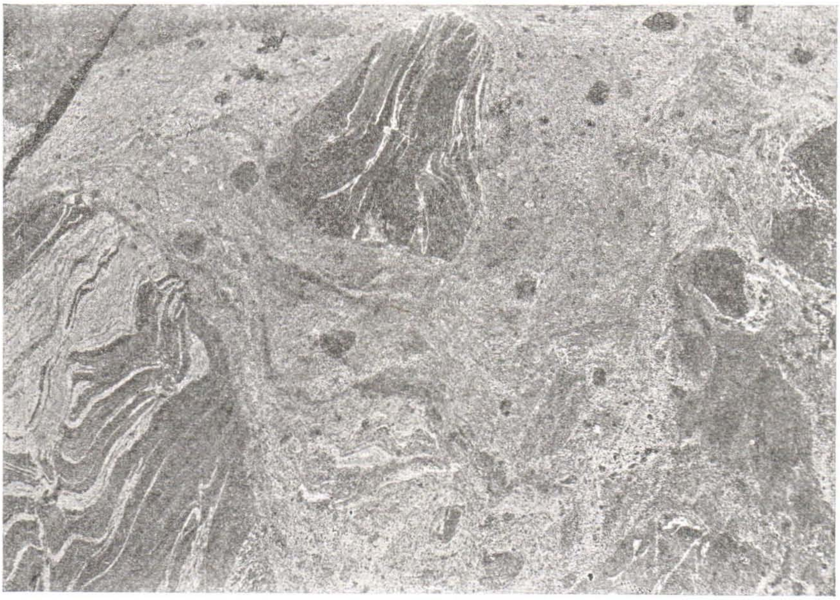

Fig. 11. Bedded leptite changed by palingenesis into an eruptive rock where some portions have flown, while others have remained as fragments. Lingonsörn in Snappertuna. C:a 1: 9 nat. size.

There is in these rocks no marked limit between what could be called metasomatic ultrametamorphism, and the injection of granitic magma.

9 km further to the S. W., we observe on the island of Lingonsörn in Snappertuna, a splendid example of anatexis, illustrating in a very typical way the palingenesis of the older rock. The rock of the southern shore of Lingonsörn is a bedded leptite which retains in many places its character of a highly metamorphic schist showing an alternation of salic and femic beds. But the greater part of it has been changed, by a process surpassing metamorphism and even »ultrametamorphism», into a rock which now behaves like an eruptive, but in

which we still observe so much of the bedded structure of the leptite that it is obvious that at least a great part of the rock is simply a leptitic schist which has been »ultrametasomatically», if such an expression is allowed, changed to such a degree as to reach the stage of refusion.

In the northern part of the same island we find again a rather typical gneissose granite which contains only rare patches of leptitic rocks, mainly their most basic parts which have better resisted the refusion.

There is a great similarity between the rock shown in fig. 11 and that which Adams observed in the Haliburton—Bancroft area of Canada (cf. his photograph of an amphibolite invaded by granite of the Methuen bathylith and partly dissolved by it) and interpreted in an analogous way.[1]

This change of the salic portions of the leptite into granitic veins is entirely in harmony with the observations on the formation of other migmatites which can be made all over the coastal regions. Their components are of a very varying character. Even when basic rocks of a uniform chemical composition, but possessing a schistose texture, have been invaded by granites, we are aware that they may occasionally become banded, whereby the granitic juices penetrate certain layers and gradually change them metasomatically into rocks with a more or less typical aplitic composition. When this is possible even with metabasites, which are generally most refractory to the action of the granite and its »juices», it is easily understood that those portions which originally possessed a more salic composition, must be easily changed, by the same process, into rocks showing a granitic character.

Many of the migmatites consisting of leptite and older granite, also in the islands lying more to the west, are very typical arterites characterized by an »injection lit par lit» of aplitic or pegmatitic material, i. e. a penetration of granitic veins in cracks following the cleavage. Such is e. g. a great part of the migmatite in the island of Rörörn. Fig. 14 shows an example of this migmatite, which contains also crystalline limestone intercalated with the leptitic portions, an evidence of its sedimentary origin.

In general, much more of the formation of the migmatites of the

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[1] F. D. Adams, On the Structure and Relations of the Laurentian system in Eastern Canada. Quart. Journ. Geol. Soc. London. Vol. 44, 1908, pp. 127—146, Plate XI.

— — and A. E. Barlow, The Geology of the Haliburton and Bancroft Areas in Eastern Canada. Rep. Geol. Surv. Canada. 1910.

coastal regions than thought hitherto, is due to those granites which are older than the metabasaltic dykes, and not to the action of the Hangö granite. With the aid of the evidence which the dykes furnish, it is possible to discriminate between both these groups of migmatites.

THE ORIGIN OF THE PARALLEL TEXTURE OF THE OLDEST GNEISSOSE GRANITES.

In these granites we able to study the origin of the most typical gneissose texture in granites and to show that it has, in many cases, very little to do with dynamometamorphism, if thereby is meant changes caused by mountain-making processes acting on solid rocks much later than their consolidation. The parallel texture indicated by rows of biotite, which gives to many varieties of these granites such a typical gneissose character, obviously originated at the same time as the fragments of leptite were split up and partly assimilated by the granite. The gneissose portions of the granite pass by gradations into arteritic migmatites, and their parallel texture follows in general the strike of the neighbouring leptite. It winds around the fragments and lies in altogether different directions in the individual veins subdividing the fragments. The angular character of these fragments is absolutely incompatible with the assumption that they were strongly compressed after their formation. The conservation of such delicate structures as those shown in figs. 5—7, prove that these migmatitic rocks in many cases have suffered no great dislocation in their mass since the time they were formed. A day spent at Bågaskär and in its neighbourhoed will convince every petrologist not bound to a dogma that the most typical gneissose granites may originate during the eruption of the granites, by processes which cannot be regarded as due to mountain-making movements of an alpine character.

On the other hand, we have found, by examining the oldest granites petrographically, many signs indicating a strong mechanical crushing of the minerals, which fact is seemingly in favour of the older explanation of the origin of these gneissose varieties by a »dynamometamorphism» or »dislocational metamorphism».

The writer was inclined formerly to interpret many gneissose granites of southern Finland in this way, but has since found that the foliation and the cataclasis in most cases are not truly secondary, but due to movements which took place either during the consolidation of the rocks or at a time immediately following it.

The parallel texture of these oldest granites is certainly everywhere anterior to the eruption of the metabasaltic dykes, which intersect the foliation straightly and also include sharply defined fragments of the foliated rock.

This circumstance restricts the formation of the parallel texture to a geologically speaking brief period, much earlier than the eruption of the granites belonging to the Hangö group and to the orographic movements with which their eruption was connected.

A part of the foliation of the oldest granites is, as already stated, due to their migmatitic character, but another part to movements which have taken place in deeper portions of the same granitic masses which were still molten while the upper portions were in large measure already consolidated.

We will, when describing the younger granitic and migmatitic rocks of the present region, those belonging to the Hangö granites, give evidence proving with certainty that also in this group of granites typical sheared rocks originated, although in exceptional cases, before the final consolidation of the same eruptive rock masses.

In the archipelago of Aland the writer has found that the foliation of the youngest granites showing such textures, e. g. of the Åva granite (whose eruption preceded that of the rapakivi granites), is anterior to the lamprophyric, pegmatitic and aplitic veins which belong to the same granite. In the oldest, gneissose granites of the region mentioned, the origin of the rows of mica which indicate the foliation, is, again, sometimes closely connected with the formation of lamprophyric veins. Also in this case the foliation is older than the last pegmatitic and aplitic exudations fram the same granites. These granites have not suffered any greater changes since these last portions of the granitic magma have solidified.

THE BASIC DYKES AND THE CHANGES WHICH THEY HAVE UNDERGONE.

GEOLOGICAL AND PETROLOGICAL IMPORTANCE OF THE BASIC DYKES.

The basic dykes which occur all over this region, intersecting the leptites and the older granites, but injected by and interwoven with the Hangö granites, possess, as has already been repeatedly emphasized, a double interest, geologically and petrologically. On the one hand, they give the criterion for separating the older and younger Archæan granites. On the other hand, they furnish a material on which the intensity of the metamorphic changes can be measured, and also the intensity of those changes which much surpass metamorphism and have been referred by the writer to the process which he terms anatexis. Also certain problems connected with the doctrine of metamorphism and the latest applications of that theory may be elucidated by the study of these dykes, and the associated effusive rocks.

Here, as usual in the Archæan, we meet, by describing the phenomena, a certain difficulty in their extreme complexity, which makes it necessary to discuss together features which are primary and such as originated at later epochs. The most logical way of treating the matter would be by beginning with a description of those dykes which still show their primary features well preserved, in order thus to ascertain what they were originally, and then later to describe those rocks which have been changed by the influence of the Hangö granite, after having given the description of that granite.

It is, however, difficult to separate the well preserved and the more intensely changed basic dykes, when describing them, because both occur in such close connection, and secondary features must in any case be eliminated during the description of the former. It seems therefore most practical here to account for all basic dykes together, passing from one locality to another, thereby also in part discussing their later anatexis through the influence of the Hangö—Ingå granite. A certain anticipation of results at which we shall arrive in later chapters will therefore be necessary.

No basic dykes of the character about to be described have ever been found intersecting the Hangö—Ingå granite. The lamprophyric dykes connected with it, which were discovered by the writer in the Åland archipelago, have not been observed in the present region, excepting some narrow zones of more basic composition which occur in an aplitic vein that will be described in a later chapter. Nor do there seem to exist any basic dykes which could be regarded as older than the gneissose granites described in the former chapter. As to their age, the dykes thus everywhere lie between the two granitic formations, constituting a sharp demarcation line between both of them.

They do not possess a local distribution, but are found everywhere along the coast, almost on every larger island where older rocks are visible, from the eastern margin of the great rapakivi area of Wiborg, in the east, to the Åland Sea in the west. Even on the Swedish side of the Baltic they appear, and have been described under different designations by Gavelin,[1] Asklund [2] and Sundius.[3]

At every place where these dykes are well preserved, they show the character of typical fissure dykes of originally basaltic composition.

Such are the dykes which are numerous in the area of gneissose granite of the archipelago of Föglö, immediately E. of the Åland Sea, S.E. of the largest of the Åland islands. In the eastern part of the Åland—Åbo archipelago, we find hundreds of similar basic dykes intersecting the oldest granites, but intermingled with younger ones. Here they are often so greatly changed that their primary characters have been in large measure obliterated, but in many places we find them still well preserved.[4]

Further to the east, in the Hangö region, they are often wonderfully preserved, even when they are intersected by numerous dykes of younger granite. For instance, in the small island of Inderskärs Westgrund, 25 km E. of Hangö, a gneissose granite is intersected by a great number of basic dykes, each of which may still be recognized, in spite of the strong metamorphism which the rock has undergone, as a fissure dyke of metabasalt. These dyke rocks show many of the characteristics of basaltic dykes, such as porphyritic texture, aphanitic contact zones, zonar structure, schlieren of different grain etc. very well preserved, and also the composition is still, in spite of the strong metamorphism which the rocks have undergone, entirely that of typical basalts. This locality will be described in the next paper of this series.

Further to the east, we find similar dykes everywhere till we reach the present region, where the dykes also at many places show well preserved primary features, as will subsequently be described.

If we now proceed from the present region still further to the east, we continue to find swarms of basic dykes of similar character,

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[1] A. Gavelin, Om relationerna mellan graniterna, grönstenarna och kvartsit-leptit-serien inom Loftahammar området. Sver. Geol. Und. Ser. C. 224, 1910.

[2] B. Asklund, Några urbergstektoniska problem från Östergötland. Geol. För. Stockholm Förh. Bd. 43. 1921, pp. 569—611.

[3] N. Sundius, Om amfibolitgångarna i trakten av Valdemarsvik—Skrikerum etc. Fennia 45, N:o 12. 1925. Sver. Geol. Und. Ser. Aa. N:o 151, pp. 25—31.

[4] In 1925, *effusive* metabasalts were also discovered at Enklinge in the Åland archipelago where they form the upper part of a formation of Archæan schists, which is separated by a distinct unconformability, marked by a basal conglomerate with pebbles of granite, from their basement of gneissose granites and leptites.

and in similar relations to other rocks. In the neighbourhood of Helsingfors the older rocks are very much mixed up with veins of Hangö granite, and the primary features proportionally obliterated, but east of the city we find again, in the Pellinge region, metabasaltic rocks which in part escaped the granitization at the time of the eruption of the Hangö granites. They occur here both as dykes and as surface flows.

Those oldest granites which occur in close connection with the leptites, interweaving them, are, in the most indubitable way, intersected by the metabasaltic dykes which radiate from the greater areas of effusive metabasalts, as has been put foıward by the writer in an earlier memoir.

On the other hand, there is hardly any locality anywhere in the regions where these dykes are observed, where they are not penetrated by veins of the characteristic Hangö granite which has in many ways changed them. We will in the next chapter give a detailed description of this granite, as it occurs in the present region, and the migmatites associated with it. Should any reader of this memoir when we ascribe, in this chapter, certain phenomena to the influence of this granite, feel uncertain about its discrimination from the older granites, we refer to this later chapter, as well as to the earlier papers where it was described. In the Pellinge region, we have been able to prove that the interval of time separating the oldest gneissose granites of the coastal regions from the Hangö granite, is of such duration that these older granites, and the associated migmatites, had been brought to the surface by erosion before the volcanic rocks were deposited, partly on them, partly on quartzitic and leptitic sediments and volcanic beds intercalated with the latter, on older gabbros etc.

Further the writer has endeavoured to prove that in the Pellinge area even two volcanic formations occur, separated by the intrusion of a granite, but as neither this granite, nor more than one group of metabasalts, seems to occur in the present area, it is not necessary here to recapitulate the reasons for that further subdivision.

What is of interest for the subject here treated, is the fact that the subdivision in younger and older granites is not of a local character, nor merely a separation of petrologically different rocks belonging to the same geological formation. The observations in Pellinge add further weight to the conclusions which we arrive at in every separate region on the southern coast of Finland, viz. that the two great formations of Archæan granites occurring there, both of which are truly plutonic rocks, are separated by a formation of fissure dykes which originally possessed a basaltic composition and whose primary textures have greater similarity to those of volcanics, than to those of any deep-seated rocks.

These basaltic dykes have obviously formed a system similar to that which we observe, for instance, in the northwestern parts of the Scottish Highlands. They prove that all over the wide region now in question the molten or at least potentially fluid subcrustal magma was basaltic, in the interval between the intrusion of both granitic formations. The older granites must have been entirely solidified before the time of the formation of the dykes. Everything shows that the fissures were formed in the uppermost, brittle portions of the earth's crust, in the »sclerosphere». It is true that also lamprophyric dykes, although they originated at the end of the solidification of the granites which they intersect, and before the crystallization of the last aplitic juices of the granitic magma, fill fissures which are almost as straight as those in which the basalts were injected. But the latter rocks show one character entirely wanting in all these »afterbirth» dykes, viz. aphanitic, originally glassy contact zones, together with a number of other phenomena which prove that the granitic masses already possessed a low temperature at the time when the basalts solidified. And these metabasalts are not, like the lamprophyres, genetically connected with aplitic dyke rocks. They are also chemically different from the lamprophyres. It is therefore possible to discriminate between both these groups of phenomena, and we shall not let the existence of the dyke rocks of more dubious character detract from the value of the evidence of the volcanic rocks concerning the conditions existing before the eruption of the Hangö granites. They witnessed this important event in the geological history of the region, but have remained as relics. The lamprophyric dykes also possess a very great interest, but mainly chemically, and because they give us a clue to the study of the differentiation processes.

It follows from what has been said above, that the two great granitic formations which have a regional extension in the present tract, can neither geologically nor petrologically be united, but are almost as separate from each other as the latest great group of granites of southern Finland, comprising the rapakivi rocks, which are of post-Archæan (late pre-Cambrian) age, is from both of them.

These different Archæan granites do not cover each other as to their extension, although they, in several cases, originally overlapped.

In comparison with the importance of the deduction, that there are at least three (two Archæan and one post-Archæan) granites of different age in these regions, the question whether there may be one or two more is less important. We will return to that question later on.

The intensity of the granitization processes which are connected with the eruption of these different granites, is much less in the youngest of them (the post-Archæan), but here also we find along the margins of the areas phenomena of injection, in some cases even of palingenesis. The latter-mentioned process, however, occurs in its most typical form in connection with the protrusion of the older, Archæan granites, especially those belonging to the Hangö group. But also among the granites of the oldest group we find the most conspicuous palingenetic phenomena. Thus we are able to conclude that palingenesis has occurred repeatedly over the same area.

DESCRIPTION OF THE DIFFERENT LOCALITIES.

THE METABASALTIC DYKE OF STAKAGRUND.

At Stakagrund, 2.5 km S.S.W .from Obbnäs Udd, the prevailing gneissose granite is cut by several dykes of metabasalt. Two of them contain porphyritic crystals of plagioclase. These dykes possess a breadth of 1—2 m.

Fig. 12. Metabasaltic dyke intersecting the eruptive breccia at the eastern shore of E. Bågaskär, Ingå.

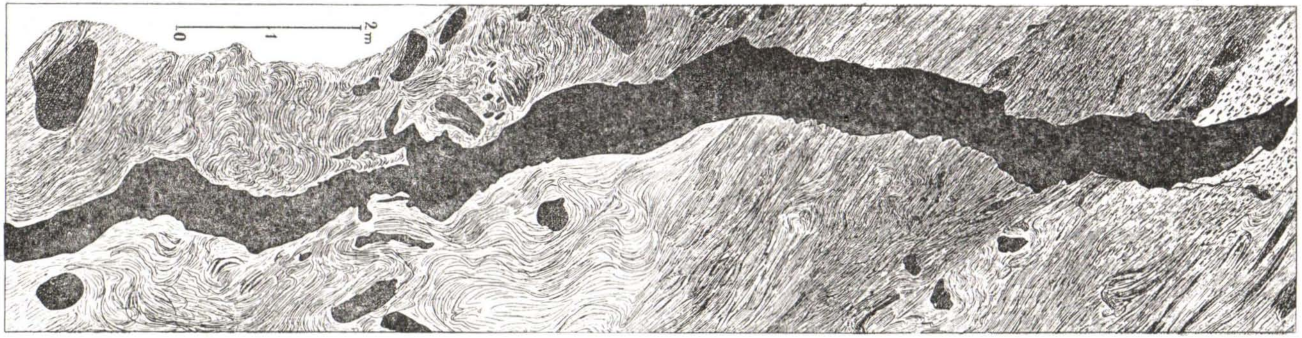

Fig. 13. The continuation of the metabasaltic dyke shown in fig. 12. It intersects an eruptive breccia. E. Bågaskär in Ingå. C:a 1: 75 nat. size.

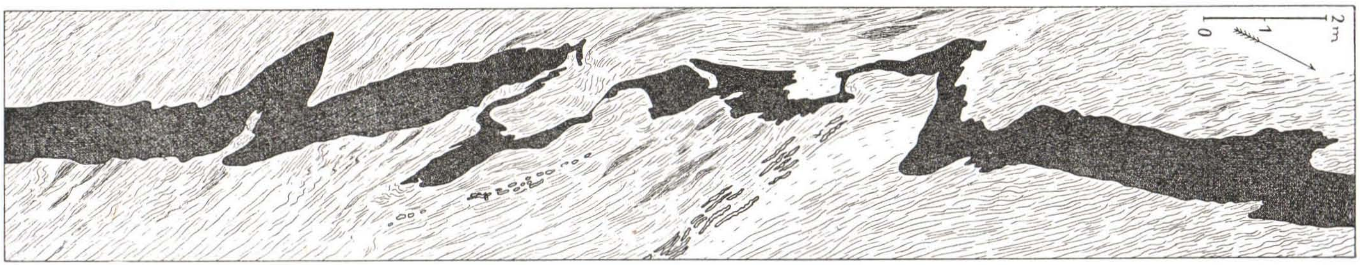

Fig. 14. Metabasaltic dyke (black) which intersects a leptitic migmatite, containing lenses of limestone and dykes of older granite (white). Rörorn in Ingå. C:a 1: 120 nat. size.

Most dykes are parallel to the foliation of the gneissose granite which strikes in 25° E., with an inclination of 80° S.E., but some of them also cut it obliquely. The granite no doubt originally belonged to the oldest granite, but was later changed by palingenesis into a migmatitic rock whose pegmatitic components now penetrate the metabasalt of the dykes.

In these dykes the metabasalt is highly metamorphic, changed into a schistose amphibolitic rock.

THE BASIC DYKES OF BÅGASKÄR.

In the westermost part of the islands of Bågaskär a basic dyke occurs which has already been mentioned on p. 27. It is almost as separate from the older rock which it penetrates, the eruptive breccia described in detail on pp. 18—27, as are the unmetamorphic trap dykes which are so common in the Åbo—Åland archipelago and also occur in one place in the present region. These younger dykes intersect all pre-Cambrian rocks which are older than the rapakivi granites and have no genetical connection with any of them. The present dyke rock of Bågaskär, again, is entirely metamorphic, a »metabasite» quite similar to the dyke rocks of Påvskär which will be described in the following pages.

Fig. 12 shows a portion of this dyke which lies near to the sound between the two islands of Bågaskär, and S. of the pilot's house. Fig. 13 shows another part of the same dyke at a place where it has been slightly bent. It can be followed to a length of nearly 100 m, but disappears further north where granites of Hangö type interweave the older rocks.

THE METABASALTIC DYKE OF RÖRÖRN IN INGÅ.

At Rörörn[1] in Ingå, 6 km SW of Bågaskär, a metabasaltic dyke which is shown in fig. 14 is seen on the northern shore. It had an original breadth of 1—1.2 m and intersects an arteritic migmatite, consisting mainly of leptite, intercalated with crystalline limestone and containing veins of older granite which is in the narrower veins aplitic or pegmatitic in character. Here no doubt can exist about the fact that a period of intrusion of granite has occurred between the deposition of the leptitic sediments and the formation of the fissure dyke which intersects the older rocks in an oblique direction against their strike.

[1] On older maps it is called Rönnörn.

The shape of the dyke is partly due to the irregular splitting of the schistose leptite, at the openting of the original fissure, partly to a later folding.

THE METABASALTIC DYKES OF PÅVSKÄR AND THE PALINGENESIS OF THE OLDER GRANITE WHICH THEY HAVE WITNESSED.

The island of Påvskär[1], E. of Bågaskär, is one of the most instructive localities for studying the basic dykes and the palingenesis of the older rocks which they have witnessed, having themselves in many cases but slightly suffered from these ultrametamorphic changes and therefore remaining as relics. The writer has previously described this locality briefly in Swedish[2].

The island is 400 m in length from E. to W. and 200 m in breadth and is surrounded by some smaller islands.

The prevailing rock is the grey plagioclase granite already described (pp. 12—16), sometimes passing by gradations into rocks richer in femic minerals, but in places in some varieties poorer in biotite and thus lighter in colour than the prevailing rock. This is in general rather homophanous, sometimes also migmatitic, containing clusters of fragments of leptitic rocks and, on the northern shore, even a big fragment of crystalline limestone (cf. p. 8—9). Also when it does not show any distinct parallel texture, it has microscopically a gneissose character. On the field, it shows a very marked difference in appearance from the red Hangö granite which occurs all over the island in varying quantities. This granite is sometimes very sharply defined against the grey plagioclase granite, especially where it forms pegmatitic dykes and veins, but also where it is equigranular. In other cases, again, it forms more irregular masses with no sharp delimitation. There is however, as already frequently reiterated, a very marked difference in age between the granites, the latter of which is older, whereas the red granite, when it occurs in typical form, is decidedly younger than the metabasaltic dykes.

Where this younger granite is absent, the original relations of the metabasaltic dykes and the oligoclase granite and many of the primary characters of the former are still very well preserved.

On a small island, Påvskärs Westgrund, lying immediately W. of Påvskär, in very low water connected with it, a number of basic dykes occur which are very well preserved.

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[1] The name of Påvskär (pr. Poveshare), which was earlier written Påfskär, means Pope's Island.

[2] J. J. Sederholm, Om palingenesen i den sydfinska skärgården samt den finska urbergsindelningen. Geol. För. Stockh. Förh. Bd. 34. 1912, pp. 285—316.

Fig. 15 is a petrological map of the main part of this little island. The older rock is a grey gneissose granite, containing clusters of leptitic fragments in different degrees of assimilation. This rock has been intersected by several very typical fissure dykes which all possess a metabasaltic composition, but whose rock has a somewhat varying shade and colour.

The broader dykes run in directions varying between N. 80° E. and N.70° E. which are not entirely conformable with the parallel texture of the gneissose granite. The oldest of them is darker on the surface than the two others which intersect it at a low angle. It already macroscopically shows feeble remains of an ophitic texture. At the contact the rock is somewhat finer grained than at the margins. The southernmost dyke is the lightest in colour. Where it intersects the dark dyke, this has been faulted. The northern of the lighter dykes is the broadest of all. It has fine grained contact zones which are at some places very distinct.

The two northernmost of the broader dykes are cut by a sharply defined, narrow metabasaltic fissure vein whose rock is almost black and is very fine-grained, almost aphanitic. It was obviously glassy originally. This dyke runs in N.W. to N. The contact with the southernmost dyke is not clearly visible. It seems possible that the narrow dyke is intersected by the broader one.

All these dykes are sharply intersected by veins of red pegmatite which present the characteristics common in the pegmatites belonging to the Hangö—Ingå granite.

The continuation of these dykes can be followed on the main island. The narrow aphanitic dyke here intersects a broad very straight dyke (fig. 16) which runs from N. to S. and has a breadth of 2.8 m. It shows a marked contrast between a middle zone darker in colour and lighter contact zones. This rock macroscopically exhibits a distinct resemblance to an ophitic texture.

This dyke rock was no doubt originally a dolerite, in no way different from a modern basalt, and the same is true also of the basic dykes of Påvskärs Westgrund. We will later give in detail their petrological and chemical description which confirms this conclusion. We wish here only again to emphasize the fact that they are real volcanic fissure dykes, decidedly younger than the granite which they penetrate. Should anybody challenge this thesis, it is possible, as already stated on pp. 31—36, to show, all along the southern coast of Finland, an overwhelming evidence in favour of it.

If we now proceed further to the east along the northern shore of Påvskär, we find, besides the continuation of the dykes already

Fig. 15. Four dykes of metabasalt intersecting an agmatitic granite, and themselves cut by a pegmatitic vein. Horizontal rock surface at Påvskärs Westgrund in Ingå. C:a 1: 150 nat. size.

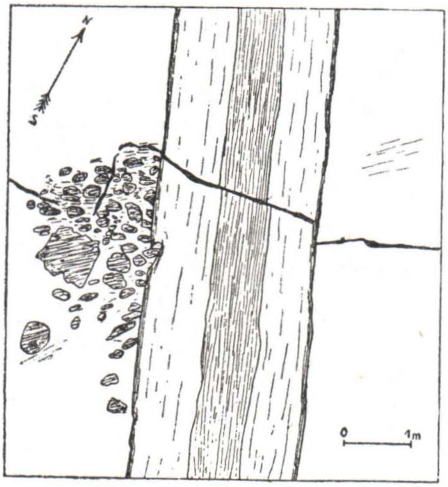

Fig. 16. Dyke of metabasalt showing an equigranular darker middle zone and dark aphanitic contact zones. It is intersected by a narrow vein of aphanitic metabasalt. Both these dykes cut a gneissose granite containing fragments of leptite. Western shore of Påvskär in Ingå.
C:a 1: 110 nat. size.

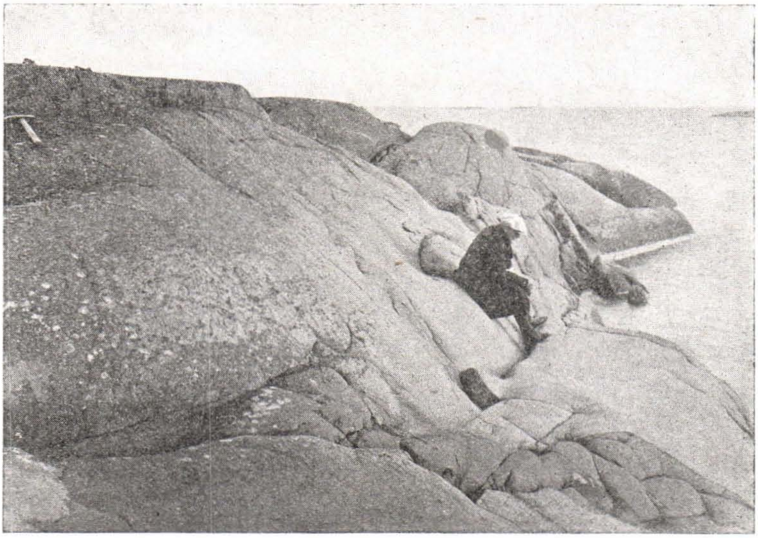

Fig. 17. Dyke of metabasalt (cf. figs. 18—20), intersecting the oligoclase granite at the southern shore of Pävskär.

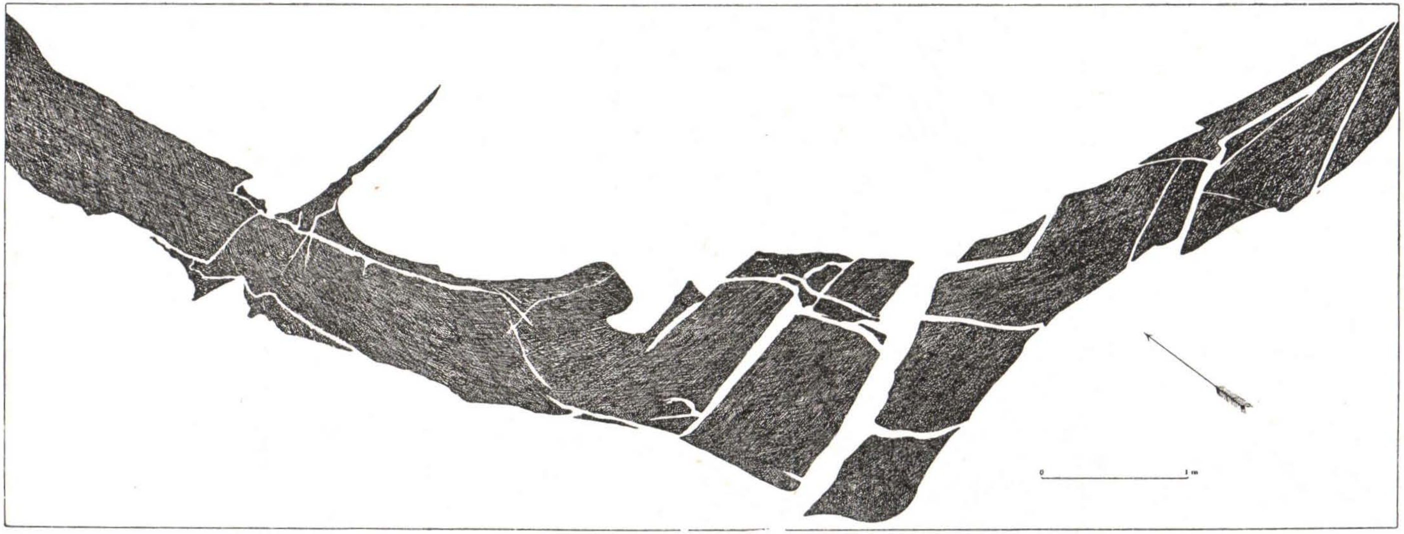

Fig. 18. Portion of the dyke of metabasalt shown in fig. 18 at the N.W. shore of Påvskär in Ingå, fractured and penetrated by palingenetic granite. 1: 150 nat. size.

described, other fissure dykes of the most typical character. Two of them may be followed from N. to S. all over the island, intercrossing on the way. One of these dykes is particularly remarkable.

We find it on the southern shore as a well preserved dyke, only slightly bent, intersecting the grey granite (fig. 17). On the northern shore this dyke is also very distinct. That it is a true fissure dyke is shown both by the existence of an apophyse which is aphanitic and was obviously originally glassy (figs. 18 and 19) and also by the fact

Fig. 19. Photograph of a part of the northern end of the metabasaltic dyke shown in figs. 17—18. C:a 1: 10 nat. size.

that the rock of the main dyke shows that schlieren-texture which is often observed in the metabasaltic dykes, in places where they are well preserved.

This typical, narrow dyke, whose breadth is only 0.6—0.7 m on an average, and which can be followed to a length of 200 m, has now been split into a great number of fragments whereafter the fissures have been filled with a granitic mass which does not show any boundary against the surrounding granite, but has the same petrological character. Fig. 18 shows a part of this fissured dyke, fig. 19 a detail of the same part of the dyke and fig. 20 shows that portion which is intersected by the broadest of the granitic veins.

According to the general rules for determining the age of eruptive rocks at their contacts, we should say that the granite is here younger than the basic rock. But at the same time it is obvious that the latter forms a fissure dyke in the same granite, which is thus both older and younger than the dyke.

There is no doubt that the dyke was formed at a time when the granite was entirely solid, at a level where the rock masses were rather brittle and where their temperature was so low as to allow part of the basaltic magma to solidify like glass. The granite, again, is a typical plutonic rock, while the dyke rock has a volcanic character,

Fig. 20. Middle portion of the metabasaltic dyke shown in Fig. 18, at the place where it is intersected by the broadest vein of palingenetic granite. Seen from the west. C:a 1: 25 nat. size.

having solidified near to the surface of the earth. Thus the eruptive character of the granite forming veins in the dyke cannot be regarded as a remnant of its original eruptivity, as is the case e. g. in the granite area of Åva, in the Åland archipelago, where a granite has been intersected by lamprophyric veins, and these have again later undergone a kind of refusion, through the influence of the juices belonging to the same granite which they intersect.[1]

In the present case, the dykes cannot be interpreted as lamprophyric, but are, as has been emphasized so many times, true metabasalts.

[1] J. J. Sederholm, Granit-gneisproblemen belysta genom iakttagelser i Åbo—Ålands skärgård I. Geol. För. Stockholm Förh. Bd. 46, 1924, pp. 147—151.

Therefore, the only possible explanation of the eruptive character of the granite is that it has been reborn, or, in other words the granite has acquired a *palingenetic* eruptivity. In its present state the granite ought to be regarded as younger than the dyke rock, but it shows no petrological difference to the rock which is cut by the dyke. This

Fig. 21. Metabasaltic dyke at the northern shore of the island of Påvskär, in part intersected by palingenetic granite (northernmost, left part of the dyke shown on fig. 1, Plate VIII). C:a 1: 20 nat. size.

granite has been in a fluid state potentially and has moved as an eruptive only where fractures have originated.

When we pursue the study of the dykes of the same island, we are able to make additional observations which elucidate these palingenetic phenomena. Several hundred meters more to the east we find, on the same northern shore of the island, another dyke running from south to north, where it disappears under the water of the sea. This dyke is shown by the map in fig. 1, Plate VIII, and the southern part of it in fig. 21.

In the northern part of the dyke, where it intersects a rock which retains the character of the grey gneissose granite, it is straight and well preserved, even showing still preserved more fine-grained contact zones. Only at the water's edge it has been scattered into fragments between which the palingenetic granite has penetrated.

More to the south the granite at both sides of the dyke is reddish in colour and rich in microcline and in general possesses characteristics not observed here in this older granite, but only seen in the Hangö—Ingå granites.

Especially in those portions of the granite which form veins intersecting also the metabasalt, the character is entirely that of the aplitic veins associated with the Hangö granite. These aplitic portions in some places behave exactly like a younger eruptive, but in other places they stop at the contact of the metabasalt, as though they were older than that. In any case they were in an eruptive state, or in a state of a renascent eruptivity, at a later epoch than the formation of the dyke, but the dyke rock has been more refractory to the action of the »juices» which have metasomatically changed the older granite, than this rock. That the mass surrounding the southern parts of the dyke have been really »more eruptive», in any case in a more mobile state than those parts of the granite which have retained their former composition, is shown by their irregular forms and by their folding and fissuring, indicating movements in a semi-plastic state.

When we walk farther to the east along the same northern shore of Påvskär, we find again a narrow dyke of regular breadth, which can also be followed such long a distance that there is no doubt about its character of a dyke, but where the surrounding rock is in part a red granite rich in microcline and presenting all the characteristics of a Hangö granite. It still retains, however, traces of the parallel texture of the original gneissose granite which has been ultra-metasomatically changed into this red granite. The dyke rock presents no traces at this place of the finer details of the original textures. It is a homogeneous amphibolitic rock, similar in texture and mineral composition to those parts of the metabasaltic dykes which occur as fragments entirely surrounded by the Hangö granite, e. g. in the region of Hangö, and which were previously described by the present writer.

In the naked rocks lying between this place and the eastern end of Påvskär, we alternately observe grey gneissose oligoclase granite and red microcline granite, sometimes so well separated by sharp contacts that anybody would designate them as genetically different granites, at times again connected by gradual transitions.

If their relations here still appear enigmatic and contradictive, the rocks of the easternmost parts of Påvskär again give a clue to the proper understanding of these phenomena.

As shown by fig. 1, Plate IX (cf. fig. 22), all the different rock formations outcropping in the island are here represented. To the

Fig. 22. Scattered portions of a metabasaltic dyke at the eastern shore of the island of Påvskär, cut by Hangö granite originated by the palingenesis in situ of the older granite (cf. Fig. 1, Plate IX). C:a 1:12 nat. size.

east, we observe very typical leptitic schists, intercalated with thin layers of limestone, while more to the east the older rock masses, i. e. those which are older than the metabasaltic dykes, were earlier constituted of oligoclase granites. Only patches of these rocks now remain, however, surrounded by and at all sides interwoven with the red microcline granite which is now the prevailing rock in the eastern part of the area shown on the map. Before the time of the »eruption» (or rather imbibition) of this red granite, there has been a sharp limit running N.—S. separating the oligoclase granite and the leptitic rocks.

Both these rocks were later intersected by two dykes of metabasalt which are still very distinctly preserved as long as they intersect the leptite. Here the youngest granite of the island is represented only by a few narrow veins of red pegmatite.

There is no doubt as to the fact that the dykes originally continued without any interruption through the oligoclase granite more to the east. They are still here in part well preserved also where the original oligoclase granite has been entirely replaced by microcline granite. But in general the dyke rock is, in such places where the microcline granite is abundant, subdivided into a number of fragments, most of them angular (cf. fig. 22) which retain, however, their former positions so as to indicate the original directions of the dykes.

The remaining portions of the oligoclase granite have also been penetrated by a network of veins of microcline granite, and the migmatite thus formed exhibits the structure which the writer has called dictyonitic (net structure). The penetration is in this case rather intimate, while on the contrary the limits between the microcline granite and the basic dyke rock are sharp.

One may object that the fragments of basic rock in the eastern part of the area surveyed may possibly not entirely retain their former places, but be derived from higher portions of the dykes which gradually sank, at the epoch of the eruption of the younger granite, along the same planes which are indicated by the vertical dykes.

However, if we scrutinize the brecciated portions of the dykes more closely, we are aware that many of the fissures filled by the granite do not intersect the whole fragment, but form openings in it which end before reaching the opposite boundary. Thus at least some of the cracks were formed while the basic dyke rock still retained its formed position, and their formation was accompanied by a solving action from the side of the granite. The brecciation cannot be due solely to a mechanical fissuring and »stoping».

Thus, the idea which these phenomena convey to the observer, is that the penetration of the younger granite into the older rocks occurred while these in large measure retained their former position, and that hereby a part of the older rock masses were never entirely solved. It has been an anatexis *in situ.*

The younger granitic magma did not, in this particular case, move upward like a powerful subterranean stream, inundating the older rocks, scattering them by »overhead stoping» and afterwards dissolving the fragments. So it has done in many cases, but here the »juices» of the younger granite permeated the older one, as oil penetrates sheets of paper; à t â c h e d'h u i l e, according to the excellent expression of Termier[1], and later it changed them »ultra-metasomatically» into a new granite which in the final stages was able to react on other rocks like an eruptive.

Fig. 23. Metabasaltic dyke intersecting leptitic migmatite, whose pegmatitic portions have only slightly corroded the metabasalt. Western shore of Kyrkogårdsö, near Porkkala in Kyrkslätt. C:a 1:12 nat. size.

The locality now described is that where the present writer first found evidence which he thought indisputable, and which has appeared convincing to many visitors, in favour of a palingenesis.

These are not isolated facts that may be regarded as exceptional. On the contrary, they are in harmony with many other observations which the writer has made in other parts of the same coast region, especially in the parish of Kökar, of the Åland Islands.

The process by which the older gneissose granite has been changed into Hangö granite will be discussed from a petrological point of view in the next chapter.

[1] P. Termier, Sur la genèse des terrains cristallophylliens. C. R. XI Congr. géol. intern. Stockholm 1910, p. 587 seq.

THE METABASALTIC DYKES OF KYRKOGÅRDSÖ.

We will here insert a short description of a locality which gives a good illustration of some points mentioned in the description of the phenomena studied at Påvskär, and further corroboration of the conclusions which we arrived at there, although this locality lies beyond the sections of the present region which have been studied in greatest detail.

Fig. 24. Continuation of the vein shown in fig. 23. Some of the pegmatitic veins intersect the metabasalt.

At Kyrkogårdsö, E. of the Barösundsfjärd, the prevailing rock is a fine-grained, rather homophanous variety of the leptites which has been very intimately permeated by pegmatite and aplite. These occur partly as cloudlike patches with a very vague delimitation, partly as veins and dykes which interweave the rock.

Figs. 23—25 which are all continuous, show different parts of a metabasaltic dyke intersecting the prevailing older component of this migmatite.

In fig. 23 the dyke is well preserved and but slightly attacked by the granite which is partly pegmatitic, partly aplitic. Its action has here in general abruptly stopped at the boundary of the dyke. Only a feeble corroding action on the dyke rock is visible where the granite is purest. In fig. 24 we find the continuation of the same dyke intersected by the red granite which forms here better separated veins but is otherwise in no way different from the pegmatitic portions of the cloudlike patches of granite in Fig. 23. And finally we observe, in fig. 25, the easternmost continuation of the same dyke, strongly faulted and in part contorted at the eruption of the same granitic veins.

Fig. 25. Continuation of the vein shown in figs. 23 and 24. The metabasaltic dyke is strongly faulted where intersected by pegmatitic veins.

For the proper understanding of these cloudlike granite portions we refer to the phenomena shown in figs. 37—39. and the subsequent description of these rock surfaces.

THE METABASALTIC DYKES OF LÖVGRUND.

The migmatite constituting the rocks on the N.E. shore of the island of Lövgrund, one km NW. of Bågaskär, has already been described in the foregoing chapter. It consists of leptitic schists interwoven with veins of the older granite which is here in great part aplitic or pegmatitic in character. Where these veins are abundant, the migmatite often shows the ptygmatic folding which is due to movements in a plastic state (figs. 10, 26 and 27). These veins certainly belong to the older granite, then they are intersected by typical metabasaltic dykes whose eruption took place after the folding of the migmatite. Especially the rock shown in fig. 10 leaves no doubt

Fig. 26. Migmatite of leptite and older granite intersected by metabasaltic dykes (M) which also cut a lump of skarn (S) interspersed with quartz (Q). The metabasite is intersected by some veins of Hangö pegmatite (P). N.E. shore of the island of Lövgrund in Ingå. C:a 1: 60 nat. size.

about the fact, that the migmatitic rock was entirely consolidated when the metabasaltic dyke was formed, and that this dyke has no genetic association at all with the aplitic and pegmatitic veins which it cuts (cf. also fig. 27).

On the other hand, we find on regarding the drawing in fig. 26, that there are also veins of pegmatite which intersect the basic dykes. These pegmatitic veins possess, e. g. in the vein shown in the

Fig. 27. Portion of the easternmost of the metabasaltic dykes shown in fig. 26. C:a 1 : 11 nat. size.

upper part of fig. 26, the character of the pegmatite connected with the Hangö granite. Other aplitic veins have a less typical character, and some of the narrow zones subdividing the dykes may perhaps even be interpreted as palingenetic portions of the surrounding migmatite, analogous to the veins of palingenetic granite shown in figs. 18—20 etc.

We observe here a very interesting fact which gives evidence concerning chemical processes connected with the metamorphism which the basic dykes have undergone. Here as at several places in the adjacent rocks, the migmatite contains fragments of a »skarn»-rock rich in epidote, malacolite etc. Such rocks often occur associated with the limestones intercalated with the leptites. The lump of skarn shown in the figure has been intersected by the basic dyke whose boundary lines are at places still discernible also within the skarn.

In general, however, both rocks have been welded together in such a way as to obliterate the outlines of the dyke, obviously because the similarity of the composition of the minerals has allowed them to react upon each other. The sharpness of the boundary between the metabasalt and the granitic gneiss, in most places, shows that no reaction between them has occurred. We are thus able to state that the metamorphic and ultrametamorphic changes may be dependent on the similarity, or difference in chemical character. There was a certain adversity between rocks of basaltic and granitic compos-

Fig. 28. Dyke of metabasalt intersecting gneissose granite which has been granitized at the same time with the dyke. Manngrund in Ingå. C:a 1 : 60 nat. size.

ition, also under the conditions which prevailed at the time when these strong changes took place.

The petrological character of the basic dykes of Lövgrund is identical with that of the dyke rocks in several other localities and will be described subsequently. The absence of aphanitic contact zones and all other similar primary characters in the dykes of Lövgrund, is an evidence of the strength of the metamorphism which they have undergone and which has to such an extent obliterated the original characters of the dyke rock in this locality.

THE BASIC DYKE OF MANNGRUND.

The island of Manngrund, one km N. of Bågaskär, consists partly of porphyritic granite, described on pp. 10—12, partly of gabbroid rocks connected with it, and red Hangö granite penetrating the older rocks in manifold ways, often very intimately.

Fig. 28 shows a basic rock forming a narrow zone, at all sides surrounded by granites. It was originally, no doubt, a dyke of metabasalt, intersecting the gneissose granite, in a direction vertical to its parallel texture. Later, however, both were injected by aplitic veins belonging to the Hangö granite which very intimately permeated the older rocks, so as to change both of them to migmatites. Here the penetration of the aplite into the metabasalt is as intimate as it is in the extremest cases previously described from the Hangö region.

METABASALTIC DYKES OF GRANÖ.

About 2 km further west we observe again, on the southern shore of the island of Granö, another case where the penetration has been in part almost as intimate as at Lövgrund but where still more of the primary features are occasionally preserved, leaving no doubt about the dyke character of the dark basic rocks. Fig. 29 is a drawing of the rock surface showing these dykes.

The oldest granite here possesses a very well developed gneissose character. This granite was later intersected by a number of narrow metabasaltic veins and one broader dyke (Fig. 29). Some of them intersect each other, and their relative age can therefore be determined. The oldest of them follow the parallel texture of the gneissose granite. They are very narrow and show an almost aphanitic texture. They were obviously originally glassy. These veins are cut by other narrow veins which intersect the parallel texture of the gneiss. Some of them show a zonar structure, being darker in the middle and showing lighter contact zones.

The broader dyke on the right side of the drawing also intersects the prevailing direction of the gneissose structure transversely, but it is possible that this structure here originated after the formation of the dykes.

Both the gneissose granite and the dykes suffered very strong changes at the intrusion of a later granite which occurs here partly as well defined narrow, straight aplitic dykes, but partly also as a network of veins which have more intimately permeated the grey granite. The basic dykes were then faulted and in part changed into rows of scattered fragments. This is especially the case with the broadest dyke, which lay in a direction that caused it to suffer more from these movements.

This locality is interesting because the changes at the time of the injection of the younger granite were very strong and yet the dyke character is so well preserved.

PETROLOGICAL DESCRIPTION OF THE METABASALTIC DYKE ROCKS.

Most of the basic dyke rocks consist of the following minerals: plagioclase, amphibole, biotite, ore (sometimes scarce or wanting), commonly also apatite and titanite. Some varieties are characterized by rather high proportions of diopsidic pyroxene. All these minerals, also the last mentioned, are of secondary origin in their present constitution, although the plagioclase grains may still in part occupy the places of the primary plagioclase laths, and the diopside possibly that of the original augite, the outlines of which must in any case have been entirely different.

We shall first describe some of the varieties containing diopside.

A thin section of the rock of the lightest dyke in Påvskärs Westgrund (cf. fig. 15) is shown in fig. 6, Plate II. The plagioclase is rather rich in Ab (andesine with An 36). There is something in its arrangement which somewhat reminds one of the original texture which was probably ophitic, but the plagioclase is now subdivided into a number of smaller grains. Between them lie small rounded crystals

Fig. 29. Gneissose granite intersected by numerous dykes of metabasalt which have in their turn been intersected by veins of aplite and in part strongly faulted. N. shore of Granö near Bågaskär in Ingå. 1 : 100 nat. size.

of diopside and bigger crystals of hornblende with more irregular outlines which are strongly pleochroic in brownish-green colours, brown biotite and minute grains of ore. On the whole the texture is rather similar to that of a hornfels, although much coarser than that usually is. In some places there are bigger crystals of pyroxene which have however the same secondary origin as the smaller grains. Both are analogous to those pyroxenes which we find e. g. in coronas in basaltic and gabbroid rocks and whose secondary origin is not doubtful.

The rock from the midst of the broadest dyke in Påvskärs Westgrund (fig. 1, Plate III) is rather similar to that of the rock just described. The plagioclase is richer in Ab (an andesine with An 30) than in the former case, and the hornblende is scarcer in quantity. Also here some of the pyroxene crystals are bigger than the rest of them. The ore is often entirely xenomorphic towards the metasilicates.

Similar to the above described is also the rock of the broadest dyke in the eastern part of Påvskär (Fig. 2, Plate III). The plagioclase, which is an andesine (An 35), occurs as irregularly shaped crystals. Between them lie well developed crystals of diopside, flakes of biotite, green, strongly pleochroic hornblende, and ore which is often xenomorphic.

If, again, we scrutinize the rock of the fine-grained contact zone of the broadest dyke in Påvskärs Westgrund, we find a composition (Fig. 3, Plate III)which is very different from that of the middle part of the dyke. The rock contains no pyroxene, but is composed of andesine (An 30), hornblende, biotite and titanite in minute crystals. Ore is absent from this rock. The hornblende is green, actinolitic, and forms rather compact crystals; sometimes, however, it has more irregular outlines and occurs also as minute needles in the plagioclase.

The narrowest metabasaltic vein of the same small island (Fig. 4, Plate III) has a similar composition, but it contains much ore, and the hornblende is here very strongly pleochroic in a dark brownish-green to green colour. The plagioclase is an andesine (An 37). The rocks shows a distinct parallel texture, caused by the parallel arrangement of the dark minerals, especially of rows of biotite.

The rock from the midst of the darkest dyke on the same small island (Fig. 5, Plate III) has a similar composition, but the brownish green hornblende is here still more abundant, while ore is scarcer and plagioclase occurs only in half of the quantity of the hornblende. It is an oligoclase (An 25). All the minerals are compact and possess rather irregular forms. There is nothing left of the primary texture.

The metabasalt from the broad dyke, shown in fig. 16, in the western part of Påvskär (Fig. 6, Plate III) shows macroscopically rather distinct remains of the original ophitic texture. Microscopically there is also something in the arrangement of the remaining patches of plagioclase which indicates the former places of the plagioclase laths. This is an oligoclase (An 23). The present plagioclase grains, however, do not possess the same optical orientation. Scattered between each of these original laths and in part intergrown with them, irregular crystals of green actinolitic hornblende, biotite and ore occur, of which hornblende occurs in the greatest and ore only in small quantity.

The metabasalt from one of the dykes in Granö shown in Fig. 29, has a similar composition, only with the difference that it shows a distinct parallel texture (Fig. 1, Plate IV). The plagioclase is an andesine (An 30). The green actinolitic hornblende forms elongated crystals which are arranged in a parallel direction. Biotite is scarce. Titanite occurs as small grains.

Lastly we will give the description of the rock from the narrow dyke in Lövgrund shown in fig. 28. Its microscopical composition is shown in fig. 2, Plate IV. The plagioclase is here an andesine (An 30). Quartz is also present, in small grains, and seems to have corroded the other constituents. The hornblende is actinolitic, with prevailing green colours, changing into light brownish-green. It forms stalk-like crystals with very irregular outlines. The biotite has also irregular forms. Ore is very scarce. Titanite occurs as rounded crystals. A few grains of calcite have been observed. The texture is characterized by the parallel arrangement of the constituents, especially of the hornblende crystals. This rock has a much more gneissose character than the other metabasaltic rocks described above.

With the aid of the Rosiwal method, the relative quantities of the minerals in a number of the dyke rocks from Påvskärs Westgrund have been determined. The result is given in Table VIII which also gives the specific gravities of these rocks, determined with the aid of a hydrargyrum pychnometer by Dr. A. H. Frauenfelder (the porosity was disregarded).

A glance at this table and also at the descriptions of the rocks given above, shows how varying is the mineral composition of these metabasaltic rocks, even of those specimens which are taken from different parts of the same dyke, viz. the broadest dyke of Påvskärs Westgrund.

Analyses were therefore made of the last mentioned rocks, with the results communicated in Tables VI and VII.

Table VI.

Metabasalt from the middle of the broadest dyke on Påvskärs Westgrund.

Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm:	
SiO_2	48.43	807	Or	8.34
TiO_2	2.04	25	Ab	22.53
Al_2O_3	16.89	166	An	30.02
Fe_2O_3	0	—		60.89
FeO	11.78	164	Di	11.86
MnO	Traces	—	Hy	3.32
MgO	6.85	171	Ol	19.02
CaO	8.92	159	Il	3.80
Na_2O	2.64	43	Ap	1.34
K_2O	1.36	15	Py	0.36
P_2O_5	0.61	4		39.70
S	0.23	7	S:a	100.59
H_2O	0.86			
	100.61			

III, 5, 2, 4, Kilauose.

The parameters in Niggli's system are the following:

si = 112, al = 23, fm = 47, c = 22, alk = 8, k = .26, mg = .51, ti = 3.9, p = .55, qz = — 20.

It is a gabbroid-gabbrodioritic magma type.

The parameters in Niggli's system are the following:
It is a gabbroid-gabbrodioritic magma type.

As seen from these tables, the chemical composition of both rocks is very nearly identical. Especially the Niggli formulæ of both show

Table VII.

Metabasalt from the contact zone of the broadest dyke on Påvskärs Westgrund.
Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm:	
SiO_2	46.96	783	Or	5.00
TiO_2	3.24	40	Ab	23.58
Al_2O_3	16.02	157	An	28.63
Fe_2O_3	2.05	13		57.21
FeO	9.63	133	Di	13.50
MgO	6.30	157	Hy	11.46
CaO	9.11	163	Ol	4.50
Na_2O	2.79	45	Mt	3.02
K_2O	0.82	9	Il	6.08
P_2O_5	0.64	4	Ap	1.34
S	0.17	5	Pyr	0.24
H_2O	2.28			40.14
	100.01		S:a	97.35

III, 5, 2, 4, Kilauose.

si = 112, al = 22.5, fm = 46, c = 23.5, alk = 8, k = .17, mg = .50, ti = 5.7, p = .57, qz = — 20.

how extremely slight are the differences. Both the contact rock and that from the midst of the same dyke were originally typical basalts.

The great difference in their secondary mineral composition and in their texture cannot have been caused by any difference in their chemical composition.

If we compare the dyke rocks from this and adjacent regions, we find that the most fine-grained varieties, which obviously were originally glassy, generally belong to those secondary types which are characterized by the combination of plagioclase, hornblende and biotite, commonly also with ore, while all those rocks which contain secondary diopside were originally more coarse-grained, probably entirely crystalline. In any case, when comparing the rocks in columns 2 and 3, Table VIII, we find that the generally accepted rule, according to which the secondary composition should be exclusively determined by chemical composition and the temperature and pressure prevailing during the metamorphism, cannot hold good.

Table VIII,

showing the quantitative composition of the Påvskär metabasalts, determined by the volumetric method.

	Lightest dyke of Påvskär Westgrund	Middle of the broadest dyke of Påvskärs Westgrund	Contact of the broadest dyke of Påvskärs Westgrund	Narrowest vein of Påvskärs Westgrund	Darkest dyke of Påvskärs Westgrund
Plagioclase	44.5	43.3	25.2	41.0	17.5
Diopside	26.5	14.6	—	—	—
Hornblende	21.4	34.4	64.4	44.9	73.2
Biotite	6.5	0.5	10.1	5.2	4.3
Magnetite and ilmenite	1.1	7.0	—	8.9	3.7
Apatite	—	0.2	—	—	1.3
Titanite	—	—	0.3	—	—
	100.0	100.0	100.0	100.0	100.0
Specific gravity	3.05	3.04	2.87	2.98	3.02

On the contrary, differences in the primary texture and mineral composition may, in rocks of identical or nearly identical chemical composition, be of influence even at very high grades of metamorphism.

Moreover we find, when comparing the specific gravities, that these cannot be explained by the »volume law», or the assumption that variations of pressure caused the original basalts to assume a higher specific weight during the metamorphism. The pyroxeniferous varieties are heavier than the rocks rich in hornblende, although both have been changed by the same conditions of pressure and temperature. We will return to this question later on.

THE GRANITES OF HANGÖ TYPE AT THE BARÖSUNDSFJÄRD AND N. OF IT, AND THE PTYGMATIC ARTERITES FORMED BY THEIR INJECTION INTO OLDER ROCKS.

Although the granites belonging to the Hangö group show a Protean variety, because of the varying amount of assimilated material, they posses, when they are less impure, a general character which is astonishingly uniform. Most of them are equigranular granites red in colour, but grey varieties also occur which are here represented N. of the Barösundsfjärd. All these granites are rich in microcline which shows a fine lattice lamellation and is usually intergrown with fine stringers of albite. The chemical character is also very uniform, with 72—74 per cent of silica, nearly 14 of alumina and 6 of potash. About a third part of the rocks is quartz, biotite forms only a small percentage, the rest being mainly felspar. Garnet is very often present in small amounts, sometimes also cordierite. These spots of garnet are sometimes intermingled with chlorite. Fluorite has not been observed in the granites of this group. They are usually very hard. The jointing and the rift are irregular, and the rocks are therefore subdivided into blocks greatly varying in size and form.

THE HANGÖ—INGÅ GRANITE.

The Hangö (or Hangö—Ingå) granite occurs nowhere in a more typical form than in Ingå in the region N.W. of the Barösundsfjärd, especially near the station Täckter on the Helsingfors—Åbo railroad and at Sonasund and Svenviken on the sea-shore. At all these places the granite has been quarried for building and monumental purposes.

Here this granite is even more typical than the granite of Hangö which is generally regarded as the type for those rocks, because the latter always shows »ghostly remnants» of older, gneissose granites or leptites, which were originally included as fragments and have been more or less completely digested. Even the Ingå granites usually show slight traces of this »nebulitic» structure, but they are in some cases almost imperceptible. Then, the rock has the character of a massive (»homophanous») granite and cannot be called gneissose. There occur, however, continual gradations between this granite and migmatites in which a schistose constituent becomes more and more preponderant.

The Ingå granite, such as outcrops in the quarries of Täckter, Sonasund and Svenviken, is equigranular. It has a rather vivid red colour, caused by the preponderance of red microcline. The quartz is light grey, and the black mica is not present in any very great quantity. Chemically it has almost the same composition (cf. Table IX) as the granites from Hangö and Skarvkyrkan, E. of that town, and of Perniö (Bjernå).

Table IX.

Granite belonging to the Hangö—Ingå group, from Svenviken in Ingå.

Analyzed by Allan Zilliacus.

	%	Mol prop.	Norm:	
SiO	74.76	1 246	Q	32.76
TiO	0.02	—	Or	27.24
Al_2O_3	13.37	131	Ab	30.92
Fe_2O_3	0.72	4	An	5.56
FeO	0.86	12	C	0.31
MnO	0.01	—	Sal	96.79
MgO	0.23	4		
CaO	1.11	20	Hy	2.03
Na_2O	3.65	59	Mt	0.93
K_2O	4.62	49	Fem	2.96
P_2O_5	Traces	—	S:a	99.75
S	0.04	1		
H_2O +	0.50			
	99.89			

I, 4, 2, 3, Toscanose.

The place in P. Niggli's system is determined by the following values:
si = 442, al = 46.5, fm = 8.5, c = 7, alk = 38, k =. 45, mg =. 46, ti = 0, p = 0, qz = + 190.

As already mentioned, the rock consists mainly of felspar and quartz, with a rather small amount of biotite.

Among the greater felspar crystals microcline is preponderant. It shows a fine lattice lamellation which is somewhat irregular and has obviously been influenced by pressure. Some of the microcline crystals are xenomorphic towards others and it seems obvious that they crystallized later than the former. There is even a microcline which seems to be later than the plagioclase and which occasionally forms rounded patches in that mineral. It may even replace part of the plagioclase of the myrmekite. It is generally clearer than the other part of the microcline and does not show a microperthitic intergrowth with albite.

Otherwise the microcline commonly contains narrow stringers of albite in microperthitic intergrowth. This mineral gives the impression of having crystallized in narrow cracks in the microcline. Minute inclusions of rounded, droplike forms also occasionally occur.

Oligoclase is always present as small crystals which crystallized before the microcline and are occasionally included in its mass. The plagioclase is as usual surrounded by fringes of myrmekite when bordering on microcline. Albite sometimes forms narrow fringes on the microcline crystals, and then myrmekite may occur as their continuation, growing into the adjacent microcline. (Fig. 4, Plate IV).

The quartz is generally xenomorphic towards the felspar. The microcline often shows barbed outlines towards the quartz. At some places cavities formed by resorption and filled with quartz reach far into the felspar, and it is obvious that a great number of the rounded quartz grains which occur included in the microcline are due to corrosion. Such felspars including rounded grains of quartz have often been designated poikilitic. G. H. Williams defined the poikilitic structure as »conditioned by comparatively large individuals of one mineral enveloping smaller individuals of other minerals, which have no regular arrangement to one another or to their host».[1] As a result of the examples of minerals showing this texture, e. g. the mottled hornblende of the »Schillerfels» from Baste in Germany, the intergrowths of felspar and quartz in effusive granitic rocks, and of his quotations from other memoirs, it becomes evident that this term refers to cases where the host mineral really envelopes, i. e. includes the grains of the smaller mineral, but not to such a case as the present where the apparently included grains are only the farthest ends of resorption cavities filled by a mineral deposited later. This is only a special case of what French petrographers have called »quartz de corrosion» (Fig. 3, Plate IV). The microcline has in part been crushed, in this case showing in polarized light a very varying extinction. Narrow shearing zones filled with small grains of felspar and quartz intersect the greater felspars and were obviously formed by movements in the rock, at a time when it was already at least in great part solid. (Fig. 5, Plate IV) The biotite, too, occurs in part as flakes in these shearing zones, but there are also greater crystals of biotite which lie between the other minerals. They are sometimes xenomorphic even towards the quartz, while they protrude in other cases into the crystals of microcline. Small grains of red garnet occasionally occur. In some of them there are fissures filled with chlorite.

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[1] G. H. Williams, On the Use of the terms Poikilitic and Micropoikilitic in Petrography. Journ. of Geol. Vol. I, p. 179.

The shearing zones do not intersect all minerals, but seem in some places to end at the border of greater quartz grains, or also continue only for a while into these, while the rest of the quartz shows only a undulatory extinction. This phenomenon gives the impression that the movements by which the shearing zones were formed took place before the final consolidation of the greater quartz crystals. There are also other reasons for assuming that the mechanical changes in the minerals are mainly »protoclastic», or rather »deuteric», and not truly secondary. We will return to that question later on.

In association also with the Hangö granites red p o r p h y r i t i c granites occur, which are sometimes very typical.

Such rocks occur e. g. in the region around L a p p b ö l e in Haapajärvi, 15 km N. of the northern shore of the Barösundsfjärd. This granite belongs to the same type as those which Eskola has described as Perniö granites. It is a rather coarse rock where irregularly shaped microcline crystals measuring 2—3 cm form the porphyritic constituents and are surrounded by a mass rich in quartz and biotite. Plagioclase is not very abundant as separate crystals. Where it occurs, it shows fringes of myrmekite when bordering on microcline. The quartz has not been very much crushed. The biotite is often xenomorphic towards the other minerals, but when bordering on felspars it also shows fringed outlines, reminding one of these biotite-symplektites which originated under the same conditions as myrmekite. The outlines of the microcline are barbed where it borders on quartz, while the plagioclase shows more even contours towards the microcline, if no myrmekite has been formed.

This porphyritic red granite is macroscopically very similar to some varieties of the Bodom granites which will be subsequently described, but in the field they are well separated. The former pass by gradual transitions into the Hangö granites.

Another porphyritic granite belonging to the same group as the Lappböle granite outcrops S. W. of the lake of Vitträsk in Kyrkslätt. It has a light grey colour, and the porphyritic felspars have angular, not rounded outlines and lie more sparsely than in the Lappböle rock.

Microcline is also here prevalent among the felspar constituents. The crystals are often bent or broken, and, especially in this case, stringers of albite, in microperthitic intergrowth with the microcline, are abundant. Oligoclase occurs rather sparsely, and shows as usual myrmekitic border zones towards microcline. The quartz shows a very strongly undulatory extinction, and has in part been entirely drawn out. The biotite has often irregular contours, sometimes with fringes of a symplektitic intergrowth with quartz. Around greater crystals of biotite small flakes of muscovite occasionally occur, encroaching upon the biotite from the outside. They seem to be of later origin than the biotite.

The grey granites belonging to the Hangö group seem in general to contain muscovite more often then the red varieties. In granites of a deep red colour, as e. g. in the rapakivi granites, muscovite usually seems to be entirely absent. The presence of this mineral indicates the action of pneumatolytic agencies which often seem to have removed the last remains of iron oxides from the felspars.

When interpreting the formation of the minerals in the Hangö granites, we find how impossible it is here to apply the traditional idea that all minerals in an eruptive rock have been necessarily formed in one casting, so that no changes could have afterwards occurred, if a subsequent »dynamometamorphism» did not later set in.

In the present case, it seems very difficult to determine a definite sequence in the formation of the minerals. Although the quartz is in general of later formation than the felspar, there are cases where it seems uncertain whether it did not crystallize earlier. Microcline seems to have crystallized during the whole process of solidification of the rock, and to be in part even later than the formation of the myrmekite. The biotite has no very definite age, and it seems possible, even probable, that it existed during the whole time of the solidification of the rock. Where we find, in these granites, incompletely digested fragments of older, gneissose rocks, rows of mica always indicate the position of the former foliation, which fact seems to prove that at least part of these biotite crystals existed already before the younger granite penetrated the older rocks.

In the same way, the narrow zones which indicate shearing movements and which are in part filled with grains of felspar and quartz, or myrmekite, or quartz alone, often showing very strong traces of crushing, seem to have originated before the last epoch of the consolidation of the minerals, at least of the quartz. We will later on once more return to these questions.

Pegmatitic and aplitic dykes are everywhere connected with the Hangö granites, and often occur in very great quantities, injecting the older rocks and forming with them typical migmatites, also alone as larger masses S. E. of Bågaskär. They always contain microcline with the same characteristic lattice lamellation as the other granites of Hangö type. Their minerals, especially the quartz and the microcline, are generally very intimately intergrown. In the pegmatite tourmaline and other pneumatolytic minerals are often present.

An aplitic rock of this group occuring as a narrow vein cutting an old gabbro on Granö in Ingå, has been analyzed by Allan Zilliacus and shows a very extreme composition.

Table X.
Aplite from a vein on Granö in Ingå.
Analyzed by Allan Zilliacus.

	%	Mol prop.	Norm:		
SiO_2	78.04	1 301	Q		46.92
Al_2O_3	12.67	125	Or		25.58
FeO	0.35	5	Ab		14.67
MnO	Traces	—	An		9.45
MgO	0.09	2	C		1.73
CaO	2.08	37		Sal	98.35
Na_2O	1.74	28			
K_2O	4.31	46	Hy		0.86
P_2O_5	0.10	1	Ap		0.34
S	Traces			Fem	1.20
H_2O	0.35			S:a	99.55
	99.73				

I, 3, 2, 3, Tehamose.

The coordinates according to Niggli are as follows:
si = 536, al = 51.5, fm = 3, c = 15, alk = 30.5, k = .62, mg = .29. qz = + 314, c/fm = 5.

The mode, calculated from the chemical analysis, would be the following:

Quartz	47.3	%
Microcline	23.8	»
Labradorite	24.2	»
Biotite	2.5	»
Apatite	0.3	»
Surplus of Al_2O_3	1.3	»
	99.4	%

The rock, however, contains about 1.5 % of epidote, and the plagioclase is according to its optical character an andesine (An 30).

The microscopical texture of this rock is shown by fig. 6, Plate IV.

MIGMATITES OF HANGÖ GRANITE AND OLDER ROCKS.

These Hangö granites permeate, in the most intimate and intricate manner, all those rocks which are older. They intersect them as dykes, which often possess a pegmatitic or aplitic character, they form with them eruptive breccias, they inject them lit par lit, they penetrate them intimately so that no boundaries are visible. In such a way a great variety of migmatites originate. Some of them may even be called »polymigmatites», as they had already been once before injected with granitic magma.

In general, only those parts of the granitic masses which are forerunners of the eruption, or belong to its waning phases, form better defined dykes or veins. The main part of these granites form one continuous mass, and have soaked through the older rock masses, penetrated them »à tâche d'huile», to use again Termier's characteristic expression.

The older rock masses, i. e. those which existed at the time of the eruption of the Hangö granite, were to a large extent leptitic in character, but they have, in this special region, been mixed up with granites in such a degree as to make it often difficult to ascertain their original composition. Most of them no doubt had the same character as the leptitic rocks already described from the Bågaskär region. At some places also gneissose granites are observed as older constituents of the migmatites, and it is certain that the older rock masses had already in many places a migmatitic composition before the eruption of the metabasaltic dykes.

Where the granitization at the time of the eruption of the Hangö granite was more complete, an almost homophanous granite resulting, the basic dykes in general disappeared. Occasionally there may be observed, in the granite, fragment-like basic patches which may be the last relics of such dykes.

Where more is retained of the pre-granitic constituent, the basic dykes always appear, although they were in some cases very much changed during the granitization.

The island of Brändö Harun, S.E. of the island of Vormö, and the small island of Stickellandet, E. of the latter island, are the best localities for studying these migmatites, and especially also the origin of the »ptygmatic» folding. The rock is here a very typical migmatite with veins of red granite in a gneissose mass which is rich in biotite and therefore has a greyish colour. The greatest part of it was originally a leptite, although it is now often granitized to such a degree as to have received a composition nearing that of a granite. In part, it shows the leptitic character with the usual banding still well preserved. It is possible, although it cannot be fully ascertained, that also older granites may have at places entered into the composition of this migmatite. The leptite is in the purer parts often rather dark and rich in biotite. It is everywhere more or less mixed up with the granite which has in great quantities very intimately permeated the schist so as to form a composite rock. But also those portions which

Fig. 30. Strongly folded veins of pegmatite in a migmatite rich in leptite. Polished specimen from the W. shore of Brändö Harun in Ingå. C:a 1 : 2 nat. size.

are now so rich in felspar that the composition is nearly that of a granite, still retain a schistose texture. The darker parts of the leptite sometimes form fragments surrounded by more granitic portions, and their forms, sometimes showing ragged outlines, then give the impression that the schistose rocks have been torn in pieces. At other places a better preserved schist and a granite alternate »lit par lit».

These intimately connected migmatitic masses have later been penetrated by better separated veins of red aplite and pegmatite belonging to the same granite which have afterwards been folded (Figs. 30—39), often in the extremest degree.

The numerous dykes of metabasalt which are generally rather sharply defined against the other rocks, but in some cases contain numerous aplitic veins, especially at the margins, have also been drawn out and folded, sometimes almost in the same degree as the aplitic veins. Fig. 31 shows such a folded dyke from the western shore of

Fig. 31. Horizontal rock surface at the western shore of the island of Brändö Harun, showing a dyke of metabasalt (black) which has been strongly folded and mixed up with veins of pegmatite (dotted) which are also folded. C:a 1 : 250 nat size.

Fig. 32. Flatlying rock surface at the N. E. shore of the island of Brändö Harun in Ingå, showing a folded dyke of metabasalt, cutting leptitic rocks. C:a 1 : 12 nat. size.

the island. There is another similar folded basic dyke on the N.E. shore (fig. 32). Both these places lie at the water line and are clearly visible only at low water.

The folding took place before the final consolidation of the granitic magma, for the folded veins are often seen intersected by others which are straight, but otherwise show quite the same character of the minerals. In the continuation the straight veins may be slightly, sometimes even strongly folded.

Fig. 33. Veins of aplite showing ptygmatic folding and intersected by two straighter veins. E. shore of Stickellandet near Vormö in Ingå. 1 : 11 nat. size.

At the injection of a straight vein the older, folded veins have occasionally been faulted (fig. 35), sometimes so much that their continuation cannot be found at the opposite side of the intersecting vein. Often we find even more than two generations of veins. Not only veins, but also portions of the migmatite containing more or less assimilated patches of leptite are seen intersecting other portions of the migmatite, and its folded veins. The same veins of migmatite may again be cut by other aplitic veins. (figs. 33, 34, 36.)

When straight veins intersect portions of the leptite containing numerous folded veins, they may intermingle with them in such a manner as hardly to be recognized (fig. 33). There are even places where the bigger felspars of the folded veins have a continuation within the borders of the intersecting straighter veins, so that it is obvious that the last crystallization in both veins took place after the injection of the latest veins.

The explanation which the writer was earlier inclined to give of these phenomena was that the veins were folded while they were still entirely in a magmatic condition. But as the boundaries between the different generations of veins are in some cases very distinct, it is also possible that their material had in many cases crystallized, in part or completely, already before the formation of the intersecting veins, and that thus the continuation of the growth of the fel-

Fig. 34. Vein of aplite in a leptitic migmatite, more or less strongly folded and in part welded together. E. shore of Stickellandet near Vormö. 1 : 9 nat. size.

spars of the older veins into the younger ones is due to a recrystallization of the minerals or a part of them.

However, the ptygmatic folding cannot have taken place through movements of an alpine character, at an epoch when the surrounding rocks were entirely solid. The migmatite was so strongly folded beceause the rock masses were in a state approaching fluidity (cf. fig. 33).

The veins were probably all originally straight, filling fissures originated in the rock masses. It is quite compatible with the assumption that these masses were plastic, or potentially plastic, that ruptures may have taken place at sudden movements.

There are cases in which veins are branching, and then the different branches have been folded independently. In this particular case it seems still more obvious than elsewhere that they were originally straight.

Fig. 35. Veins of pegmatite which have been faulted at the injection of a younger vein. N. E. shore of the island of Brändö Harun. C:a 1 : 11 nat. size.

In general, the granitic veins are vertical, but there are others, as e. g. that shown in fig. 36, which have obviously filled fissures

Fig. 36. Folded veins of pegmatite in the migmatite of Brändö Harun, some of which have had a flatlying portion before the folding. C:a 1 : 20 nat. size.

that were originally in a nearly horizontal position. We observe also here that the veins which intersect each other belong to several generations.

Fig. 37. Veins of aplite showing ptygmatic folding. A little below the middle their limits are indistinct and partly obliterated. Vertical section. Polished specimen from the W. shore of Brändö Harun in Ingå. 1 : 3 nat. size.

Fig. 38. Vertical section of a migmatite with folded veins from Brändö Harun, cut 3 cm from the specimen shown in fig. 32 and parallel to it. In the lower parts the aplitic veins show falding outlines. 1: 3 nat. size.

The most striking evidence in favour of a primary origin of the folding is afforded by the phenomena shown in figs. 37—39. As we are aware, cloudlike portions of aplite gathered in the rock in an epoch subsequent to the folding of the veins. When comparing figs. 37 and 38, which show photographs of cuts through the same specimen at a distance of only 3 cm from each other, we find that the folded veins may be very distinctly preserved at one place, while they have entirely lost their outlines and merge into the cloudlike aplite at another place very near to the former.

Fig. 39. Folded veins of pegmatite which have in part been almost obliterated at the penetration of cloudlike portions of aplite. Horizontal surface at the W. shore of Brändö Harun in Ingå. C:a 1 : 8 nat. size.

The obliteration of the older veins is still more distinctly to be seen in fig. 39.

As seen in many of the examples given, the amount of compression of the rock containing the veins, at their folding, has often been very considerable. The same is true also as to the basic dykes.

Fig. 40 shows similar veins from the railroad station Täckter in Ingå, 14 km N.W. of the islands now in question. They have been compressed in such a degree that the thickness of the bundle is in part $^1/_6$ of the length of the veins which have been folded.

In 1913 the writer described these phenomena in an article in Neues Jahrbuch für Min. Geol. etc.[1] Spurr has since described similar folded veins from American gneisses[2] and found a compression of 50 to 30 per cent, and in some cases a proportion of 4 to 1. His figures are thus very similar to those of the present writer.

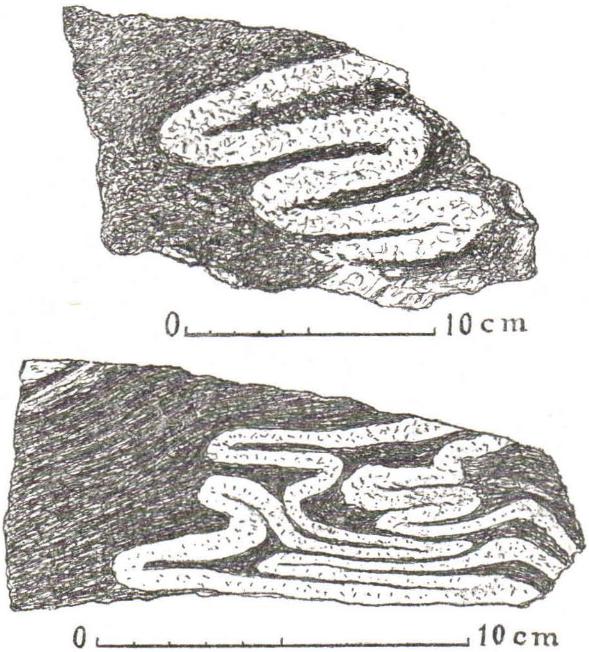

Fig. 40. Migmatite rich in leptite, containing veins of aplite which show strong ptygmatic folding. Polished slabs from a railroad cutting W. of Täckter, at the Helsingfors—Åbo railroad. Upper fig. 1 : 3, lower 1 : 2 nat. size.

At some places the material of the veins shows a slight differentiation of alternating basic and acid portions. Fig. 41 shows a vein on the western shore of Brändö Harun which intersects many of the folded veins but is itself also slightly folded. The vein has further a zonar structure, being pegmatitic at the contacts and aplitic in the midst. It contains stripes which are very rich in biotite and approach a lamprophyric composition. This rock has a very well developed schistosity, so that it resembles a mica-schist (Fig. 1, Plate V).

[1] J. J. Sederholm, Über ptygmatische Faltungen. N. Jahrb. Min. B.-Bd. 26, 1913, pp. 341—512.

[2] J. S. Spurr. The Ore Magmas, New York 1923, pp. 164—167.

It consists of biotite, oligoclase, microcline and quartz. The schistose texture must have originated before the vein was folded. The shearing is certainly not of secondary origin.

In the folded veins, we never observe any evidence of a proportionally strong mechanical change at the places where the veins are most strongly bent (fig. 42). If the folding were of alpine character, one would expect to observe a mechanical crushing of the minerals at least in such cases as are shown in figs. 30, 40 etc., where the

Fig. 41. Slightly folded vein of pegmatite, with aplitic zone at the middle and containing stripes rich in biotite. Horizontal rock surface at the shore of Brändö Harun in Ingå. C:a 1 : 10 nat. size.

breadth of the present system of folds is only from $\frac{1}{2}$ to $\frac{1}{6}$ of the total length of the veins before their folding. Also the schistose component of the migmatite shows no evidence of crushing (cf. fig. 43). The final crystallization has taken place after the folding.

Moreover, we have found similar folded veins of aplite, although only in exceptional cases, also in connection with the youngest granites of Finland, the rapakivi rocks, which have never taken part in any mountain making movements at all, and where they therefore cannot be explained as due to folding of an alpine character.[1]

However, if the material of the veins was in part solid already before their folding, it was at least potentially fluid, i. e. the granite was probably resolved and recrystallized in such a degree as to oblit-

[1] Cf. l. c. p. 497 and Migmatites I, p. 87.

Fig. 42. Aplite from a folded vein in the migmatite of Täckter (Fig. 35) at the place where the folding is strongest. No phenomena of cataclasis are visible. Crossed nicols. 15 ×.

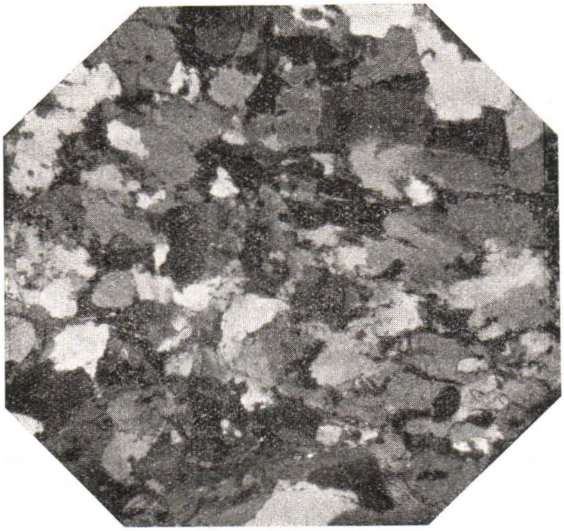

Fig. 43. Schistose component of the migmatite of Täckter. Crossed nicols. 20 ×.

erate all mechanical changes which may have taken place during the folding. This explains the fact noted previously that the minerals of the veins continued their growth into the neighbouring rock even after the time of the folding.

A curious feature is the rather uniform breadth of many veins, at places where they are folded and where they are not. One would rather expect the veins to vary greatly in thickness at different places where they have been more and where they have been less strongly folded. In some cases that has really taken place, so that parts of

Fig. 44. Serpentinizing streaks of foam in the Vrangfossen rapids, Telemarken, Norway.

the veins have been drawn out into the thinnest sheets, looking like files in sections transverse to the axes of the folds (cf. figs. 33—36), but in other cases we do not observe any marked difference. It seems possible that the folding movement which has changed the veins has been very slow and that they hereby have acted in a certain way as drains on the magma pervading the surrounding rock. Thus every crack or every zone of weakness that originated in the minerals of the veins may have been healed and they have thus retained their breadth or even been widened. We are thus aware that the folding is, in many ways, not comparable to that which occurs in solid rocks, nor exactly to the fluidal movements common in glassy rocks. This is the reason why the writer has thought it necessary to give it a special name, calling it p t y g m a t i c.

However, it is evident that the phenomenon in question has more affinity to fluidal movements than to the typical folding of solid rocks. A colleague of the writer, Mr. O. Trüstedt, has called his attention to the analogy in appearance which is shown by stripes of foam in rapids, especially at places below waterfalls. Mr. Trüstedt has communicated the photograph shown in Fig. 44, taken at Vrangfossen, Telemarken, in Norway. Now it is true that these foam stripes lie at the surface of the water, and have accumulated by the action of waves and currents. In spite of this difference as to their first origin, there is some analogy with the ptygmatic folding. In both cases

Fig. 45. Vertical surface showing striation indicating movements of the rock masses at the end of their solidification. E. shore of Brändö Harun in Ingå.

there ought to have been an undulating action caused by movements to and fro, or by a different velocity of the current in different places. A similar undulation may be seen in thin films of oil covering moving water, for instance in the gutters of a city.

It is difficult to give an adequate idea of the fascinating phenomena treated here by mere description, and a few photographs. They ought to be seen in the field, among the naked rocks of the archipelago. There the evidence in favour of the explanation given here seems to be overwhelming, and every endeavour to explain the phenomenon as folding of alpine character, as Sander has tried to do,[1] will meet with insuperable difficulties.

At many places movements have taken place in the rock masses at a time when the rock was already entirely solidified, giving rise

[1] B. Sander, Studienreisen im Grundgebirge Finnlands. Verh. Geol. Reichsanst. Wien 1914.

to striæ on the walls of the fracture, indicating the direction of the movements. The gliding planes, which may be cased with quartz etc., are in the main parallel with the schistosity of the rocks and often follow boundaries between rocks of different composition. This phenomenon is seen in fig. 45, which shows a striated surface, striking N.40° E. and dipping 80° S., at the boundary between a metabasaltic dyke and the granite on its northern side. The striæ dip 60° to the east. It is the same phenomenon which has been described by Cloos from Silesia[1].

Fig. 46. Migmatite consisting of leptitic components and aplitic veins, some of which are garnetiferous. Northern shore of Vormö in Ingå, near the pier (The photograph has been slightly retouched by the phototypist). C:a 1 : 10 nat. size.

The migmatites consisting of leptitic rocks mixed with veins of Hangö granite are often rich in g a r n e t s. This garnet is usually an almandine. Those garnetiferous migmatites are especially common among the rocks of Vormö, e. g. near to the pier at the northern shore. As is shown by fig. 46, the garnets are especially numerous in those aplitic veins which have been the last to solidify, while the portions consisting of leptitic rocks are free from garnets.

Garnets occur, elsewhere too, in the rocks of the same islands, with preference in the aplitic veins, but are often very irregularly

[1] Hans Cloos, Streckung und Rutschstreifen im Granit von Zobten in Schlesien. Abh. Preuss. geol. Landesanst. N. Folge. Bd. 89, 1922.

dispersed. Sometimes they occur as greater patches, sometimes as groups of small grains whose arrangement reminds one of dendritic structures. The more fine-grained garnetiferous rocks have a certain resemblance to some »granulites» of Lapland and Saxony, although the latter are commonly still more fine-grained and also more schistose.

HAS THE HANGÖ GRANITE BEEN SUBJECT TO METAMORPHISM?

We will once more return to the question whether, or in what measure, the granites of Hangö type show any phenomena that may be called metamorphic or cataclastic. This problem has long been discussed, and it has been somewhat difficult, also for the present writer, to arrive at a definite conception. He already thirty years ago emphasized the fact that the parallel texture of these granites is never due to dynamometamorphism s t r i c t e s e n s u. The rows of mica which often give to the granite a gneissose texture have not been deposited in trituration zones formed during mountain making processes acting on solid rocks. They are in most cases remains of older schistose rocks which have been assimilated by the magma.

Another question is whether the individual minerals of these granites have suffered any secondary changes. Eskola thinks that their texture is a true texture of consolidation, with no secondary features, and especially regards the undulatory extinction of the quartz as a primary phenomenon, due to the unequal contraction of the minerals during the consolidation of the rock.[1]

The present writer is more inclined to regard the phenomenon, in this particular case, as due to a real cataclasis, and in fact such a texture as, e. g., that shown in fig. 5, Plate IV, can hardly be explained otherwise than by a fracturation of the minerals of a rock mass that had already solidified. There are portions of these rocks where the minerals have been really mylonitized, and judging from the microscopical sections the crushing may as well here, as in any other rock, be designated cataclastic, or »dynamometamorphic».

There is often, perhaps, rather a difference of expression than of opinion. The terms are inadequate to give a full idea of what has taken place. The inference drawn from the above, is that these phenomena are not truly secondary, but due to movements which

[1] P. Eskola, On the Petrology of the Orijärvi Region in Southwestern Finland. Bull. Comm. géol. Finl. N:o 40, pp. 24—27.

took place before the consolidation of the last portions of the magma of the Hangö granite. In some cases a recrystallization of certain minerals occurred after the formation of the fracturation zones. Occasionally even mineral grains which exhibit quite a primary character seem to have crystallized after the crushing took place. The rock is not the result of one consolidation of the magma (which should have in some cases been followed by movements in solid rock), but to a complicated series of events during which injection and consolidation, crushing and healing, have repeatedly occurred. No mechanical or mineral changes can be called truly secondary here, some of them may be described as »deuteric» in the sense defined by the writer, but there are also such movements as may rather be termed »protoclastic». If these phenomena are to be called metamorphic, they should rather be ascribed to an »autometamorphism» than to a subsequent »regional metamorphism». In some cases they might be designated as »protometamorphic», in others as »deuterometamorphic». But even if we burdened the nomenclature with the most numerous terms, we could not adequately define all these complicated processes all of which fall, however, within the wide realm of anatexis. What we have to get rid of, is the old schematical idea of crystallization processes of the granitic magmas at great depth according to the same regular scheme as determines the solidification of a lava, or a dry acid magma rapidly cooling near to the surface, where all minerals are formed in one casting. At greater depth, eruptive and metamorphic processes overlap, and rocks of different character and different age blend into each other. The petrologist cannot here command the rocks to behave decently and regularly, by following laboratory laws, but has before everything to learn, by a careful study, the often labyrinthian ways of nature.

THE PETROLOGY OF THE PALINGENETIC CHANGES.

The question now arises as to what conditions prevailed in the older granite when it was *in statu renascendi*, and whether it is possible to follow the changes which it underwent, with the aid of the microscope.

It is impossible to think that by the fracturation of the dyke rock shown in fig. 18, open fissures were formed. At the depth where granitic veins are formed, certainly a *horror vacui* prevails. Thus the fissures ought to have been gradually filled with granitic material in the same measure as they were opened. At the beginning, each vein was very narrow and became gradually thicker by the influx of more material from the sides. As no brecciated structure or any seams against the adjacent granite are visible, the granite ought to have been able to flow.

But, on the other hand, the preservation of delicate structures at other places in the same granite shows that great portions have been immobile since they solidified. Thus there was only a latent fluidity which led to a motion when the pressure was locally relieved. The movement was of the same character as that of redhot iron which may be wrought into different shapes without showing any flaw. It is necessary to think that a recrystallization has taken place, but where the palingenetic granite possessed the same chemical position as the older one, and the recrystallization took place under similar conditions as to temperature and pressure, the recrystallized rock may have become rather similar to the old one.

Table XI.

	Average of 4 analyses of typical granites of the Hangö group, calculated as waterfree and reduced to 100.	Average of 7 analyses of gneissose granites from southwestern Finland reduced to 100.	Differences between these averages.
SiO_2	74.10	71.92	+2.16
TiO_2	0.16	0.34	—0.18
Al_2O_3	13.88	13.90	—0.02
Fe_2O_3	0.64	0.67	—0.03
FeO	1.13	2.60	—1.47
MnO	0.01	0.06	—0.05
MgO	0.38	1.12	—0.74
CaO	1.24	3.13	—1.89
Na_2O	2.71	3.94	—1.23
K_2O	5.72	2.12	+3.60
P_2O_5	0.03	0.20	—0.17
S:a	100.00	100.00	± 5.76

Table XI, column 1, gives the average of the 4 analyses of typical Hangö granites which have been hitherto made. For comparison, we give the average of the older granites in column 2, and in column 3 the amounts which ought to be added, or subtracted, from the latter average in order to give the former. As we are aware, the deficiencies are in SiO_2 and K_2O, of which altogether 5.76 per cent ought to be added, while the same amount of femic constituents, and soda, are to be subtracted. The amount of alumina has remained unchanged. An addition of aplitic »juices» rich in potassium silicate, or a subtraction of such constituents as would yield a basalt, or a lamprophyre, would effect the change.

Now, the rock masses which have undergone anatexis were not composed exclusively of older granites, but also of leptites and other rocks of which some possessed an andesitic, or even a basaltic composition. This necessitated the transfer of larger amounts of the materials which were interchanged, but on the whole the chemical process has been of the character outlined.

Chemically, the anatexis may be described, in this case, as an ultrametasomatosis. The result at which we have arrived is in harmony with that obtained by V. M. Goldschmidt in his study of Norwegian arterites.

It will of course always be difficult to follow this process, which has been so destructive of the old mineral composition of the rock and of its former texture. It is only if we can find any relict minerals of the older rock still preserved, that we may be able to follow the progress of the changes or their forms retained in pseudomorphs.

The best place for studying, also petrologically, the change of the older gneissose granite into a Hangö granite, is Påvskär.

A microscopical study was made of a rock series showing every gradation from the grey gneissose oligoclase granite, through a reddish granite still retaining a distinct parallel texture, to a typical Hangö granite rich in microcline. These specimens were taken from a place near to that metabasaltic dyke described on p. 47 which shows no trace of primary structures. Anyhow, the dyke rock ought to have suffered a complete recrystallisation, and the same is a fortiori true as to the granite which was much less refractory to the influence of the granitic juices.

The gneissose granites are richer in biotite and plagioclase, while the granite of Hangö type as usual is characterized by its richness in microcline.

Those varieties which macroscopically still show more of the characters of the original gneissose granite, are richest in plagioclase in which, however, the antiperthitic intergrowth is but seldom visible. The hornblende has disappeared, and instead of that we find only biotite and chlorite (Fig. 2, Plate V). The latter mineral is not secondary, and where it occurs together with biotite, it seems probable that this mineral is later than the chlorite. The occurrence of the chlorite, which is often surrounded by grains of quartz, seems to indicate that at least the initial stages of the anatexis have been characterized by low temperature and a high amount of water.

The interpositions in the felspar, especially also the antiperthitic texture, and all those features in the gneissose granite which indicate cataclastic changes of the minerals, have in part disappeared. The quartz has especially in the red varieties, more similar to Hangö granite, a uniform optical orientation, its fractures having obviously been healed.

The microcline shows resorption cavities of which one visible in fig. 3, Plate V, has been partly filled by biotite, after which the rest of the cavity has been filled up by quartz.

There are, in some cases, also cataclastic phenomena which seem to be later than the penetration of the younger granitic magma. The bigger microcline crystals may be pentrated by narrow zones of small mineral grains, indicating a beginning of mortar structure (Fig. 4, Plate V) and the lamellæ of the oligoclase crystals may also be bent (Fig. 5, Plate V).

In some cases the texture is rather gneissoid (Fig. 6, Plate V) with rounded crystals of felspar cemented by quartz in rather great quantity.

THE ›GRANITIC JUICES.»

The opinions of the writer have developed in such a direction that he is inclined to ascribe more and more importance to the granitic exudations or »granitic juices», or what has been designated by French geologists as l e s m i n é r a l i s a t e u r s, an expression which has, however, not exactly the same meaning. The ideas which Goldschmidt developed in his memoir on the veined gneisses of western Norway[1], as well as Niggli's important researches, have also led to the same result, i. e. to emphasize the importance of the solutions, or gases, associated with the granitic magma.

The commonly used expression »juices» as a designation of the exudations from granitic magmas is, however, not very adequate, because it refers to a very vague analogy with processes in the vegetable kingdom from which in general terms have not been borrowed for petrology. It would be well to discover a better term covering these phenomena which are so often discussed.

There are two ways of developing a nomenclature for these things, one by creating terms designating the processes, the other

[1] V. M. Goldschmidt, Die Injektionsmetamorphose im Stavangergebiet. Vid. Selsk. Skrifter. Kristiania 1920. Nr. 10.

by forming names of the concrete things which exist or are supposed to have existed.

Colony has proposed to describe the aplitisation of rocks as a deuterization,[1] thus widening the sense of the term deuteric, proposed by the present writer as a designation of metamorphic changes which are not truly secondary, so as to cover a petrological process or what is generally called aplitization. Now it is true that the Greek word deutera also means afterbirth, and therefore might give a suggestion of processes following the eruption of a magma. But, on the one hand, the aplitic veins are not always later than the solidification of the main part of the magma, but may also have originated at a very early epoch of the eruptive activity, and, on the other hand, the word deuteric has already got another sense, defined by the present writer, and cannot therefore be freely used in a different meaning by another author.

The process of the formation of exudations from the granitic magma might properly be called a diaphoresis, whereby physicians name certain processes of exudation, if this word were not too similar to Becke's diaphtoresis. Instead of that anaphoresis might be used, but it has also its drawbacks. In general, it seems more necessary to possess terms which cover phenomena or things observed, than such designating the process. Now many petrological terms refer to a certain analogy between the molten magmas of the earth and the blood of the human body. Such a word is consanguinity. In the same way, the present writer has used the word arterite, and he also pointed out, some years ago, that there may be a granitic magma, or granitic juices, also of »venous» character, although, in the absence of a heart and separate vein systems, this magma is usually apt to be mingled with the »arteric» magma.[2] Holmqvist has since developed the same idea in creating the term venite for some of the veined gneisses which the writer calls arterites, but in which, as Holmquist thinks, the veins could be proved to be exudations from the adjacent rocks, not necessarily having any connection with a deep-seated eruptive granitic magma.[3]

In all cases studied by the writer the existence of such a connection can be proved, or seems probable. Holmquist's term is,

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[1] R. J. Colony, The Final Consolidation Phenomena in the Crystallization of Igneous Rocks. Journ. Geol. Vol. 31, 1923, pp. 169—178.

[2] J. J. Sederholm, Gneisfrågan och andra urbergsspörsmål. Geol. För. Stockholm Förh. Bd. 30. 1908, p. 165.

[3] P. J. Holmquist, Typen und Nomenklatur der Adergesteine. Ibid. Bd. 43, 1921, pp. 612—631.

however, formed according to the same principles as the term arterite.

The writer later compared the granitic »juices» with the s e r u m of animal blood. This word could, however, hardly be used as a petrological term, but there is a corresponding Greek word i c h o r (Gr. ἴχωρ, serum, lymph, pus, also blood of the gods) and this seems to be a good expression. The writer thus proposes to introduce, instead of the word granitic juices, the term granitic ichor, preliminarily with no more strictly defined signification than that possessed by the word juice. It will soon be possible, on a more detailed knowledge of the character and state of aggregation of this ichor, to give to the term a stricter definition. It need not be restricted to »juices» of granitic rocks, but may cover exudations from rocks of different composition, e. g. those which have permeated the neighbourhood of nepheline-syenites and similar rocks. In any case, it would not cover such gaseous matters transpiring from eruptive bodies as cause the typical pneumatolysis, where mainly fluor, boron, chlore, phosphore etc. have been exhalated, but mainly things showing gradations between an aqueous solution and a very diluted magma, eventually also a magma containing much water in a gaseous state.

If anybody approves of the general reasoning of the writer, but objects to the introduction of a new term, he may simply use the words s e r u m or l y m p h parabolically.

THE OBBNÄS AND BODOM GRANITES.

Immediately east of the Barösundsfjärd a rounded area of coarse porphyritic granite occurs which forms a great part of the forelands of Obbnäs and Porkkala and has therefore been called the Obbnäs area. It is rounded and has a long diameter of 15 km and a short of 5—6 km. To the southwest, there seems to be a continuation of this area under the surface of the sea, as the islands of Sommaröarna, on the outer side of the Barösundsfjärd 10 km from Obbnäs Udd, as well as some smaller islands between them and the coast, still consist of the same granite.

18 km more to the N.E. a similar area of granite occurs which is also rounded and sharply defined. It has almost the same size as the Obbnäs area, its length being 16 km and the breadth 4.5—6.5 km. The rock is here less coarse than in the Obbnäs area and only in part porphyritic, while over a great part of this area equigranular granites prevail. This area is not visible on the map.

As will follow from the subsequent detailed description, these granites are both petrologically and geologically distinguished from the older granites of the region and nearly related to each other. Both these rounded areas lie along, but on different sides, of a valley which is partly filled with lakes, and, as the author has shown elsewhere [1], must be regarded as indicating an old fracture line. Breccias with cement of quartz occur as boulders near to the S.W. part of this line. It cannot be decided with certainly whether the dislocation is posterior or anterior to the eruption of the granite.

In any case, both the direction of this valley and the longest axes of the granite areas follow the strike of the older gneissose and schistose rocks. The foliation of these older rocks has of course conditioned the »rift» of the rock masses. This circumstance may have caused the splits which followed the same main directions originated at different epochs.[2]

A genetic connection between both these granitic areas is in any case obvious, and we will therefore here describe them together.

THE OBBNÄS GRANITE.

The typical Obbnäs granite (cf. fig. 53) is a rather coarse-grained aggregate of red microcline, greyish white oligoclase, dark grey quartz and black biotite. It has in a polished surface a lively and beautiful colour. It is very similar to one of the red varieties of the coarse Graversfors granite of Sweden which is well known as a monumental stone. The similarity is so great that both these granites might be used together in the same monument.

The greater felspar crystals consist of microcline and measure usually c:a 3, sometimes 4—5 cm in length. They are in part rounded, in part more irregular in form. The latter is still more true as to the smaller felspar crystals which partly consist of microcline, partly of oligoclase. The biotite forms well defined crystals between the felspars, and is accompanied by titanite, often forming unusually big crystals, of apatite, ore and small crystals of zircone.

[1] J. J. Sederholm, Weitere Mitteilungen über Bruchspalten. Bull. Comm. géol. Finl. N:o 37, 1913, p. 11.

[2] We still find analogies among much younger granites. Thus the area of rapakivi granite N. E. of Ladoga lies with its longer axis parallel to the strike of the »Ladogian» schists and to their contact with the gneissose granites of their basement, a boundary line which seems to have played a considerable role during different pre-Cambrian epochs.

There is a regular succession of crystallisation between the minerals. The oligoclase (An 25) shows idiomorphic crystal forms also when surrounded by microcline. In some cases the outlines are sinuous or dentated owing to the formation of deuteric plagioclase, or of myrmekite, encroaching upon the microcline. This myrmekite was formed at a late epoch. The microcline shows a beautiful lattice lamellation, much more regular than that observed in the microcline of the Hangö granite (cf. the figures). It is in a rather regular way intergrown with albitic stringers forming a microperthite.

The microcline is in general idiomorphic when bordering on biotite and quartz. The biotite is dark brown and strongly pleochroic and forms rather big crystals preferably lying between the felspars and is then entirely xenomorphic, but it has also often encroached upon the neighbouring plagioclases, occasionally in symplektitic intergrowth with quartz. Also a green compact hornblende often occurs. The quartz is in general xenomorphic and has corroded both the felspars and the biotite.

Small crystals of apatite and zircone and somewhat bigger ones of titanite are common, especially in the biotite, where they occasionally lie crowded.

Fluorite is almost always present, although sometimes in small quantities, lying between the other minerals.

The biotite crystals of the granite from the quarry near Obbnäs Gård contain intercalations of a light brown, almost colourless birefringent mineral with rather strong refraction (Fig. 1, Plate VI) which the writer has not been able to identify. It does not form crystals, but crystalline aggregates.

The rock minerals show signs of having suffered from the influence of pressure. The biotite lamellæ have been broken and bent (Fig. 2, Plate VI) and the quartz shows usually an undulatory extinction. Some portions have even been very strongly crushed, but there seems to have been practically no crystallization of minerals since this cataclasis, and the crushed portions have therefore not been healed and in that way thereby changed into grains with different optical orientation.

In 1909 Professor Pentti Eskola was kind enough to analyze the granite of Obbnäs with the result shown in Table XII.

When determining Niggli's coordinates, we get the following result:

si = 31, al = 39, fm = 21, c = 14, alk = 26, k = .64, mg = .22, ti = 1.6, qz = + 107.

Table XII.

Granite from the quarry near Obbnäs Gård.
Analyzed by Pentti Eskola.

	%	Mol. prop.	Norm	
SiO_2	68.40	1 140	Q	24.30
TiO_2	0.52	6	Or	36.47
Al_2O_3	14.57	143	Ab	18.14
FeO	0.87	5	An	12.79
Fe_2O_3	3.57	50	Sal	89.90
MnO	0.05	1		
MgO	0.72	18	Di	0.71
CaO	2.84	51	Hy	6.72
BaO	0.09	1	Mt	1.16
Na_2O	2.21	35	Il	0.90
K_2O	5.79	62	Ap	0.34
P_2O_5	0.25	1	Fem	9.89
H_2O+	0.12	—	S:a	99.79
H_2O-	0.56	—		
S:a	100.56			

1, 4, 1, 3, Liparose.

It is a granodioritic magma type, near to the granodiorite from Cristallina, Luckmanier, but somewhat richer in SiO_2 and K_2O and poorer in CaO.

The Obbnäs granite has a rather loose texture and is somewhat brittle. It has been used for structural purposes, a big quarry having been opened at Obbnäs Fjärd during the world war. The output was used for fortifications in Reval, but since the war this quarry has been lying idle.

The jointing of the rock is rather regular and subdivides the rock in rectangular parallelopipedic blocks some of which are of considerable size. The hills consisting of this granite are rather low, but often show rather steep declivities, especially on the southern side. Their forms are rather regular where they have not been deformed by a fissuring continued after the Ice Age, when the hills received their rounded and smoothed forms.

Macroscopically certain varieties of the Obbnäs granite may resemble, on the one hand, some rapakivi granites, but on the other hand also the porphyritic granites of the Hangö—Ingå Group, e. g.

that of Lappböle described on p. 66. For reasons to be stated, it is improbable that it has any genetical connection with either of these granites, and it also petrologically shows characters distinguishing it from both of them.

The granite of the Obbnäs area is in general very uniform in texture and mineral composition. Only next to the contacts the grain of the porphyritic variety may sometimes be less coarse. Occasionally varieties with a more brownish colour occur.

A middle-grained equigranular red granite occurs as narrow dykes traversing the main variety and also as somewhat greater masses next to the eastern boundary, in some hills near Gunnarskulla. This granite grades into the porphyritic variety. The minerals are similar to those of the latter, but the quartz is intergrown with the felspar and often still more strongly crushed than in the coarse granite. The same is true of the biotite. Myrmekite is sometimes abundant. Fluorite occurs also in these equigranular varieties.

A pegmatite which is genetically connected with the Obbnäs granite, also occurs both in this rock and as apophyses in the adjacent rock. The felspar and the quartz are often well segregated, so that the former may form the contact zones, and the latter the middle of the dyke. Or, the felspar may form porphyritic crystals entirely surrounded by quartz. This pegmatite is rather different from that of the Hangö granite where all the constituents are generally much more intimately intergrown.

Fragments of other rocks occur in the Obbnäs granite, but are usually not very numerous. In some places, especially near to the boundaries, they may be abundant, and these fragments show some very interesting phenomena.

They generally consist of a basic rock, which occasionally shows remnants of a parallel texture and then is very similar to the more basic portions of the »leptitic» rocks which have been parts of the roof of the batholith. The femic minerals of these fragments have obviously migrated so as to be concentrated in certain portions of the fragments which may thus be changed, in the midst or at one side, into dark rocks very rich in hornblende. Sometimes they are drawn out in tail-like protuberances consisting mainly of femic minerals.

In the big quarry at Obbnäs fjärden we find a number of such fragments which consist of just such a massive basic rock, which entirely resembles, however, the most basic portions of the leptitic fragments. This rock is microscopically very interesting. The dark minerals consist of a light greenish monosymmetric pyroxene, green strongly pleochroic hornblende and biotite. These minerals are all intergrown with quartz. The felspar is in part an andesine (An 35), in part microcline.

Although the minerals sometimes show crystal forms towards the quartz, this has also corroded them in the strongest possible measure (Fig. 3, Plate II). But the quartz is also intergrown with the biotite, forming myrmekite-like symplektites which have in part encroached upon the plagioclase. In fig. 4, Plate VI, again, it is very obvious that the rim of the plagioclase seen to the right in the figure has been replaced by hornblende.

These phenomena suggest the idea that the minerals have been repeatedly dissolved and recrystallized, while at the same time the chemical composition of the rock masses was continually changed.

We will later when describing the contacts, account for phenomena which seem to be analogous to the above mentioned.

THE BODOM GRANITE.

In this connection, too, the granite of the Bodom area, lying outside of the region shown on the coloured map, may be petrologically described.

The typical Bodom granite is much less coarse-grained than the Obbnäs granite, the bigger felspars measuring only 0.5—1, sometimes 2—3 cm in length, but otherwise it shows as to mineral composition and texture a great similarity to that granite. Its colour is red or brownish red and it is very uniform (homophanous) in texture. It outcrops in small rounded hills, and possesses like the Obbnäs granite a regular jointing, which causes the rocks to be divided into parallelopipedic blocks. The texture is rather loose and the rock is, also in the more fine-grained varieties, not as tough as the Hangö granite.

While these varieties, where the different minerals are so coarse as to give the rock a somewhat variegated appearance, are so similar to the Obbnäs granite that they might be regarded as less coarse-grained equivalents of it, there are other varieties in which the constituents form still finer grains, and then the rock is an equigranular red granite of an appearance which is not very characteristic. It is, however, very similar to the equigranular rock occurring in some places at the margins of the Obbnäs area, indubitably in genetical connection with it.

In the typical Bodom granite the succession of the minerals is almost the same as in the Obbnäs rock. The oligoclase shows the best idiomorphism, and the quartz is xenomorphic. The biotite occasionally possesses a somewhat better crystal form towards the microcline than in the rock of the southern area, but it is also, in many cases, decidedly xenomorphic (Fig. 5, Plate VI, and Fig. 2, Plate VII). It is also seen encroaching upon the plagioclase. In part it may be substituted by green hornblende which becomes prevalent in some varieties.

The microcline crystals, too, here show a very beautiful lattice lamellation, and are in a rather regular way intergrown with stringers of albite. The quartz is as a rule entirely xenomorphic, but it has very often strongly corroded all the other main constituents. The dentated boundaries of the oligoclase towards the microcline are not due to a corrosion on the side of the latter, but always to a later continued growth of the plagioclase, during which this encroached upon a microcline which had earlier crystallized. It is thus a deuteric phenomenon. Hereby the marginal portions of the plagioclase are not always myrmekitic. Occasionally they may, also in cases where there is no doubt that the plagioclase has encroached upon the microcline, consist of plagioclase alone (cf. fig. 6, Plate VI, where we observe, however, also one crystal of plagioclase which has a myrmekitic continuation). This fact proves that there can hardly be, as Becke thought possible, a regular relation in the quantity of quartz and oligoclase in the myrmekite formed at the expense of the microcline.

Myrmekite sometimes also occurs as small grains which may form rows intersecting the felspars (Fig. 1, Plate VII). This is the initial stage of the formation of a mortar texture. This texture is in general not due to mechanical changes alone, but to movements in a mass where crystallization was at the same time going on.

The encroachment of the symplektite of biotite and quartz, or of biotite alone, upon plagioclase, shows itself also in these granites to be entirely analogous to the formation of the myrmekite. Both are deuteric, not truly secondary phenomena.

The titanite also forms rather big crystals. Apatite and zircone occur under the same circumstances as in the Obbnäs granite.

Fluorite is almost always present in the granites of the Bodom area, often in rather big quantity. It fills interstices between the bigger minerals (upper part of fig. 2, Plate VII).

Its presence is of great importance as a diagnostic of these granites, because it has never been found in the Hangö granites. Eskola explicitly mentions its absence from them as an important character.[1]

Also in the granites of the Bodom the quartz and biotite often show conspicuous signs of having been crushed, without having undergone any subsequent recrystallisation.

[1] l. c. p. 29.

The non-porphyritic middle-grained red granites of the Bodom area are microscopically not very different from the typical variety, and they are always connected with that by gradations.

Although they may be sometimes macroscopically somewhat similar to the Hangö granites, the characteristics which we have depicted make it easy to discriminate between them. Even geologically they are well separated, as will result from the description of the contact relations given subsequently.

Pegmatitic dykes and veins seem to occur also in the Bodom area, although not very frequently.

THE CONTACT RELATIONS OF THE OBBNÄS AND BODOM GRANITES.

Both the granites in question occur in well defined rounded areas and are not regional in extension, as the Hangö granites. The contacts have been carefully surveyed, those of the greatest part of the Obbnäs area by Dr. H. Hausen, and those of the Bodom area, by the writer. As it is important to prove the independent position of these granites, the observations on the contact phenomena may be resumed in detail.

At the N.W. boundary of the Obbnäs area, the immediate contacts are in some places visible. The typical Obbnäs granite and a migmatitic gneiss with veins of Hangö granite are often seen very near to each other. The latter-mentioned rock also occurs as fragments in the granite, e. g. near to Strömsby Sjöbodar. At Strömsby Gård the porphyritic granite shows a parallel texture next to the contact.

At Kantvik, 1 km from the main contact, there is, near to the villa of Mr. Takolander, a dyke of Obbnäs granite, and another of a pegmatite with idiomorphic felspars, surrounded by quartz, both dykes cutting a migmatite containing veins of Hangö granite.

W. of Loviselund, the contact between a migmatite rich in veins of Hangö granite, and the Obbnäs granite is visible. The latter is less coarse grained than usual next to the contact.

At Bollnäs and near to the road between Hilabäck and Tolls, the Obbnäs granite and the migmatite are also seen near to each other, and it is obvious that there is a well defined boundary between these rocks.

S. of Tolls, near the road to Porkkala, a contact between the Obbnäs granite and a migmatite with veins of Hangö granite is visible in a horisontal rock surface which is shown in the map in fig. 47. Next to the contact the migmatitic structure is less distinct than further away from it. Obviously an anatectic action on the side of the younger granite has taken place. The contact line is anyhow sharp in the main, and in a zone next to it the porphyritic felspars are smaller than in the typical granite. This place lies near to the northernmost end of the Obbnäs area.

If we now follow the eastern contact, starting from this place, we find E. of Gunnarsby a leptitic migmatite with pegmatitic veins, and in these older rocks dykes of Obbnäs granite, not quite so coarse as the typical variety.

At Gunnarskulla, we find a red granite of Hangö type, and S.E. of that place also a migmatite, but at the farm houses a typical Obbnäs granite.

E. of Biskopsböle, we find, in a low rock behind a crofter's cottage, a contact between the younger granite and a leptitic migmatite.

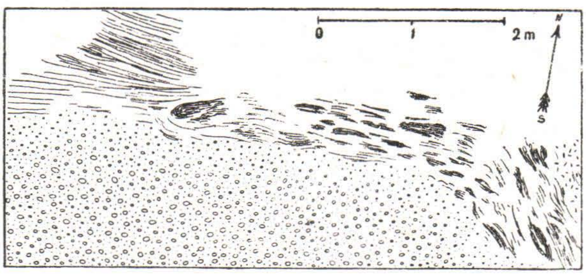

Fig. 47. Contact between Obbnäs granite and migmatite containing veins of Hangö granite, and a dyke of Hangö pegmatite (to the right in the figure). Near the road S. of Tolls railroad station in Kyrkslätt. C:a 1 : 80 nat. size.

N. W. of Järsö there is also a contact between the same rocks.

In the foreland S.W. of Järsö, the contact is visible at several places, e. g. W. of the above-mentioned place. The older rock consists of a greyish red, not quite homogeneous, equigranular granite in which also dykes of pegmatite occur. The contact surface against the Obbnäs granite is flatlying, and the limit is sharp. In general the texture shows no changes next to the contact. Only at one place a fine-grained variety occurs next to it. At another place in the neighbourhood, the porphyritic felspars of the Obbnäs granite are rectangular and are arranged parallel to the contact surface next to it. The contact line is here often sinuous, in great part owing to the flatlying position of the contact surface, but it is always sharp. In the southernmost part of the foreland there is again a sharp contact between the Obbnäs granite and a strongly folded leptitic migmatite. A similar contact is seen in a small island S.W. of this place. In another adjacent island there is an eruptive breccia cemented by Obbnäs granite.

The island of Linloholm is again traversed by the contact line. At the eastern shore a dark migmatitic leptite is in contact with the Obbnäs granite, whose texture is not changed at all next to the contact which follows the strike of the schistose rock. A red granite forms dykes both in this granite and the adjacent older rock, which occasionally contains big crystals of biotite. At other places in the same island, the granite forms intrusive lenses in the migmatite next to the contacts, which may then be less sharply defined.

In the Kanskog Landet (S.E. of Linloholm), we find lenses of a granite resembling the Obbnäs granite, at a distance of more than a kilometre from the main contact, and in a small island near to this place, a dyke of pegmatite is also observed which is similar to those which occur in connection with the afore-said granite.

In a small island near Hilkö, a little more to the north, there is also a dyke of pegmatite, measuring 0.3 m in breadth, which certainly belongs to the Obbnäs granite. It has a zonar structure, with felspar at the contacts and quartz in the middle, containing also isolated crystals of felspar. E. of Linloholm a similar pegmatite also occurs, cutting the older rocks.

Again, S. of Linloholm, in the islands of Lillö and Fågelholm, dykes and lenses of Obbnäs granite occur at a certain distance from the main contact. They traverse a migmatite, but some lenses of granite also follow the strike of this rock.

Near to the contact also, at the southern shore of Linloholm, apophyses of Obbnäs granite, as well as pegmatitic and aplitic veins belonging to it, occur in the older, gneissose rocks, partly transversally against their strikes, partly following them. In the latter case, they form a migmatite with the older rocks which have been here twice injected with granite.

On the shore of the adjacent part of the mainland we also find, near Hakkenpää, contacts where the injection from the side of the Obbnäs granite has been more intimate than elsewhere. A red granite passing by gradations into the Obbnäs granite here occurs. This granite, and also pegmatitic varieties, occasionally interweave the older migmatite, but there is also visible, according to Hausen, a dyke of typical Obbnäs-granite, cutting an older red granite.

At Hakkenpää there is a contact between a typical Obbnäs granite and a leptitic migmatite containing folded veins of pegmatite.

S. of these places, we observe Obbnäs granite still on the northern shore of Stor Lövholm. Here a pegmatite belonging to this granite occurs also as veins in the migmatite which here is rich in garnets, forming rather big spots in the gneiss. An equigranular granite, which seems to belong to the Obbnäs granite, also occurs here. It contains fragments of a dark amphibolitic gneiss.

W. of this place, the boundary line traverses the southern part of Stor Svartö and the northernmost foreland of the island of Getö. Here the contact is very well visible. It is sharp in the main, but a few veins and lenses of younger granite occur next to it in the older rock which is a migmatite with veins of Hangö granite. The contact surface dips 70°—80° S.

The contact phenomena on the southern shore of Obbnäs Udd are extremely interesting, but will be treated separately later on. The granitization has here been connected with the formation of basic contact rocks.

In the south of the easternmost of the islands of Sommaröarna, there also occur rocks in connection with Obbnäs granite which probably belong to its cover of older rocks. We observe here a strongly granitized leptitic migmatite. At least some of its veins probably belonged to an older Archæan granite, but the injection with the younger Obbnäs granite has been so intimate as to make it difficult to say which is which. Rocks rich in biotite also here occur as fragment-like portions surrounded by a typical Obbnäs granite. Some parts of the latter-mentioned rock are again, in a very curious way, connected with veinlike stripes which have solidified later than the main mass of the porphyritic granite. The rock of these sinuous veins is rich in biotite, and its felspars are arranged parallel to their walls. These veins have some similarity to certain veins of the aplite-lamprophyre series which the writer has described from Följskär, among the Aland islands, although they are less typical in the present locality.

The contacts of the Bodom granite are more difficult to study than the contacts of the granitic areas next to the coast, because they are not so well exposed as these.

The best contact which the writer has found in the former area is visible W. of Träskända in Esbo. If we follow the road to Handbäck which starts from the main road 900 m S.W. of Träskända, we find 500 m more to the N. a little hill on the E. side of the road. It consists of a migmatitic gneissose granite containing bigger crystals of felspar and cut by several veins of a pegmatite which has all the characteristics of the pegmatites connected with the Hangö granite. The southern part of the rock is formed by a typical brownish red Bodom granite which is only a trifle less coarse than in the main area. It here probably forms a dyke. Its boundary cuts the older rocks transversely to their strike, and it contains some fragments of the pegmatite (fig. 48).

If we follow the boundary lines of the granitic areas farther to the east, we are able everywhere to trace them sharply on the map, but the immediate contacts are seldom visible.

Tavastkulla, N. of the lake of Långträsk, lies on a rock whose main part consists of a strongly folded migmatitic gneiss with veins of pegmatite. On the northwestern slope we observe a homophanous porphyritic granite which no doubt belongs to the Bodom granite. It also occurs as dykes in the upper part of the same rock. It shows

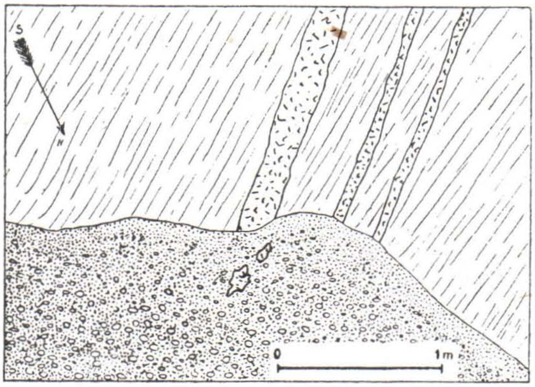

Fig. 48. Contact between Bodom granite and older, gneissose granite, cut by veins of pegmatite belonging to the Hangö granite. W. of Träskända in Esbo. C:a 1 : 47 nat. size.

here a parallel arrangement of the felspars, probably due to fluidal movements.

On the hill E. of Tavastkulla a similar red porphyritic granite forms the northern part of the rock, while its main part consists of a strongly folded migmatite where most of the veins no doubt belong to the older granites. On the uppermost part of the hill porphyritic granite also occurs.

At the easternmost part of the boundary, we find in Lappböle a red granite of Bodom type with felspars measuring 1—2 cm in diameter, and at a distance of a few hundred metres from it, rocks of a typical migmatite. The immediate contact is not visible.

At the northern contact we everywhere find a strong contrast between a massive granite of uniform composition and migmatites consisting of leptitic rocks and veins in varying amount of Hangö granite, in part also older gneissose granites, but nowhere are there any sharp contacts visible.

The rock on which the village of Meilby is situated consists of older gneissose rocks forming an eruptive breccia with veins of Bodom granite which is in part less coarse-grained than elsewhere. This eruptive breccia does not resemble that which originated by the eruption of the older granites, but possesses a peculiar character. More to the north, the granitic veins occurring in the migmatitic gneisses differ in character and no doubt belong to the older granites.

All along the northwestern boundary of the Bodom area we find similar conditions: in the main, a marked limit between a homophanous granite, outcropping in rounded hills which already topographically differ from the more irregularly shaped hills of the older granites, and gneissose granites containing veins of older pegmatite. Near to the contacts also dykes belonging to the Bodom granite occur.

Although this granite, in general, is not so well defined against the surrounding rocks as the Obbnäs granite, there is no doubt that it also is different in age from the afore-mentioned rocks. The Bodom, as well as the Obbnäs granite, has in the most typical way penetrated the older rock masses, punching holes in them. There are no primary gradations between them and the older granitic formations. The similarity in their petrological character and their relations to adjacent rocks is so great as to make it certain that both areas geologically belong to each other. And if the evidence gained at all the contacts, especially at those of the Obbnäs area, is taken into consideration, it seems indubitable that these granites are decidedly younger than the surrounding rocks.

THE ERUPTIVE BRECCIA AT THE SOUTHERN CONTACT OF THE OBBNÄS AREA, AND DIORITIC ROCKS ORIGINATED THROUGH THE SYNTEXIS OF GRANITE AND BASIC FRAGMENTS.

At the southern boundary of the Obbnäs area, near to the place where the narrow zone begins which forms its continuation to the south, the contacts possess an unusual interest, because phenomena may here be studied which throw considerable light both on the assimilation and differentiation processes.

The naked rock surfaces at the southernmost shore of Obbnäs Udd, S. and S.W. of the cottage of Professor Kajanus, give an excellent opportunity of studying these phenomena. Here we find the Obbnäs granite in contact with the older rocks which surround it and have formed the roof of the granitic batholith. These rocks here consist of rather basic leptites mixed with veins of aplite belonging to the Hangö granite. The strata of leptite, as well as these veins, are strongly crumpled and contorted. It is a typical ptygmatic migmatite.

This rock forms greater masses on both sides of the bay below the cottage. The migmatite has here a rather typical character and

Fig. 49. Eruptive breccia consisting of Obbnäs granite and fragments of Hangö granite and arteritic migmatite, whose folded veins have been straightened out during the anatexis. S.W. shore of Obbnäs Udd. C:a 1 : 11 nat. size.

is cut only by sparse straight dykes of pegmatitic granite, belonging to the younger massive and intersecting the older folded granitic veins.

Nearer to the contact with the Obbnäs granite, these older rock masses become split up and are gradually changed into a cluster of big fragments, entirely surrounded by granite. The rock of the fragments in part retains its former composition, in part it is more or less strongly changed, passing by gradations into massive rocks of dioritic composition which assume an eruptive character.

Besides these basic rock varieties, we observe in the granite of the naked rocks which form the western part of Obbnäs Udd, a great number of fragments of a light microcline granite which shows a spotted appearance (cf. fig. 49). The dark spots now consist mainly of biotite flakes, but are obviously pseudomorphs after garnets. This granite no doubt belongs to the Hangö—Ingå granite. There are also sharply defined fragments consisting mainly of pegmatite which is entirely similar to that which is genetically connected with the Hangö granite.

Most of the fragments, however, consist of a migmatite. In the neighbourhood of the fragments of a rather basic migmatite, the granite passes by gradations into a dioritic rock which still shows the great porphyritic crystals characteristic of the Obbnäs granite, but whose groundmass is very rich in biotite, hornblende and plagioclase.

Table XIII gives an analysis, made by Mr. A. Zilliacus, of this rock.

Table XIII.

Syntectic diorite from Obbnäs Udd.
Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm.
SiO_2	62.32	1 038	Q — 15.30
TiO_2	1.20	15	Or — 12.79
Al_2O_2	16.10	158	Ab — 34.58
Fe_2O_2	0.00	—	An — 19.18
FeO	6.75	94	Sal 81.85
MnO	spår	—	
MgO	1.25	31	
CaO	4.76	85	Hy — 11.90
Na_2O	4.09	66	Di — 0.71
K_2O	2.22	23	Il — 2.28
P_2O_5	0.57	4	Ap — 1.34
S	0.16	5	Py — 0.24
H_2O	1.23		Fem 16.47
S:a	100.65		S:a 98.32

II, 4, 3, 4, Tonalose.

Its formula according to Niggli is as follows:
si = 227 = al = 34.5, fm = 27.5, c = 18.5, alk = 19.5, k = .26, mg = .25, ti = 3.3, p = .87, qz = + 49.

The rock has a quartzdioritic (granodioritic) composition.

Microscopically we also find that this rock (Fig. 3, Plate VII) has the composition of a quartziferous diorite or a dioritic gneiss. The bigger felspars mainly consist of microcline, which is in part subdivided by small faults in rectangular fields which give to it a chessboard-like appearance. In some cases, also, oligoclase (An 26) occurs, and

Fig. 50. Fragment of a migmatite, consisting of a basic leptite and folded veins of pegmatite, with a border zone of porphyritic diorite which has originated through the anatexis of the rock of the fragment. S. shore of Obbnäs Udd, S. of the cottage of Professor Kajanus. C:a 1 : 20 nat. size.

this mineral is prevalent in the more equigranular mass surrounding the bigger felspars. It also contains much quartz which is rather cataclastic, and hornblende which is pleochroic in yellowish brown to bluish green colours, and, in a smaller quantity, biotite, besides some ore, titanite, apatite and epidote. The texture of this rock is intermediate between that of an eruptive granite and a gneissose rock formed by anatexis, or »ultrametamorphism.»

Already the close association between the two phenomena: on one hand the existence of a great number of fragments derived from the roof and more or less strongly changed by the influence of the granite, and on the other hand a basic facies of the granitic magma, makes it probable that there is a genetical connection between them. There is also direct evidence in favour of the assumption that the fragments have been changed through refusion into this dioritic rock and that a migration of material from the fragments into the granite surrounding them has taken place. The darker minerals sometimes form aureoles around these fragments or protuberances projecting from them. Fig. 50 shows a fragment of a ptygmatic migmatite of a rather basic average composition, which has below a border zone consisting of a homophanous dioritic rock which is obviously nothing else than an ultrametamorphic portion of the fragment. This border zone has quite the same character as the diorite occurring in greater masses in the eruptive breccia more to the east. It is impossible to interpret this basic border as a contact zone formed by

Fig. 51. Fragment of a basic migmatite in Obbnäs granite, surrounded by a halo of basic rock. S. shore of Obbnäs Udd in Kyrkslätt (cf. fig. 52).

differentiation of the magma of the granite, since it occurs only at one side of the fragment, within its borders, obviously genetically connected with it.

Near to that fragment there is another one which shows at one side a tail-like protuberance consisting of a mass rich in biotite, while at the other end a similar rock occurs which is very rich in biotite and forms an aureole around the fragment. (Figs. 51—53). There is an obvious connection between the fragment and these zones rich in femic minerals. Certain portions seem to have been dissolved out of it and to have later spread into the granite by diffusion.

The migmatite occurring as fragments in the westernmost part of Obbnäs Udd shows, where it has not been changed in a higher degree by the influence of the younger granite, the characteristic »ptygmatic» folding of the aplitic veins. But where the action of the granite has been more intense, we occasionally observe the gradual disappearance of the folding and the change of these fragments into such where dark and light stripes, all of them straight (Fig. 49), alternate. The darker stripes are richer in hornblende than the basic

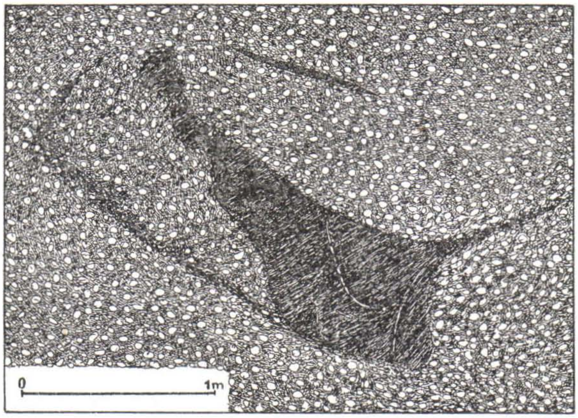

Fig. 52. Schematical drawing of the rock surface shown in fig. 51. 1 : 40 nat. size (the uppermost dark stripe is a fragment).

Fig. 53. Easternmost portion of the fragment shown in figgs. 53 and 55. 1 : 20 nat. size.

parts of the original fragments, while the lighter stripes continue to show a granitic composition, consisting mainly of microcline and quartz.

Obviously a continuous solution and recrystallization both of the femic and salic minerals has taken place within the fragments. Both these constituents have had a general tendency then to segregate in stripes parallel to the schistosity. These portions of the granitic veins which were not parallel to the schistosity, have been gradually obliterated, and their material has been either redeposited along the cleavage, or else removed. But when the recrystallisation has proceeded farther, both the schistose texture and the alternation of basic portions and granitic veins have become entirely obliterated, and the mixture of fragments and granitic magma has become completely homogenized, so as to form a »syntectic» rock of dioritic composition.

In fig. 49 some portions of the breccia are visible where the fragments may still be distinctly recognized, while there are others where they have been entirely homogenized.

Fig. 54. Migmatite belonging to the Obbnäs granite forming a fissure vein in Hangö granite. S. W. shore of Obbnäs Udd in Kyrkslätt. C:a 1 : 12 nat. size.

Those portions of the rock which now possess a dioritic composition have during the anatexis reached the state of a real magma. Therefore they occasionally form distinct veins and dykes in the fragments of older rocks.

Not only this homogeneous syntectic dioritic rock occurs as dykes and veins in the fragments, but at one place, shown in fig. 54, a fissure in the Hangö granite has been filled by a rock which still retains the inhomogeneous character of the migmatite. This observation is entirely in harmony with others which we have been able to make in this area, and in other parts of the coastal regions, which prove beyond doubt that even parts of the older rocks which still partly retain their original composition, a fortiori those portions that have been strongly granitized, have become plastic and even apt to flow like an eruptive magma, filling every fissure as soon as it originated.

THE LAMPROPHYRIC ROCK OF STOR ÅDGRUND AND ITS RELATIONS TO THE OBBNÄS GRANITE.

At the western boundary of the Obbnäs area a peculiar basic rock occurs in the small island of Stor Ådgrund.

The greatest part of this small island is composed of a porphyritic granite which is a trifle less coarse than the typical Obbnäs granite, but in all other ways similar to it, and no doubt belongs to its western border zone. At the eastern shore of the island a basic porphyritic rock outcrops in a zone which has a breadth of 30—40 m and shows a very irregular delimitation against the granite. Between this zone and the porphyritic granite a zone of a middle-grained aplitic granite, 0.5—3 m broad, occurs, which no doubt belongs to the same magma.

The basic rock nowhere shows intrusive contacts towards the granites, while on the contrary the aplite forms numerous dykes and veins in the former and certainly solidified later. In most places the boundaries are tortuous, as shown in Fig. 55. The contacts are rather sharp, and strangely enough the porphyritic plagioclase crystals of the basic rock are often more numerous next to the contact. In its immediate neighbourhood, the granite contains small fragments of the basic porphyritic rock and even isolated small plagioclases of the same character as those occurring in the basic rock, from which they have obviously been detached. In some places the porphyritic crystals in the basic rock are very sparse, while in others they are crowded, also farther from the contact with the granite.

The basic rock is composed of plagioclase (andesine with 35 An) hornblende, quartz, mainly in micropegmatitic intergrowth with felspar, ore, titanite and apatite. The plagioclases of the porphyritic crystals often contain patches of the groundmass, and in some cases they obviously form skeleton crystals (Fig. 4, Plate VII) which cannot, in this case, have been formed by the resorption of bigger crystals, but, on the contrary, are idioblastic constituents which were formed later than the groundmass. Quartz, too, occasionally occurs as isolated grains which may resemble porphyritic crystals deformed by resorption (Fig. 5, Plate VII). They are not to be interpreted in the same way, as they obviously originated by the solving action of silicic acid on the basic rock, quartz having later solidified in these cavities, filling them. In one of these greater quartz grains a slender hornblende needle is seen protruding which has obviously grown out from the wall of the cavity. On the other hand, a fissure in the quartz crystal is filled with microcline.

The fine-grained mass between the phenocrysts is composed of thin laths of plagioclase, needles and stalks of hornblende, which is

Fig. 55. Contact between a lamprophyric rock and aplite belonging to the Obbnäs granite. W. shore of Stor Ådgrund in Ingå. C:a 1 : 8 nat. size.

pleochroic in green and yellowish brown colours, ore, which is probably ilmenite, because it is often surrounded by a rim of titanite, pyrite as sparse crystals, needles of apatite, some epidote and quartz which is abundant in certain varieties. The quartz is then intergrown with felspar in such a way as to form a typical micropegmatite (Fig. 6, Plate VII).

As the analysis shows a rather high content of potash (the norm has 21.13 per cent of potash felspar) it is probable that most of the felspar of this micropegmatite is orthoclase or microcline. Plagioclase, however, also occurs intergrown with quartz. In general, this micropegmatitic intergrowth is not here as regular as that of the granitic rocks.

The quartz has, in the same way as in some rocks described by the writer in a previous memoir, corroded parts of the adjacent plagioclase.[1] Cf. fig. 6, Plate VII, where there seems to be little doubt that the forms of the greater felspars are due to resorption. Also, the femic minerals encroach upon the adjacent plagioclases, and in general the distribution of the different minerals does not show that strict regularity which is characteristic of primary basaltic or diabasic rocks.

Some of the minerals are rather strongly crushed, but there has been no chemical action accompanying these movements or later than them. The aplite which penetrates this basic rock shows still more distinct signs of having undergone crushing.

All these phenomena seem to be rather contradictory and difficult to explain. The author was formerly inclined to think that the basic rock might have originated through an ultrametamorphic action of the granite on the older metabasaltic dyke rocks which are so common in the same region. In no other cases, however, have those older metabasalts acquired such a texture, or mineral composition, as here. They show, in general, the character of rather typical metamorphic rocks, while the texture of the basic rock of Stor Ådgrund is somewhat different.

Macroscopically some varieties of this basic rock have a certain resemblance to those »trap» rocks which occur as dykes all over southwestern Finland and are genetically connected with the ossipites (anorthosite-gabbros) which often occur near to the areas of rapakivi granites, which rocks they immediately precede in age. One dyke of these trap rocks occurs also in the present region in the island of Vormö. When they occur in greater quantity, the ossipites are often porphyritic, the phenocrysts being formed by labradorite crystals which have often a considerable size.

However, as is seen from the foregoing description, it does not seem probable that the plagioclase crystals of the present rock are really primary constituents. Moreover, the whole rock shows a texture

[1] J. J. Sederholm, On Synantetic Minerals. Bull. Comm. géol. Finl. N:o 48, 1915, pp. 76—77, 120—121, 145—146.

and a composition which do not resemble those of primary basic rocks, and it does not show, either, any closer analogy to those varieties of the diabases of southwestern Finland which have undergone metamorphism in contact with granites penetrating them.

In the initial stages of the metamorphism of the latter rocks, the formation of synantetic minerals, and in the more advanced stages a uralitization of the common character is characteristic. Any rocks more closely resembling that of Stor Ådgrund have not been observed among them. If, as the writer is inclined to think, the porphyritic texture of the present rock originated by a strong contact action from the side of the aplite, then those varieties whose texture mostly resembles those of primary porphyritic rocks are not at all to be regarded as relics of a primary rock, but on the contrary mark the last result of the changes which are due to that contact action. It is a metamorphic rock mass which was on the way of assuming the character of an eruptive rock.

Chemically too, this rock cannot be regarded as a diabase, or a basaltic rock, and differs from all known diabasic and gabbroid rocks of Southern Finland.

Table XIV gives an analysis of the basic rock of Stor Ådgrund, made by Mr. Allan Zilliacus.

Table XIV.
Lamprophyric rock from Stor Ådgrund in Kyrkslätt.
Analyzed by Allan Zilliacus.

	%	Mol. prop.	Norm
SiO_2	55.60	927	Q — 16.02
TiO_2	1.49	19	Or — 21.13
Al_2O	15.34	150	Ab — 16.24
Fe_2O_3	5.27	33	An — 22.52
FeO	5.03	69	Sal 75.91
MgO	2.32	58	Hy — 6.12
CaO	6.91	123	Di — 2.65
Na_2O	1.90	31	Mt — 7.66
K_2O	3.56	38	Il — 2.89
P_2O_5	1.33	9	Ap — 3.02
S	0.32	10	Py — 0.60
H_2O	0.89		Fem 22.94
S:a	99.96		S:a 98.85

II, 4, 3, 3, Harzose.

The rock corresponds to the normal-dioritic rock type of Niggli. The formulæ according to his system are as follows:

si = 173, al = 28 fm 36, c = 23, alk = 13, k = .55 mg = .30. ti = 3.5, p = 1.6, qz = + 21.

The percentage of K_2O is astonishingly high, and could not be detected microscopically. This is a fact often met with in lamprophyric rocks.

The writer's study of the rocks of the Åbo—Åland archipelago has made him acquainted with dyke rocks which show certain analogies with the rock of Stor Ådgrund. Both the youngest pre-rapakivi granites of this region, as well as the granites belonging to the same group as the Hangö granite and the oldest, gneissose granites, are there connected with basic dyke rocks which have a very close genetical connection with the aplites of the same granites. In all cases the aplitic portions of these eruptive masses solidified later than the basic portions, just as is the case with corresponding rocks of Stor Ådgrund.

In several cases, the processes of differentiation through which these basic dykes originated have had an obvious connection with the formation of migmatites. The granitic magma has digested basic material in such a measure as to cause a lack of harmony in its chemical composition. It may be called a case of petrological indigestion, if such an expression is allowed. The granite has absorbed more basic material than it has been able long to keep assimilated, and has therefore soon again segregated it.

In any case, these things merit the closest attention, because we are here able to find a clue to the processes of differentiation which have obviously played such a great rôle also in the anatexis.

GEOLOGICAL AGE OF THE OBBNÄS AND BODOM GRANITES.

It is obvious from the above mentioned facts that the granites in question are easily distinguished from the granites of the Hangö—Ingå group. These are regional in extension, occurring all over southern Finland, from the southern margin of the great Wiborg area of rapakivi granite to the Åland Sea, and also W. of it. They are seldom homogeneous, but are commonly mixed up with more or less intimately assimilated fragments of older rocks, and they have seldom quite definite boundaries. The general impression which they give is that the older rocks have, all over the region where they occur, been s o a k e d with the magma of these granites, and its ichor.

The present granites are almost entirely homophanous. They are of a deep and uniform red colour and they form well defined areas. They cut all the surrounding rocks and contain at the boundaries fragments of them, also of Hangö granite and of migmatites consisting of older rocks with veins of this granite. These migmatites were everywhere completely solidified before the eruption of the later granites.

Dykes and veins connected with them occur only near to the boundaries of the areas.

There is a certain macroscopic similarity between some varieties of the granite in question and such as belong to other groups, but, on the other hand, they show characteristics which make it possible to distinguish them with certainty from those.

They are looser in grain and more regularly jointed than the granites of the Hangö group, although possessing neither of these characteristics in the same degree as the rapakivi granites.

They never show open pores or caverns like the rapakivi granites, but they contain as a rule f l u o r i t e, filling interstices between the other minerals. G a r n e t, which is so common in the Hangö granites, is here lacking.

Such a regular microperthite as here is not found in the Hangö granites, while the corroding action of the quartz has in the latter been still stronger than here, and also myrmekite is more common. The cataclastic phenomena are also stronger in the older granite, and have there been followed by a subsequent deposition of quartz.

There have never been found any gradual transitions between granites of this type and such as belong to the Hangö group.

It is more difficult to determine the relations between the granites in question and the rapakivi rocks, because they never occur in contact in the regions around Helsingfors. Originally, these granites were regarded as somewhat older than the rapakivi, because the latter is almost entirely devoid of cataclastic phenomena, while such have been observed in the granites now in question, although not in a very conspicuous form. It was also thought possible that the Onas granite of the Pellinge area might be somewhat younger than the Obbnäs granite, perhaps even as young as the rapakivi, because the former showed a lesser degree of cataclasis, and was besides more similar to the rapakivi granite.

Later the writer found that most of these cataclastic phenomena were due to movements which accompanied, or in any case had not been much later than, the eruption of the same granite. He therefore began to doubt whether it was legitimate to use the grade of metamorphism (which in this case would be an »autometamorphism») as a criterion of geological age. If that character was due more to the depth in which the granites had solidified, and to their richness in granitic ichor, then it might well be possible that rapakivi granites deeper down could assume the characters of granites similar to the Obbnäs and Bodom granites.[1]

In any case, it became necessary to make a renewed investigation in the field in order to decide whether there were any true transitions between the rapakivi granites and those granites which belonged to the same group with the Obbnäs granite.

Now there are, among the Åland Islands, granites which in all ways are very similar to the granite mentioned, and these lie near to the rapakivi and are also in contact with the ossipites (anorthosite-gabbros) which immediately preceded the rapakivi in age. Here the relative age of the granites in question may therefore be determined.

In the summer of 1925 the writer found at last quite decisive contacts between the Lemland granites belonging to the present group and the Åland rapakivi, and could state that the latter was certainly younger, penetrating the Lemland granite in dykes and containing numerous fragments at the contacts. Moreover, he found that the contacts between the ossipite of pre-rapakivi age and the Sottunga granite, another granite of the same group, proved beyond doubt that the basic rock was younger than the Mosshaga granite which was thus a f o r t i o r i older than the rapakivi.[2]

The existence of a »diabase granite», genetically connected with the ossipite, but which had been earlier by some geologists regarded as belonging to the granite, had made the contact relations obscure and had caused them to be interpreted differently, for a while also by the present writer.

All the granites of the Åland Islands which resemble the Obbnäs and Bodom granites petrologically and in their geological behaviour, viz. the Lemland, the Mosshaga and the Åva granites, may now be regarded as certainly being older than the rapakivi granites. These never show any transitions into granites which possess the habit characterizing Archæan and »Ser-Archæan» granites.

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[1] J. J. Sederholm, Granit-gneisproblemen belysta genom iakttagelser i Åbo—Ålands skärgård. Geol. För. Stockholm Förh. Bd. 46, 1924, pp. 129—153 and 253—271.

[2] J. J. Sederholm. Indelningen av de fennoskandiska graniterna och en urbergsdiskordans i skärgården. Föredr. Geol. För. Stockholm Förh. Bd. 47. 1925, pp. 536—542.

In Sweden also, granites entirely similar to the Obbnäs granite occur, e. g. by Graversfors, where they have been studied in great detail by Asklund, together with whom (partly also with Dr. Gavelin) the writer has visited both these Swedish areas and the Finnish areas now in question. These Swedish granites are in many places cut by basic dykes which certainly belong to the pre-rapakivi ossipites.

Asklund refers these Swedish granites of the region near Norrköping to the same group as the Småland (or Vexiö) granites, and also calls attention to the great similarity between the latter, especially the Virbo granite, and the Onas granite of Finland.[1] The present writer also, already long ago, called attention to the many analogies between all these Swedish and the Finnish granites mentioned.[2]

It is of great interest to note their chemical affinities.

Table XV.

	Granite from Obbnäs gård.	Brown granite from Gravers-fors in Sweden.	Granite from the quarry of Onas.	Average of Obbnäs and Onas granites.	Average of 3 analyses or Virbo granites from Oscars-hamn in Sweden.
SiO_2	68.40	67.93	71.08	69.74	69.22
TiO_2	0.52	0.30	0.29	0.41	0.70
Al_2O_3	14.57	16.28	14.26	14.42	14.25
Fe_2O_3	0.87	2.85	1.12	1.00	2.22
FeO	3.57	1.38	2.31	2.94	1.11
MnO	0.05	0.07	—	0.03	0.73
MgO	0.72	0.90	0.53	0.63	0.62
CaO	2.84	2.81	0.96	1.90	1.61
Na_2O	2.21	1.80	3.49	2.85	3.16
K_2O	5.79	5.02	5.61	5.70	5.26
P_2O_5	0.25	—	—	0.13	—
H_2O	0.68	0.53	0.60	0.64	0.66
BaO	0.09	—	—	0.05	—
	100.56	99.87	100.25	100.44	99.94

The analyses in columns 1 and 2 of Table XV show that the Obbnäs granite and the brown granite of Graversfors in Sweden have a very similar composition. Both are more granodioritic in

[1] B. Asklund, Petrological Studies in the Neighbourhood of Stavsjö at Kolmården. Granites and Associated Basic Rocks of the Stavsjö Area. Sver. Geol. Undersökn. Avh. o. Upps. Ser. C. N:o 325, 1925.

[2] J. J. Sederholm. Ladogium Redivivum. G. F. F. Bd. 38 1916. p. 32—40.

character than the Onas granite (column 3) which has lower contents of CaO, MgO and also iron oxides. But, if we take the average of the Obbnäs and Onas granites (column 4), and compare it with the average of the three analyses of Virbo granite from Oscarshamn communicated by Holmquist (column 5), we get almost identical figures. Only the Swedish figures for MnO are abnormally high, owing to the influence of one of the analyses. This fact should be due to some casual circumstance.

The Virbo granite is, according to Holmquist, characterized by a content of fluorite, and it has besides many petrological features in common with the Finnish granites in question. The writer has also observed an unusual richness of fluorite in granitic veins occurring near the town of Norrköping in Sweden. These veins are very probably genetically connected with the Graversfors granite. In general the Swedish granites of this group seem to be also characterized by a content of fluorite.[1] For all the reasons stated above, it seems to be certain that both the Obbnäs and Onas granites belong to a group of late pre-Cambrian granites intermediate in age between the Hangö type of granite and the rapakivi granites. The writer is inclined to think that their age is nearer to that of the latter than to the former. In Sweden, however, the Småland granites have been referred to a group older than the Stockholm granite, which is regarded as a typical »Ser-Archæan» granite.

The reasons for this grouping were at the beginning in part the great stress which in Sweden was laid on the connection between the Småland granites and the effusive porphyritic rocks connected with them, which were all thought to belong to an old »formation of porphyries». In numerous papers, the present writer disputed this old Swedish idea according to which the quartz-porphyritic rocks of Sweden form a genetical entity, and tried to show that the hälleflintas and quartz-porphyries are connected with granites of very different ages.

As to the Stockholm granite, it is extremely similar to some grey granites occurring at Kumlinge in the Aland archipelago of southwestern Finland and also to the granites of the Uusikaupunki (Nystad) region. Both these granites have the most indubitable connection with the red granites of the Hangö group which possess a regional extension. These granites must therefore be older than the Obbnäs granites, and, under the assumption that this is to

[1] P. J. Holmquist, Studien über die Granite von Schweden. Bull. Geol. Inst. Upsala, VII, 1906, p. 146—169.

be correlated with the Östergötland and Småland granites etc. of Sweden, also older than these.

The Småland granites of Sweden occur over wide areas. The same is true as to the so called post-Kalevian granites of northern Finland which show many analogies to them. These granites are separated from the central granites, which the writer correlates with the Hangö granites, by a sedimentary formation intermediate in age. These post-Kalevian granites are at the boundaries occasionally more intimately mixed with the adjacent rocks than the granites of the smaller areas in southern Finland. As to these there seems to be no doubt about their genetical difference from the adjacent older granites.

In any case all these granites form a petrologically and chemically well characterized group.

TRAP DYKE.

On the northern coast of the island of Vormö a dyke of a fine-grained diabasic rock is visible which is entirely similar to the »trap» dykes common in southwestern Finland, which are genetically connected with the coarse-grained ossipites (anorthosite-gabbros)[1] of Jaala, Vidskär in Föglö, Höggrunden in Eckerö etc. The eruption of these rocks took place immediately before that of the rapakivi with which they are often closely associated in their distribution. They occur in Jaala E. of Heinola), in the Åland Islands, in Ångermanland in Sweden and in southern Russia close to the rapakivi areas. The rapakivi granite is at all places of later age, penetrating them at the contacts.

The present dyke has a breadth of 2—2.5 m and can be followed to a length of about 20 m. The adjacent rock, which the dyke cuts with sharp contacts, is a migmatite with pegmatitic veins. The dyke runs in a N.W.-ly direction, and the walls are vertical. Cf. the map in fig. 56.

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[1] For these rocks different designations have been used. They were earlier called diabases; on the general map of the ancient rocks of Finiand published in 1910 they were designated labradorites, and in the new edition of 1927 they are termed anorthosites. The typical varieties, however, contain rather large amounts of femic minerals (mainly pyroxene and ore), and also those varieties which are richer in felspar do not yet posses the composition of typical ladoradorites. The chemical composition of the most common types is nearest to that of the ossipite group of Niggli. The rocks in question do not, however, contain any olivine, as do the typical ossipites of North America. The question about the best designation for this group of rocks may still be held open.

By microscopical examination we find that this rock consists mainly of small crystals of plagioclase and flakes of biotite, with small grains of ore. The plagioclase is an andesine (An 30). It forms laths with rather irregular outlines which have a length of

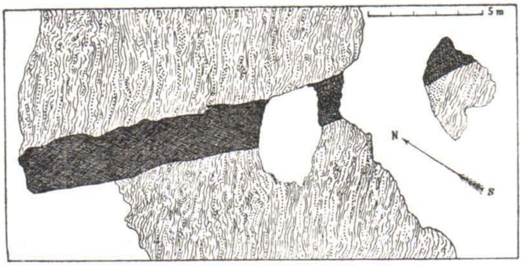

Fig. 56. »Trap» dyke cutting migmatite. Horizontal rock surface on the southern shore of the island of Vormö. 1 : 300.

0.1—0.3 mm. A few crystals are bigger, measuring 0.8 mm in length. No pyroxene is visible. The biotite was probably formed synantetically at the boundaries of ore and plagioclase, or also at the expense of a glassy matrix which possibly existed between the andesine laths. In

Fig. 57. Microphotograph of fine-grained basic dyke rock (»trap») from the southern shore of Vormö. Parallel nicols. 17 ×.

any case, the biotite is secondary, or possibly deuteric. At some places there are stripes of small grains of quartz, sometimes associated with calcite. These minerals are later than the other constituents. Cf. the microphotograph in fig. 57.

This rock has certainly nothing to do genetically with any of the metabasaltic dykes of the region which are all older than the Hangö granite, which the dyke penetrates. Anyhow those older dykes were probably geologically rather similar to it before they were changed by metamorphism.

CONCLUDING REMARKS.

ON SOME THEORIES CONCERNING METAMORPHISM.

We have already, while petrologically describing the rocks of the present region, touched upon several theoretical questions, in cases where the observations have had a direct bearing upon them. We will now discuss at greater length some of those theoretical questions, as well as the methods to be used in this line of research, the classification of metamorphic and ultrametamorphic rocks etc.

There are few phenomena of importance relating to the metamorphic and ultra-metamorphic changes which have taken place in the rock masses of the coast regions of southern Finland that are not exemplified in the Barösundsfjärd region. We are therefore now able to give at least preliminarily some of the general theoretical conclusions to which our study has led, retaining their further elucidation and definite formulation for later memoirs. The writer also uses the opportunity to state his position, from the point of view of an inductive petrologist, as to theoretical opinions concerning metamorphism which have been expressed by different authors.

The metabasalts of the group to which belong the dykes of the present region, as well as those occurring elsewhere in the coastal areas, and the uralite-porphyrites of the Pellinge region, are a material of exceptional value for the study of metamorphic phenomena. They form a series of rocks which were originally almost identical in their chemical composition, but which now show gradations between varieties which still retain their primary mineral composition and such as have undergone the strongest possible metamorphism. The writer has continued the study of these rocks since he published, in 1891, his first pamphlet (a Doctor's dissertation) on the uralite-porphyrites of the Tammela—Kalvola region, W. of Hämeenlinna (Tavastehus). In this pamphlet he also gave, in a short chapter, his opinion on some questions concerning metamorphism. These statements, to which he still adheres, having in part sunk into oblivion, he ventures briefly to recapitulate some of them.

As acknowledged by Grubenmann [1] and others, the writer was the first to express, in this pamphlet, the idea that the character of the metamorphic processes changes with varying depth.[2]

A more elaborate discussion of the same subject was, out of personal considerations, left out of this pamphlet. Somewhat later the writer prepared another communication on the same question, containing also lists of minerals characteristic of different zones of depth. But when he found, by correspondence with Professor Becke in Vienna, that others were busy with the same questions, treating them from a more exact physico-chemical point of view, this paper was never published.

The writer however remained in close contact with the petrologists who developed the doctrine of metamorphism on the basis of the ideas of the Vienna and Zurich schools, especially with the late Professor W. Grubenmann. In the general trend of ideas there remained a rather close affinity between the writer and this distinguished petrologist whom he was happy enough to regard as his personal friend. Especially in the somewhat modified form in which the ideas of the Zurich school were expressed in the latest work of Grubenmann and Niggli, Die Gesteinsmetamorphose, the similarity between their ideas and the opinions of the writer is very great.

There was however, at the outset, a certain difference between the views of the Vienna, partly also of the Zurich school, and those held by the present writer on one fundamental idea, and in part also as to the point of issue. The opinions of the writer had been empirically founded on the observation of the great difference in character between the metamorphic rocks of Alpine type, and those of Archæan type. Becke, again, based his theoretical views partly on such empirical considerations, but also partly, and perhaps in still larger measure, on a physico-chemical reasoning. He expressed these theories already in 1895, in a short communication,[3] and developed them later in 1903.[4]

As has been observed by Loevinson-Lessing, the rock-building

[1] U. Grubenmann, Die Kristallinen Schiefer, Berlin 1904, p. 55.

[2] J. J. Sederholm, Studien über archäische Eruptivgesteine aus dem südwestlichen Finnland. Tschermaks Min. u. Petr. Mitt. XII, 1891, pp. 140—141.

[3] F. Becke, Ueber die Beziehungen zwischen Dynamometamorphose und Molekularvolumen. Jahrb. Min. II, pp. 182—103. 1896.

[4] F. Becke, Uber Mineralbestand und Struktur der kristallinischen Schiefer. R. IX Congr. géol. intern., Wien, 1903, pp. 553—570.

Cf. also F. Becke, Typen der Metamorphose. Föredr. Geol. För. Stockholm Förh. Bd. 42. pp. 183—190. 1920.

minerals may be subdivided into two groups, one comprising those where the molecular volumes are smaller, and the other where they are greater than the sums of the molecular volumes of the oxides which compose them.[1] The former, the minus minerals, were believed to occur more commonly in the crystalline schists, while the latter, or the plus minerals, should be more common in the eruptive rocks.

Loevinson-Lessing himself did not, however, draw these conclusions, but pointed out that the regularity in the paragenesis of the plus and minus minerals was not very great. Becke again, as well known, thought that this difference was of fundamental importance in explaining the changes which rocks undergo by their metamorphism. He expressed the idea that the metamorphism of the crystalline schists was largely influenced by the circumstance that the rock masses strive to reach, under the influence of pressure, another chemical equilibrium whereby they assume such a mineral composition that their molecular volume becomes smaller than that of the minerals of the corresponding unmetamorphic rocks. According to this so-called volume law there should thus be a general tendency of the metamorphism caused by pressure, to create rocks with an increased specific gravity.

Several objections have been made against the volume law, e. g. by Boeke[2] from a theoretical point of view, by Leith and Mead,[3] and lately by Waldemar Lindgren.[4] He observes that by metamorphic processes numbers of molecules not necessarily corresponding are interchanged; only the same volumes are to be filled up as are solved away. Harker has expressed a similar opinion[5] and earlier remarks made by the present writer go in the same direction. However, the idea embodied in the definition of the volume law has gradually become rather generally accepted at least on the European continent.

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[1] F. Loevinson-Lessing, Studien über die Eruptivgesteine. C. R. VII Congr. géol. intern. St. Pétersbourg, 1897, pp. 194 seq.

[2] H. E. Boeke, Grundlagen der physikalisch-chemischen Petrographie, 1915, pp. 384—388.

[3] C. K. Leith and W. J. Mead, Metamorphic Geology, A. Textbook, 1915, pp. 183—197.

[4] W. Lindgren, Volume Changes in Metamorphism, Journ. Geol. Vol. 26, 1918, pp. 542—554.

— — The Nature of Replacement. Econ. Geol. VII, 1912, pp. 521—535.

— — Metasomatism. Presidential Address. Bull. Geol. Soc. Amer. Vol. 30, 1925, pp. 247—262.

[5] A. Harker, Anniversary Address of the President. Quart. Journ. Geol. Soc. London, Vol. 74, 1918, pp. LXIII—LXXX.

Metamorphism is commonly defined as a response to changed conditions of pressure and temperature, and the former is often thought to play a preponderant rôle. A metamorphic rock has even been described as a rock which »came under the influence of the volume law». Out of this law the most far-reaching conclusions as to the conditions in the lower parts of the earth's crust have been deduced.

In the opinion of the present writer, petrological experience is, in many cases, at variance with these conceptions. He will here resume some of this evidence, especially as far as it is derived from the regions now in question.

One of the most common and important metamorphic changes is that which is characterized by the uralitization of the pyroxenes and other minerals of rocks of basaltic composition. It is therefore of great importance to decide whether this process has been really accompanied by a decrease of the volume. This question has already been discussed by several previous writers.

Thus Weinschenk [1] made, in his memoir on Dynamometamorphism and Piëzocrystallization, the following remarks which are here quoted in translation: »Moreover, I wish to remark to those who regard the uralitization as a paramorphic phenomenon, that this change cannot be attributed to pressure, as the hornblende is less dense than the augite, i. e. occupies a greater volume; one should expect, on the contrary, the inverse phenomenon. Some petrographers try to escape this difficulty by taking into consideration the quantity of water which most hornblendes contain. The hornblende has then a lower volume than that of the pyroxene to which a corresponding quantity of water is added».

Eskola also later discussed the question as to whether the uralitization can be explained according to the volume law.

In most cases discussed by him he found an increased volume in the amphibolitized rock, and concludes that the result decidedly proves that the formation of the amphiboles is not controlled by the so-called volume law, as defined by Becke. He thinks, on the other hand, that it is an indisputable fact, corroborated by all petrographic experience, that the formation of the amphiboles is favoured by high pressure, and therefore asks how this fact can be brought to agree with the result mentioned above. After a discussion of a number of facts elucidating the genetical relations of amphiboles and pyroxenes, he arrives at the result that the only way of explaining the

[1] E. Weinschenk, Dynamometamorphisme et piézocristallisation. Mém. prés. au VIII Congr. géol. intern. Paris 1900, p. 333.

formation of amphiboles in accordance with the volume law, would be either by assuming that the temperature, during the metamorphism, must have been high enough to cause the specific volume of the water to become considerably larger than 1, which would have caused the amphibolitization to be accompanied by a decrease of volume, or else by assuming that the amphiboles were more compressible than the pyroxenes.[1]

This problem may be elucidated by directly comparing the specific gravity of a basaltic rock which has undergone uralitization, with that of the corresponding unmetamorphic rock.

If we determine the primary composition by calculation, as Eskola has done, there is always an element of uncertainty. It is therefore preferable to make the comparisons in areas where some parts of the same formation are metamorphic while others have remained unchanged.

The rock of the island of Virskär, and some adjacent islands in the Pellinge area, consists of a basaltic rock whose primary constitution is almost completely preserved. In the adjacent island of Sandö, we find a rock which originally had an identical composition and texture, but was later entirely uralitized. The specific gravity of the former is 3.08, that of the latter only 2.85. These determinations were made by Dr. K. O. H. Frauenfelder.

This is not a fact which stands isolated. It seems to be rather general that uralitized metabasalts have a specific gravity of only 2.8—2.9, while the unmetamorphic rocks with the same chemical composition commonly have a gravity of about 3.0, or more.

As we have stated above, metamorphic dyke rocks which have an identical chemical composition and have been changed while lying near to each other, and under identical conditions of pressure and temperature, show remarkable differences in their specific gravity, those containing s e c o n d a r y pyroxene being h e a v i e r than those containing hornblende and biotite.

All these facts are not in favour of the volume law as generally conceived.

It was evident long before this discussion of the volume law began, and has been recognized also by the adherents of the theory mentioned, that the change of a basaltic rock into a uralite-porphyrite does not take place in such a way that the pyroxene is simply changed into hornblende. Already in 1885 Rosenbusch remarked that the

[1] P. Eskola, Om sambandet emllan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. (Engl. Summary). Bull. Comm. géol. Finl. N:o 44 pp. 9—107 and 143—145. 1915.

composition of the uralite is not identical with that of the augite of which it retains the form, and that thus the formation of the pseudomorph does not stricte sensu possess the character of a paramorphic change, »nicht im strengsten Sinne des Wortes den Character einer echten Paramorphose besitzt».

The present writer also pointed out, in 1891, how complicated were the processes by which a basalt had been changed into a uralite-porphyrite. In no case, as he remarked, had it yet been proved by comparative analyses that a rock-forming silicate had been changed into a new mineral without substantial changes.[1]

As to the uralite-porphyrites then studied by the writer, he arrived at a result which he summed up in the following words (translated from the German): »The metamorphism of the different mineral constituents may thus essentially be regarded as due to an interchange of material.» He further remarked: »Several facts, as the occurrence of hornblende on fissures in the rock, as protuberances of the uralite crystals, within the plagioclases, and in general the whole behaviour of the newly formed minerals, seem to prove that a lively transport of material has taken place, not only between the adjacent minerals, but in the whole rock mass». The writer therefore concluded that water (of course of higher temperature) had been a main agent in the metamorphism. The pressure would have facilitated the changes partly by causing a minute fracturing of the rock whereby the surface to be attacked by the solvents would often be almost indefinitely increased, partly also by directly increasing the chemical energy and the solvent power of the water.

If this reasoning is correct, as the writer still believes that it is, it is also rather difficult to imagine that the change of the augite into uralite, and similar changes, should have been determined mainly by the »volume law». This would be easily intelligible, if simply a recrystallization of matter in situ had taken place. But if uralite is formed by the interreaction of different minerals, whose constituents are solved in water and carried to other places in the rock, to be deposited as new minerals, which sometimes are quite irregularly dispersed like weeds in an overgrown field, and as fringes around the uralite crystals, then it is hardly possible to think that there would be any regular ratio between the molecular volume of the original augite, which after all has yielded only a part of the constituents of the uralite, and the molecular volume of this mineral. On the other hand, it is then easily understood that the metamorphic rock as a

[1] This statement may now appear too sweeping; a few exceptions exist.

whole may become even less dense than the original rock which crystallized out of a molten magma.

If there were any metamorphic change caused by pressure alone, as at least some of the older theories on metamorphism admitted, we should expect to find it, if anywhere, in such cases where two adjacent minerals have reacted upon each other. But even in these cases, by the formation of what the writer has called synantetic minerals, it can be proved that a solvent has been active which has carried material also from more distant places.

On the other hand, it is true that most of the reactions during the process of metamorphism take place within the boundaries of each individual rock mass. E. g. at the contact between a granite and a dyke of metabasalt cutting it, we do not find any transitional zones, but a sharp dividing line between both of them. This fact is only seemingly at variance with the conclusion formulated above, according to which water has been a main agent, transporting material from mineral to mineral. For not only the formation of the synantetic minerals, but in general all metamorphic changes, are due to an interreaction between two or more definite minerals and a solvent (which often does not carry very great quantities of additional material). Mainly within each individual rock mass, the composition conditioning this interchange exists, and each molecule liberated by solution is very soon again tied, kindred minerals being formed. The secondary minerals therefore occur in certain regular associations, in the same way as the minerals of the the primary rocks.

Most metamorphic rocks may be compared to countries which are selfsupporting in their national economy, because surrounded by walls of strong protective tariffs.

In the discussion of the theoretical applications of the »volume law» another mineral, besides the secondary hornblende, has played a considerable rôle, viz. the g a r n e t which has been called by Fermor a g e o l o g i c a l b a r o m e t e r.[1] His theory about the existence of an e c l o g i t i c s h e l l below the crust of acid rocks is partly a logical deduction from the volume law, but is based also partly on some interesting facts observed by him and other geologists of India, according to which a number of different rocks in the Archæan of the Deccan peninsula all contain garnet in abundance.

As many of these rocks are similar to such as occur elsewhere among rock masses which have certainly undergone regional meta-

[1] L. L. Fermor, Preliminary Note on Garnet as a Geological Barometer and on an Infra-Plutonic Zone in the Earth's Crust. Geol. Surv. India. Vol. XLIII, Part I, 1913, pp. 41—47.

morphism, the same explanation seems also here to lie nearest at hand. Holland has shown that the garnet of the charnockite has originated through the change of the hypersthene, and it is difficult to understand why this change should have here another cause than elsewhere.[1]

Eskola later, for somewhat different reasons, arrived at the same theoretical result as Fermor, in his study of Norwegian basic rocks of Palæozoic age. Among the gabbros studied by him such occur as are highly garnetiferous, and Eskola regards the garnet as a primary constituent indicative of crystallization at great depth, according to the conceptions of the volume law.[2]

Eskola excludes the garnet formed in granitic rocks from this reasoning, while Becke, like Fermor, is inclined to regard it from the same point of view as the garnet of the eclogite. The present writer does not see any reason for assuming for the garnets of granitic rocks, also if there are some differences in the composition, quite a different origin from those of the gabbros and eclogites.

In both cases, however, he doubts whether the garnet can be regarded as a geological barometer. The granitic rocks studied by him often contain almandine in abundance. Some cases have been described already in this memoir. He has always found the garnet to be either a blastic (or »protoblastic»[3]) mineral or a product of the crystallization of that aplitic or pegmatitic magma which was the latest to solidify, obviously because it was rich in solvents.[4] Garnet also very regularly occurs in such basic rocks as have been influenced by granitic ichor.

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

— — The Charnockite Series, a Group of Hypersthenic Rocks in Peninsular India. Mem. Geol. Surv. India. Vol. 28, Part. 2, 1910, p. 161.

[2] Pentti Eskola, On the Eclogites of Norway. Vidensk.-Selsk. Skrifter, I Kl. N:o 8. 1921.

[3] M. Weber, Die Protoblastese. Geol. Rundschau, Bd. XIV, H. 4, pp. 337—351. 1923.

[4] Väyrynen thinks that the formation of the garnet in granitic rocks is due to a surplus of MgO and FeO, a deficiency of H_2O and K_2O. This conclusion is mainly based on chemical reasoning. However, the geological occurrence of the garnet, which occurs lining the walls of drusy cavities, as idioblastic crystals in schists and in crystalline limestones, in contact zones around eruptive masses, in the last crystallized aplitic veins of granites etc., seems to indicate that their formation has been in some way favoured by the presence of water.

(cf. Heikki Väyrynen, Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens, Bull. Comm. géol. Finl. N:o 57, p. 53.)

A very typical instance of the near connection between the formation of garnets and emanation from granites has been lately studied by the writer in the Enklinge area of schists, in the archipelago of Åland. Here strongly metamorphic basaltic rocks often show a transitional zone rich in garnet next to varieties which have been granitized.

At Kantalahti, on the Kola Peninsula, where »garnet-amphibolites» mentioned also by Eskola, occur, the writer has found migmatitic rocks extremely rich in garnet, occurring especially in their schistose parts. The »garnet-amphibolites» of this region have very probably been formed at the time when this granitization took place.

That the garnets both of the acid and basic rocks, possibly with the exception of the ijolite of Kuusamo (its titaniferous garnet is very different in composition from others; the whole rock is also, however, of rather doubtful origin) originated by metamorphic, autometamorphic, or ultrametamorphic processes, or by a »primary» crystallization in analogous conditions, or are in general due to hydato-pyrogene agencies, seems to be so generally true that we want very definite proofs before we accept the conclusion that the garnet of a gabbro is due mainly to abnormal pressure. Eskola's description of the Norwegian eclogites shows that they exhibit many of the phenomena characteristic to metamorphic rocks, such as kelyphitic intergrowths of the minerals etc., and that these eclogites occasionally occur as pegmatitic dykes which show border zones that have been changed into amphibolites. This change has taken place, as he admits, by the action of mineralizers, and before the last igneous rocks belonging to the same series erupted. Thus there seems to be evidence in favour of the assumption that a u t o m e t a m o r p h i c changes, which were due rather to the influence of mineralizers emanated from the magma than to a change of position of the rock masses, have taken place in these rocks before their final consolidation. If it is so, then also the formation of the garnet may be due to similar agencies, and there is no necessity to think that it should have been caused by an abnormally high pressure. In any case, the hypothesis about the existence of an eclogitic shell below the sialic crust is not yet sufficiently warranted by evidence won in the field. Thus far, it is more to be regarded as a deduction from the volume law which has not yet been empirically proved to be valid to such a degree as to allow of such bold extrapolations.

In general, when grouping the minerals of the metamorphic rocks, it seems necessary to take into consideration not only the indications they give about temperature (»geological thermometers») and pressure (»geological barometers») but also about the presence of water and other solvents (what may be called »geological hygrometers»). The augite of basaltic and gabbroid rocks is pyrogene in comparison with actinolitic hornblende which may be called a hydatopyrogene mineral, and the chlorite seems to indicate the presence of still more water. Also, if the individual minerals do not always give any certain indication in this respect, combinations of minerals may do it. The combination of plagioclase, augite, olivine and titanomagnetite is thus certainly indicative of a pyrogene origin, while during the formation of a rock consisting of plagioclase, actinolite and biotite, water has probably always been concomitant, whether the rock be metamorphic in the common sense or autometamorphic.

In the meteorites we are able to study rocks of purely pyrogene origin. The absence from them of such minerals as actinolite, epidote, garnet, chlorite and even micas, in whose formation water or pneumatolytic agencies have been active, is very conspicuous.

The importance of pressure has been overrated also in another way, when it has been thought that the mylonitisation of rocks has been a chief characteristic of metamorphic rocks, while it occurs mainly in those of alpine type. As many times emphasized by the present writer,[1] the Archæan rocks are often almost devoid of cataclastic phenomena visible to the naked eye. The »rock flowage» which Van Hise thought characteristic of what he called »anamorphism»[2] (a name which, by the way, is open to grave objections from a linguistic point of view, and also unnecessary, because most petrologists do not regard as metamorphic those changes which Van Hise called »katamorphic») is often practically absent from Archæan rocks which have however undergone a very strong metamorphism. The original features often remain so unchanged that not even faults of a millimeter's length may be detected. E. g. the amygdulæ of the metabasalts of the Pellinge area, or the narrow dykes of originally vitrophyric rocks which cut them in all directions, show almost no disfiguration at all. The granulation of minerals is often more a chemical phenomenon than a physical, i. e. it is due to solution. In other cases it is »deuteric», not truly secondary. Cataclasis is in general a destructive process, it is not creating new minerals and rocks. The use of the term dynamometamorphic for every metamorphic change which cannot otherwise be accounted for, should be discontinued, as not warranted by facts.

[1] J. J. Sederholm, Faltung und Metamorphose im Grundgebirge und in alpinen Gebieten. Geol. För. Stockholm Förh. Bd. 41, 1919, pp: 249—256.

[2] C. R. Van Hise, A. Treatise on Metamorphism. Mon. 47. U. S. Geol. Surv. 1904, p. 1011.

As has been emphasized by the present writer and many other petrologists, especially of the French school, a sufficient quantity of s o l v e n t s seems in most cases to be an indispensable condition of metamorphic changes. These solvents are in general exudations from eruptive masses, either visible or hidden at great depth. Most of that metamorphism which has been active in the Archaean, and especially in the coast regions of southern Finland, may thus (where it is not an autometamorphism) be designated as a r e g i o n a l c o n t a c t - m e t a m o r p h i s m.

The t i m e f a c t o r is also very important, especially determining the completeness of the metamorphic changes.

It is self-evident that the action of the solvents is dependent of t e m p e r a t u r e and p r e s s u r e. The writer, who has himself, at an early epoch, emphasized the significance of the v a r y i n g d e p t h, by no means wishes to minimize the importance of these factors, also that of pressure, although he thinks that it has sometimes been overrated, especially by drawing deductive conclusions.

It is hardly necessary, when discussing the »volume law», to point out that many of those petrologists who have believed in its validity, have at the same time given much importance also to other agencies, among them the solvents. As is well known, Professor Becke's own important petrological work has developed this line of research in many different directions, and the volume law has only been one of the working hypotheses which he has used, and he has applied it with great caution. It must also be admitted that the volume law has been of very great value as a working hypothesis, both because of its suggestiveness and because it has compelled the petrologists to a study of the metamorphic rocks by more exact methods than before, taking advantage also of the important results of modern physico-chemical research.

These new methods, whose aim seems to be to revolutionize petrology, are in large measure founded on the ideas of Becke and Grubenman, and also the idea embodied in the volume law has here played a considerable rôle.

The writer will here say some words also about this trend of modern petrology, although this discussion has a less intimate connection with the subjects treated in this memoir.

Grubenmann divided the metamorphic rocks in three groups, each corresponding to a different zone of depth. In the latest edition, published in collaboration with Professor Niggli, this subdivision in three groups has not been quite so much emphasized. Becke, again, has always used a dual division.

Grubenmann's ideas, which were in full agreement with Becke's fundamental notions, in many ways foreshadowed those of the modern physico-chemical school. Thus, for instance, he regarded the eclogites as rocks which had always been formed in the lowest zone, thus at very great depth, although not by the direct crystallisation of a magma.

Logically, it is possible to develop Grubenmann's idea of the existence of such zones of depth, characterized by different associations of metamorphic minerals, in still greater detail. Admitted that the silicatic rocks very easily respond to changed conditions as to pressure and temperature, we may be able to distribute the metamorphic rocks, by classifying them, not only on three zones of depth, but on a great number of subdivisions, each corresponding to a certain chemical equilibrium, characterized by special conditions of pressure and temperature. And, as every mineral association may be sooner or later artificially reproduced, we may be able to refer each metamorphic rock which an empirical study brings to our knowledge, to some of these synthetic types whose conditions of origin are exactly known. We could then classify the metamorphic rocks, as Eskola has proposed, in groups (he calls them »mineral facies») each of which represent a certain chemical equilibrium,[1] and the origin of which would have to be elucidated by laboratory methods.

This conception opens an alluring vista over a development where we shall be able more and more to substitute for the vagueness of the older, mainly descriptive methods, new exact physico-chemical notions. Every petrologist will be glad of the progress made along this line of research, also if he cannot entirely share the most fargoing conceptions of the protagonists of the physico-chemical school, nor be ready to abandon the older methods of a mainly descriptive study.

As has been recognized also by the master Becke himself, it is doubtful wether the metamorphic changes really show such a great regularity as to correspond to an ideal classification.[2]

The silicatic rocks by no means easily and rapidly respond to changed conditions of pressure and temperature. As has been pointed out by several previous writers, rocks solidified at the greatest depths may be brought to the surface by erosion without materially

[1] P. Eskola, The Mineral Facies of Rocks. Norsk. Geol. Tidskr. Vol. VI, pp. 143—194. 1920.

[2] F. Becke, Zur Facies-Klassifikation der metamorphen Gesteine. Tschermaks Min. Petr. Mitt. Bd. 35, pp. 215—230. 1922.

changing their mineral composition, also when they have certainly not undergone »quenching». Other rocks formed on or near to the surface, as e. g. some of the basalts of the Pellinge region, may be sunk to deep levels where granitic magma is able to exist in a fluid state and where pressure and temperature have obviously been very high, without showing any more conspicuous changes in their composition.

The analogy between the silicatic rocks undergoing metamorphic changes and those marine salts whose study gave the impetus to the use of the phase rule by petrological investigations, is in general by no means complete. The salts are easily solved, and all their compounds react on each other at each new change of the conditions. In the metamorphism of silicatic rocks, there may be instances, as e. g. when an eruptive magma with high temperature suddenly acts upon its contact zone, where a similar complete »revaluing of all values» takes place.[1] In most cases, however, the changes are slow and gradual, and especially in the initial stages, but probably also at an advanced state of metamorphism, often only some of the minerals may take part in the reactions. Thus, for instance, the epidotization of the plagioclase, the chloritization of the biotite or the pyroxene, the serpentinization of the olivine, may leave other constituents more or less intact. The study of the »synantetic minerals», again, has shown that in many cases metamorphic minerals are mainly formed by an interchange of material between two adjacent minerals, however, with some addition of material from more distant sources. It is true that the forces set in play by these changes commonly have some influence also on other minerals of the same rocks, but it is conceivable, and certainly occurs in nature, that some minerals, e. g. the quartz, often also much of the felspars, remain chemically almost unaffected, while the other are strongly changed. Relics occur in metamorphic rocks not as exceptions, but in many of them as a rule, and already this circumstance restricts the application of the phase rule in their study.

We have here stated that rocks which have originally been basalts of nearly uniform composition and which have been metamorphosed under identical conditions of pressure and temperature, show a very varying secondary mineral composition. Rocks which have originally been glassy are very different from those which were doleritic, and in general we have found that there are many exceptions

[1] V. M. Goldschmidt, Die Kontaktmetamorphose im Kristianiagebiet. Vidensk.-Selsk. Skrift. Mat.-Naturw. Kl. N:o 1. 1911.

to the thesis of the physico-chemical school, according to which the mineral composition of any rock is controlled only by temperature, pressure and chemical composition. On the contrary, we have found that original differences in texture and mineral composition may have an important bearing on the secondary composition, also at a very high degree of metamorphism.

As many of the metamorphic rocks are in a state of imperfect equilibrium, we must, as was pointed out already long ago by Johnston and Niggli, in their classification group them around those equilibrium systems which have been studied chemically, and cannot subdivide them in equilibrium types to which only some of them belong.[1] Not only have many of the metamorphic rocks been only partly changed and contain a great quantity of relict primary minerals, but even when the rocks contain only secondary minerals, there may be such among them as represent different conditions of origin.

Rocks are things with a history which may be read by the study of their present characters. Geology is a science of time, studying the succession of events. It is not applied physics or chemistry, although these sciences may give an important aid to geology.

It is just because the metamorphic rocks represent very different stages of change, that their empirical study, by the aid especially of the microscope, is so fascinating and reveals so much about the processes which the rocks have undergone.

Petrological field work, and the study of all the minute features which indicate changes of the minerals, may afford evidence for deciphering the metamorphic rocks as important as that revealed by the new laboratory methods. At the present moment, of course, the latter appear most promising, because they are new, and therefore throw a sudden light on so many questions. It will probably soon be possible, thanks to the endeavours of petrologists like Niggli, Goldschmidt, Eskola and others, to get a new subdivision of the metamorphic rocks grouped around their equilibrium types. But it is certain that a future classification of metamorphic rocks will show their rich variety and account for their innumerable transition stages, and not be a rigid scheme giving place only to equilibrium types which are rather rare in nature.

Moreover, we have to remember that the facies of a metamorphic rock is determined not only by their mineral composition but also

[1] John Johnston and Paul Niggli, The General Principles Underlying Metamorphic Processes. Journ. Geol. Vol. XXI, pp. 481—516 and 588—624. 1903.

by their texture. A fine-grained phyllite, still showing many minute features of a sedimentary rock, may be composed of the same minerals as a coarse-grained mica-schist which occasionally becomes almost as massive as a granite. Both of these schists can hardly be said to belong to the same metamorphic facies. Long after the time when a certain chemical equilibrium has been reached, the minerals of the rock may continue to grow, being solved and re-crystallized, whereby the rock is strongly changed, although not so much as to its chemical composition.

ON AUTOMETAMORPHISM, ANATEXIS, PALINGENESIS ETC.

While the changes of the leptites and the basic dyke rocks in the present region, as well as of the supercrustal and dyke rocks in the area described in the first memoir of this series, are due to a metamorphism caused by intruding granites, the changes of the minerals of the granites themselves is due to a metamorphism caused by the same granite that was changed. It may thus be designated as an a u t o m e t a m o r p h i s m. It has in each case been ended before the deposition of the supercrustal rocks which separate the granite in question from the next following, or the eruption of the dykes connected with volcanic rocks.

To this autometamorphism is mostly due the cataclasis of the granitic rocks and in part also their foliation. These changes are not »dynamometamorphic» in the common meaning of the word, since they are not truly secondary and are not due to the action of orogenetic processes later than the eruption of the same granites. The ideas of the writer have apparently more similarity with those which Weinschenk expressed in his teory on p i e z o-c r y s t a l l i z a t i o n.[1] However, this petrologist thought that pressure on a magma which was still in large measure fluid could cause the parallel orientation of the flakes of mica. A fluid, however, can only receive a parallel texture by fluidal motion, but when the foliation of the gneissose granites originated, a real cataclasis of the minerals in rock masses which were already solid must have taken place. But this mylonitization is deuteric, not truly secondary, for not only does the mica which coats the foliation planes belong to the same granitic magma, but also veins associated with it may be later than the foliation. Occasionally, even a complete recrystallization of an already solid

[1] E. Weinschenk, Dynamométamorphisme et piézocristallisation. Mém. prés. au Congr. géol. intern. VIII France, pp. 1—17. 1900.

granite may take place when it is soaked with its own ichor. The movements in the granitic masses have continued until a very late epoch of their consolidation, when real faults, at which the walls are coated with granitic minerals, could originate.

All these autometamorphic phenomena are least conspicuous in the youngest granites. These have solidified in higher levels, after having lost a great part of their water, and in them the movements of the underlying magma masses have made themselves less felt. The granites of the middle (second) group are connected with abundant masses of aplites and pegmatites, and their magma has consequently been rich in ichor. Here we find the strongest solving action both on the surrounding rocks and on the already solidified portions of the same granites. The eruptive processes have also had the most complicated character, with a steady repetition of new eruptions. The gneissose varieties of these granites have mostly originated through the assimilation of older, schistose rocks.

The oldest granites are the most gneissose, not, as was earlier thought, because they have taken part in a greater number of orogenetic processes, but because their protrusion was so intimately connected with the great mountain-making processes at the close of the Svionian period.

We thus arrive at a conception of the solidification of the granites which is rather different from that which has been earlier prevalent also in Finland. They have been in many ways remoulded before they got their definite shape, but this remoulding took place during the period of their protrusion.

That protrusion took place under a steady brecciation of the overlying rocks. The term »overhead stoping» does not, however, give a quite adequate idea of the whole process. In this a solution and assimilation of the scattered fragments played a considerable rôle, and the granitic magma often advanced »à tâche d'huile» (Termier). As has been shown by Goldschmidt in his masterly studies of the granitization phenomena of the Bergen district,[1] what the present writer calls the granitic ichor may be able to solve away, also without a stronger brecciation of the invaded rock, certain portions of mica-schists which are replaced by new minerals. We find evidence in the same direction everywhere also in the regions now in question. The ichor of the granite has been able intimately to penetrate the older rocks, giving them a new, »palingene» eruptivity, even in cases when

[1] V. M. Goldschmidt, Die Injectionsmetamorphose im Stavanger—Gebiete. Vidensk.-Selsk. Skrift. I. Mat. naturw. Kl. N:o 10. 1920.

their chemical composition has remained unchanged. In most cases, however, they have been gradually changed, when soaked with the granitic magma, or its ichor, and their composition has more and more approached that of the new granite.

This intimate penetration, and a continued mechanical splitting of the older rocks, have gone hand in hand, and so has originated the Protean variety of migmatitic rocks of which we have here described many different types. It has been one of the main purposes of these memoirs to develop the classification and nomenclature of these mixed rocks, the product of processes which we may with Holmquist designate as u l t r a m e t a m o r p h i c, because they surpass in strength those which take place by the metamorphism.

The writer, however, does not think that they are only stronger in grade, but also essentially different, because leading to the formation of rocks which are no more crystalline schists, but in which at least one of the components behaves as an eruptive. He therefore prefers the name a n a t e x i s which corresponds to r e f u s i o n, although in some cases r e - s o l u t i o n would be more appropriate.

The word refusion does not imply that a dry fusion should have taken place in such a way that the basic magma existing at great depth forced its way upwards through overhead stoping and gradually became more and more acid, in the measure as it assimilated rocks richer in quartz and felspar. The anatexis of the crustal granitic masses has been caused, in the opinion of the present writer, mainly by the influence of emanations from the abyssal magma, whatever may have been its composition. The granitic magma, thus formed, forced its way further upwards, also by stoping. The word p a l i n g e n e s i s which the writer has used alongside with the designation anatexis, refers to the geological age, meaning that the rock in question has been reborn, in other words received a new eruptivity.

Such rocks as have undergone anatexis are now generally designated with very different names. Many of them are called g n e i s s e s, a name which says very little, as there are gneisses of eruptive, sedimentary and hybrid origin. The name injection gneisses conveys the idea that the magma has been forcibly immitted, as by squirting, and the term v e i n e d g n e i s s e s is applicable only on the rocks where the granite really forms well defined veins. If we then call other of these mixed rocks e r u p t i v e b r e c c i a s, we get the impression that they are entirely different from the veined gneisses, while both are often only varieties of the same rock masses. Moreover, the granite becomes in many cases preponderant in these mixed rocks, and then neither the name gneiss nor breccia is entirely appropriate.

For all these reasons, the present writer thinks it necessary to use a designation for these hybrid rocks which really characterizes their appearance and origin. They look like mixed rocks, and they originated by the mixture of older rocks and a later erupted granitic magma, and therefore the name m i g m a t i t e is the most appropriate. The difference between an a r t e r i t e (arteritic migmatite), or a veined gneiss, and an a g m a t i t e, or an eruptive breccia, lies mainly therein that in the former a schistose rock has been subdivided especially along the planes of foliation, while in the other case massive, sometimes also schistose, rocks have been broken up into angular, scattered fragments. The terms n e b u l i t i c g r a n i t e s, comprising migmatitic granites where the fragments of foreign rocks have been almost completely assimilated, and s t i c t o l i t e s, or granites where spots of blastocrystalline minerals are the only reminiscences of such assimilated fragments, make this series complete for purposes of classification.

What adds to the variety of these mixed rocks, is the great difference of their components. The older components of the migmatites may be schists of varying composition, leptites, mica-schists, quartzites and tuff-schists, but also metabasalts, gabbro etc., while the eruptive components may belong to different granites, sometimes to two and even more of them. At the western contact of the Onas granite, of the Borgå—Pellinge area, the writer has studied eruptive breccias in which at least three, possibly four granites of different ages occur as veins, and such »p o l y m i g m a t i t e s» are in general rather common in the coast regions of southern Finland. In the present region, they commonly contain veins of only two granites.

With a more complete assimilation of the older rocks, it will in some cases be rather difficult to determine the original character of the older components, e. g. to discriminate between granitized gneissose granites and very strongly granitized leptites. In most cases, however, so much of the original character is preserved at least in some of the fragments, that we are able to say what the invaded rocks have originally been like.

In any case, the rocks in question are certainly mixed rocks, since even if a part of the veins may be derived from older material which has been dissolved, this dissolution has always, in the present regions, where the migmatitic rocks are perhaps more typical and manifold than anywhere in the world, taken place in connection with the protrusion of a granitic magma. There is hardly any granitic vein in these regions about which it is not possible to determine to which granite it belongs, and there is no granite which has not created migmatites, also such showing the characteristic ptygmatic folding of the veins. However, the two youngest granites have done it in a very small measure.

The essential unity of the granitization phenomena is obvious. There is a difference between them only as to grade, not in principle. If the veined rocks with a local extension have been formed by the injection of a real magma, the same is true also as to the migmatites connected with the older granites.

The hypothesis of an anatexis, as defined by the present writer, implies that part of the material of the younger rocks has been derived from older rocks, in cases where these have had a suitable composition. But it is impossible to think that the veins should be exclusively of metamorphic origin. That is conceivable when the rocks which have undergone anatexis are older granites, whose composition does not differ so much from that of the younger ones. But even in these cases we find a penetration of magma arriving from greater depth. In other cases we find granitic veins intimately injecting also such rocks as metabasalts, quartzites, even limestones which do not contain the constituents necessary to form a granite. When migmatites are formed by the mixing of leptitic or metabasaltic rocks and of a granite, the quantity of the former may be only a small part of the whole rock, while the rest is granite.

The writer cannot therefore share the opinion of Holmquist, according to whom many of the veined rocks which the writer has called arterites should be regarded as v e n i t e s, i. e. as rocks where the veins should be mainly exudates from the surrounding rocks. This idea has been prevalent in Sweden since older times, whereby in general no nearer explanation has been given of the cause of the ultrametamorphic changes. As the present writer also thinks that during anatexis a »refusion», or »re-solution» of the older rocks takes place in large measure, especially at very great depth, and Holmquist, on the other hand, admits that granitic magmas may develop out of the formation of »venitic» veins, the difference in principle is not very great between these conceptions. The present writer

[1] P. J. Holmquist, Typen und Nomenklatur der Adergesteine. Geol. För. Stockholm Förh. Bd. 43, p. 612—631. 1921.

— — Adergneisbildung und magmatische Assimilation im Grundgebirge Schwedens. Geol. För. Stockholm Förh. Bd. 29, pp. 313—354. 1907.

— — Utkast till ett bergartsschema för urbergsskiffrarna. Ibid. Bd. 30, pp. 269—293. 1908.

— — The Archæan Geology of the Coast-Regions of Stockholm. Ibid. Bd. 32, pp. 789—908. 1910.

has, even earlier than Holmquist, used the same expression as he favours; in a discussion in 1908 he pointed out that the different kinds of magmas (which Holmquist called warm and cold magmas) would »in a certain way correspond to arterial and venous blood», but he asked Holmquist how they could avoid mixing, when separate systems of veins do not exist in the rock masses (cf. p. 88).

The difference between the two antagonistic views lies mainly therein, that Holmquist's is more neptunistic, that of the writer more plutonistic. The latter thinks that the granitic masses, which have been mobilized already at a very great depth, and their emanations, invade the solid rock masses rising from below, when their van-guard of pegmatitic veins may advance even long before the great army, in some cases joining with revolutionary forces of the country invaded. To Holmquist, the granitic veins of the mixed rocks are in large measure due to the action of such revolutionists, acting alone, on their own initiative, and often having little direct connection with the invaders.

The invading granite has commonly a different composition from the rocks invaded. This difference may in some cases be measured by a small percentage, but is often considerable. The invading granite retains its former composition, in spite of the assimilation on an immense scale. Thus, the assimilation process must have been followed by a d i f f e r e n t i a t i o n. It is, however, very difficult to find in the field syntectic rocks or other evidence of this process. The basic rocks dissolved in the granite seem to disappear as by magic, perhaps escaping together with the volatile, or fluid constituents. Only in rare cases phenomena are observed that seem to give an indication of what has happened. So the »b a s i c h a l o s» around fragments in the Obbnäs granite tell of a diffusion extending to a certain limit. In greater fragments in the same granite the femic constituents have been concentrated in certain parts, which has even received an ultrabasic composition. In the eruptive breccias of Obbnäs Udd a certain segregation of the femic and the sialic portions is conspicuous, and it seems even possible that the former has crept down along the contact and formed lamprophyric rock varieties.

Such lamprophyric or »epibasitic» rocks occur in all Finnish granites, excepting perhaps the rapakivi. They are found also in the present region, although in the Hangö granites only in very small measure. The writer has studied them in other parts of the coast regions where they are much more typical, and hopes that their study will give a clue to the enigma of the differentiation processes connected with the anatexis, as well as to several other petrochemical problems.

In general, the phenomena here studied show, in spite of their unity in the main, a rather varying aspect in different regions, and their study must therefore be continued.

The circumstance that gives most interest to these studies is that we are able here to follow processes which have taken place at very great depths, greater than that in which most other eruptive rocks have solidified, or rock masses have been metamorphosed.

Terms such as ultra-metamorphism, ultra-metasomatism etc. already indicate that we have here to do with phenomena belonging in a certain way to an ultra-petrology.

It is true that if we take into consideration the size of the globe as a whole, our observations even of rocks from the deepest levels which erosion has revealed, reach only skindeep towards the interior of the earth. But in the progress downward of geology they may anyhow allow us to advance a little step forwards.

EXPLANATIONS OF THE PLATES.

All microphotographs have been taken by the author.

PLATE I.

Fig. 1. Leptite from the N. W. shore of Bålaskär in Ingå. Mineral composition: oligoclase, quartz, hornblende, biotite. Cf. p. 6. Crossed nicols. 10 ×.

Fig. 2. Porphyritic gneissose granite from Strömsö, W. of Barösund in Snappertuna. Min. comp.: quartz, oligoclase, microcline, biotite. Cf. p. 10. Crossed nicols. 10 ×.

Fig. 3. Gneissose granite from Ändö in Ingå. Min. comp.: microcline, quartz, oligoclase, biotite. C . p. 15. Analysis p. 16. Crossed nicols. 16 ×.

Fig. 4. Myrmekite in porphyritic granite from Flakholm in Ingå. Cf. p. 11. Crossed nicols. 17 ×.

Fig. 5. Antiperthite in gneissose granite from Påvskär in Ingå. Cf. p. 13. Analysis p. 16. Crossed nicols. 10 ×.

Fig. 6. Oligoclase showing faulted lamellæ in gneissose granite from Påvskär in Ingå. Cf. p. 13. Crossed nicols. 10 ×.

PLATE II.

Fig. 1. Older pegmatite, strongly crushed, from Rörörn in Ingå. Min. comp.: Oligoclase, quartz, microcline, biotite. Cf. p. 15. Crossed nicols. 9 ×.

Fig. 2. Older aplite from Lövgrund in Ingå. Min. comp.: quartz, microcline, oligoclase, biotite. Cf. p. 14. Crossed nicols. 16 ×.

Fig. 3. Oligoclase granite from the western shore of Påvskär in Ingå. Min. comp.: quartz, microcline, biotite, hornblende. Cf. p. 15. Crossed nicols. 9 ×.

Fig. 4. Lamprophyre from Påvskär. Min. comp.: andesine, diopside, hornblende, magnetite, biotite, apatite. Cf. p. 14. Parallel nicols. 17 ×.

Fig. 5. Lamprophyre from W. Bågaskär in Ingå. Min. comp.: hornblende, andesine, biotite, ore, apatite. Cf. p. 24. Analysis p. 24. Parallel nicols. 16 ×.

Fig. 6. Metabasalt from the lightest dyke on Påvskärs Westgrund. Min. comp.: andesine, diopside, brownish-green hornblende, biotite, ore. Cf. pp. 57—58 and 62. Parallel nicols. 17 ×.

TABLE III.

Fig. 1. Metabasalt from the middle of the broadest dykes on Påvskärs Westgrund. Min. comp.: andesine, greenish-brown hornblende, diopside, ore, biotite. Cf. pp. 58 and 62. Analysis p. 60. Parallel nicols. 15 ×.

Fig. 2. Metabasalt from the broadest dyke in the rock surface shown in fig. 1, Plate IX, on the eastern shore of Påvskär. Min. comp.: andesine, diopside, hornblende, biotite, ore, apatite. Cf. p. 59. Parallel nicols. 15 ×.

Fig. 3. Metabasalt from the contact zone of the broadest dyke on Påvskärs Westgrund. Min. comp.: green compact hornblende, andesine, biotite, titanite. Cf. pp. 58 and 62. Analysis p. 60. Parallel nicols. 17 ×.

Fig. 4. Metabasalt from the narrowest dyke on Påvskärs Westgrund. Min. comp.: brownish green hornblende, andesine, ore, biotite, Cf. p. 58 and 62. Parallel nicols. 17 ×.

Fig. 5. Metabasalt from the darkest dyke on Påvskärs Westgrund. Min. comp.: brownish-green hornblende, andesine, biotite, ore. Cf. 58—59 and 62. Parallel nicols. 17 ×.

Fig. 6. Metabasalt from the broadest dyke on the western shore of Påvskär. Min. comp.: hornblende, andesine, biotite, ore, Cf. p. 59. Parallel nicols. 9 ×.

PLATE IV.

Fig. 1. Metabasalt from Granö in Ingå. Min comp.: green hornblende, andesine, titanite, biotite. Cf.: p. 59. Parallel nicols. 15 ×.

Fig. 2. Metabasalt from Lövgrund in Ingå. Min. comp.: andesine, hornblende, biotite, titanite, ore. Cf. p. 59. Parallel nicols. 16 ×.

Fig. 3. Hangö granite from Täckter in Ingå. Min. comp.: microcline, (microperthite) quartz, oligoclase. Cf. p. 65. Crossed nicols. 17 ×.

Fig. 4. Hangö granite from Täckter. Min. comp.: oligoclase, with border zone of albite and myrmekite, microcline, quartz. Cf. p. 65. Crossed nicols. 25 ×.

Fig. 5. Hangö granite from Sonasund in Ingå. Min. comp.: microcline, cataclastic quartz, oligoclase, biotite. Cf. p. 65. Crossed nicols. 11 ×.

Fig. 6. Aplite belonging to the Hangö granite, from Granö in Ingå. Min. comp.: plagioclase, microcline, quartz, epidote. Cf. p. 68. Analysis p. 68. Crossed nicols. 17 ×.

PLATE V.

Fig. 1. Lamprophyric rock, strongly schistose, from a narrow zone in a pegmatite dyke on Brändö Harun in Ingå. Min. comp.: biotite, oligoclase, microline, quartz. Cf. pp. 77—78. Crossed nicols. 17 ×.

Fig. 2. Granite from transitional zone between gneissose granite and Hangö granite. Northern shore of Påvskär. Min. comp.: chlorite with calcite, oligoclase, microcline, quartz, biotite. Cf. p. 86. Crossed nicols. 17 ×.

Fig. 3. Microcline with resorption cavities filled with biotite and quartz in granite from a transitional zone between gneissose granite and Hangö granite, on the northern shore of Påvskär. Min. comp.: microcline, oligoclase, quartz, biotite. Cf. p. 87. Crossed nicols. 30 ×.

Fig. 4. Granite from transitional zone between gneissose granite and Hangö granite. Northern shore of Påvskär. Min. comp.: microcline, quartz, oligoclase, biotite. Cf. p. 87. Crossed nicols. 12 ×.

Fig. 5. Oligoclase with bent lamellæ in granite from a transitional zone between gneissose granite and Hangö granite on the northern shore of Påvskär. The oligoclase in surrounded by microcline, quartz, chlorite, calcite etc. Cf. p. 87. Crossed nicols. 11 ×.

Fig. 6. Granite showing gneissose texture, from transitional zone between gneissose granite and Hangö granite on the northern shore of Påvskär. Cf. p. 87. Crossed nicols. 10 ×.

PLATE VI.

Fig. 1. Obbnäs granite from Obbnäs Gård in Kyrkslätt. Min. comp.: oligoclase, microcline, quartz, biotite, titanite, unknown mineral lying between the lamellæ of the biotite. Cf. p. 91. Crossed nicols. 11 ×.

Fig. 2. Biotite with strongly folded lamellæ in the Obbnäs granite, from the quarry at Obbnäs fjärden. Cf. p. 91. Crossed nicols. 11 ×.

Fig. 3. Basic fragments in the Obbnäs granite from the quarry at Obbnäs fjärden. Min. comp.: biotite, partly in symplektitic intergrowth with quartz, andesine, hornblende. Cf. p. 94. Crossed nicols. 17 ×.

Fig. 4. The same rock as in fig. 3. Min. comp.: andesine, biotite, partly symplektitic, hornblende encroaching upon andesine. Cf. p. 94. Crossed nicols. 19 ×.

Fig. 5. Bodom granite from Meilby in Esbo. Min. comp.: xenomorphic biotite, microcline, oligoclase, quartz. Cf. p. 95. Crossed nicols. 16 ×.

Fig. 6. Bodom granite from Rödskog in Helsinge. Min. comp.: oligoclase with a border zone of albite, microcline, quartz etc. Cf. p. 95. Crossed nicols. 17 ×.

PLATE VII.

Fig. 1. Microcline in the Bodom granite with a granulated zone rich in myrmekite. Sjöskog in Helsinge. Cf. p. 95. Crossed nicols. 17 ×.

Fig. 2. Bodom granite from a locality E. of Bodom gård in Esbo. Min. comp.: biotite which is xenomorphic towards quartz, microcline, oligoclase, fluorite (in the upper part of the section). Cf. p. 95. Crossed nicols. 19 ×.

Fig. 3. »Syntectic» diorite from island S. of Professor Kajanus' cottage, Obbnäs udd, Kyrkslätt. Min. comp.: oligoclase, quartz, microcline, hornblende, biotite. Cf. p. 104. Analysis p. 103. Crossed nicols. 11 ×.

Fig. 4. Lamprophyric rock with a porphyroblast of plagioclase from Stor Ådgrund, at the boundary of Kyrkslätt, Sjundeå and Ingå. Min. comp.: plagioclase, hornblende, biotite, ore, titanite. Cf. p. 108. Crossed nicols. 18 ×.

Fig. 5. The same rock as in Fig. 4, with a secondary crystal of quartz. Cf. p. 108. Crossed nicols. 18 ×.

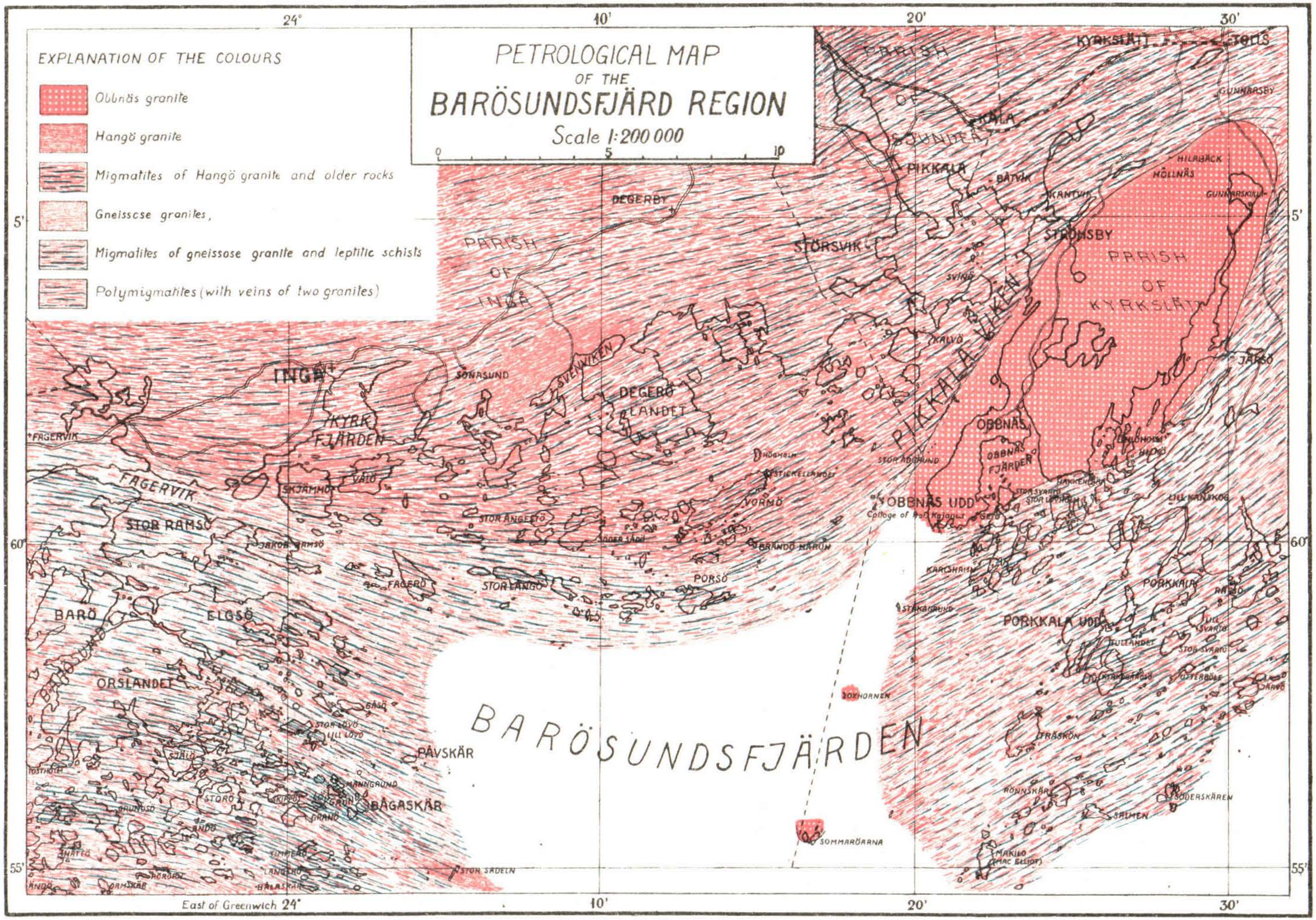
Fig. 6. The same rock as in fig. 4, showing a micropegmatitic intergrowth of quartz and plagioclase. Cf. p. 110. Crossed nicols. 75 ×.

PLATE VIII.

Fig. 1. Metabasaltic dyke, in part well preserved, in part folded, cutting gneissose granite (white) and leptites and intersected by palingenetic granite (dotted). Flatlying rock surface at the northern shore of the island of Påvskär. 1:20 nat. size.

PLATE IX.

Fig. 1. A typical example of palingenesis. Map of rock surface at the eastern shore of Påvskär in Ingå. 1:100 nat. size.
To the left l e p t i t i c s c h i s t s, (drawn after nature), cut by straight veins of p e g m a t i t e, (white) belonging to the Hangö granite, to the right g n e i s s o s e g r a n i t e (shaded) penetrated by H a n g ö g r a n i t e (w h i t e). Dykes of m e t a b a s a l t (b l a c k) cut the leptitic schists and have also continued through the gneissose granite, but are now subdivided in a number of fragments. Cf. pp. 48—50.



MAANMITTAUSHALLITUKSEN KIVIPAINO, HELSINKI 1926.

Fig. 1.

Fig. 2.

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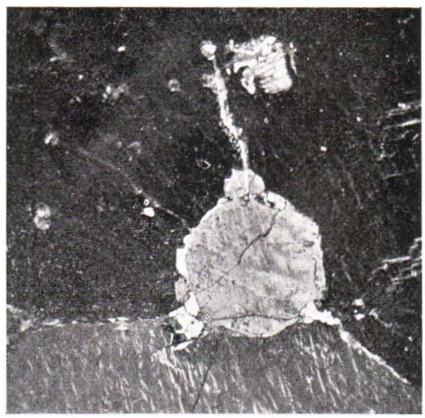

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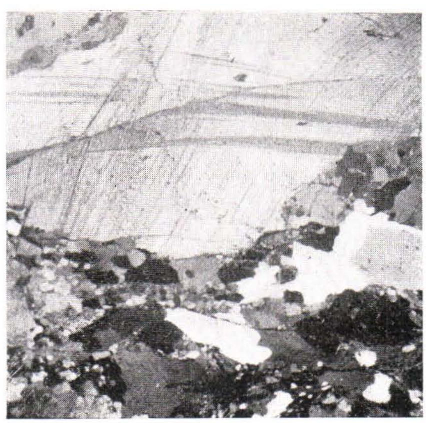

Fig. 6.

J. J. Sederholm: On Migmatites II.

PLATE II.

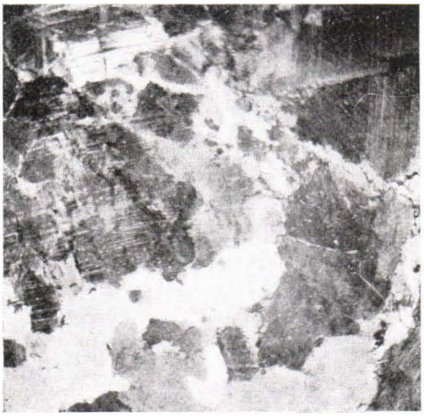

Fig. 1.

Fig. 2.

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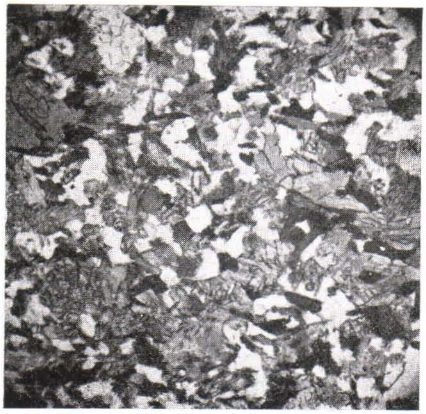

Fig. 5.

Fig. 6.

J. J. Sederholm: On Migmatites II.

Fig. 1.

Fig. 2.

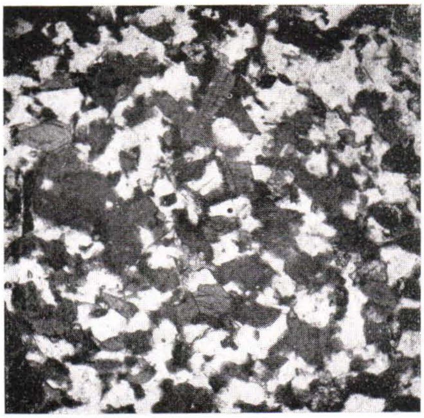

Fig. 3.

Fig. 4.

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Fig. 1.

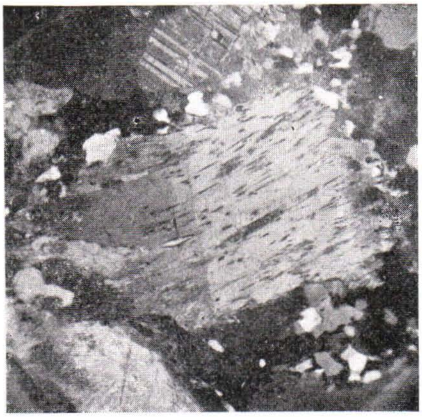

Fig. 2.

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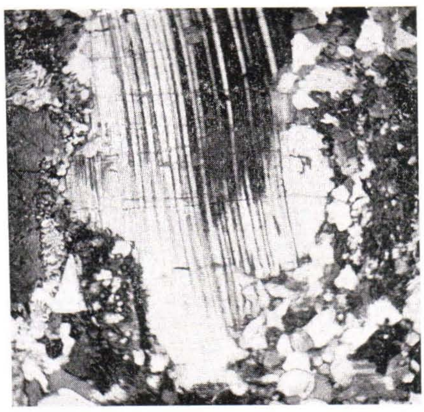

Fig. 5.

Fig. 6.

J. J. Sederholm: On Migmatites II.

PLATE VI.

Fig. 1.

Fig. 2.

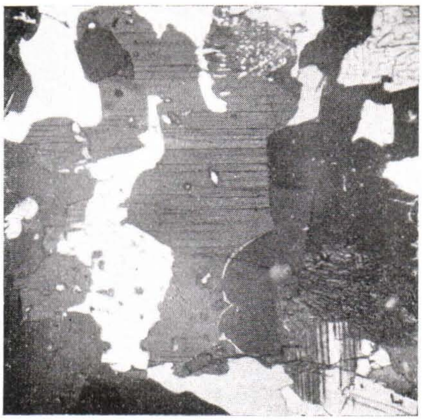

Fig. 3.

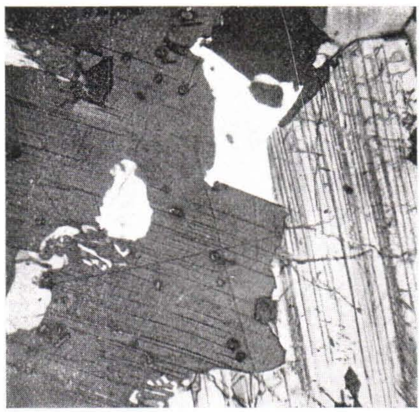

Fig. 4.

Fig. 5.

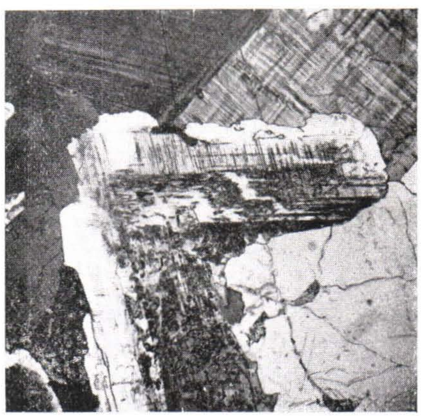

Fig. 6.

J. J. Sederholm: On Migmatites II.

PLATE VII.

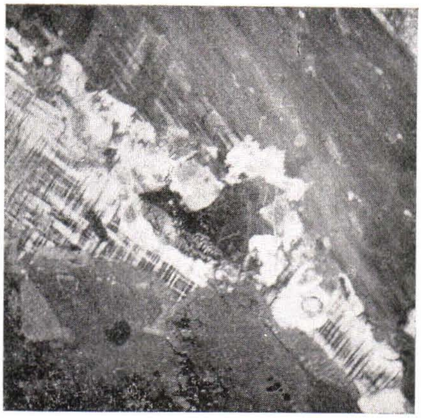

Fig. 1.

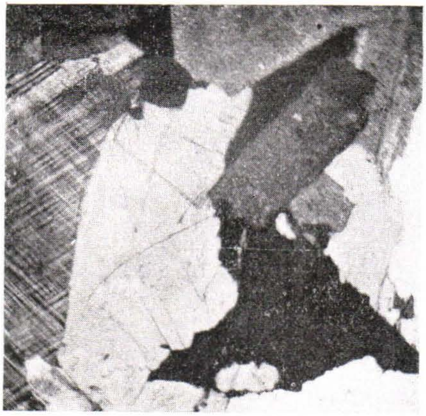

Fig. 2.

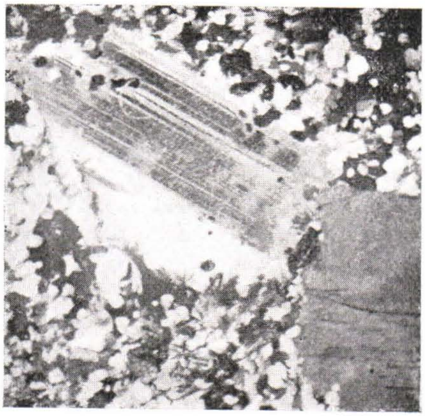

Fig. 3.

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J. J. Sederholm: On Migmatites II.

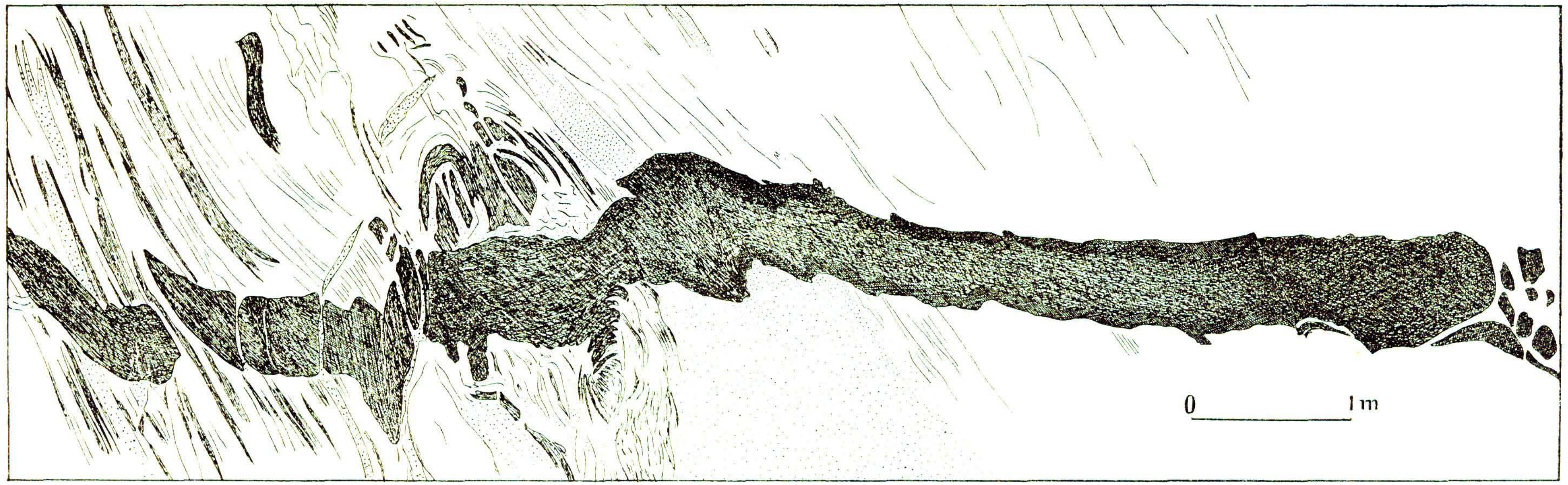

Fig. 1. Metabasaltic dyke in part intersected by palingenetic granite. Northern shore of the island of Påvskär. 1 : 25 of the nat. size.

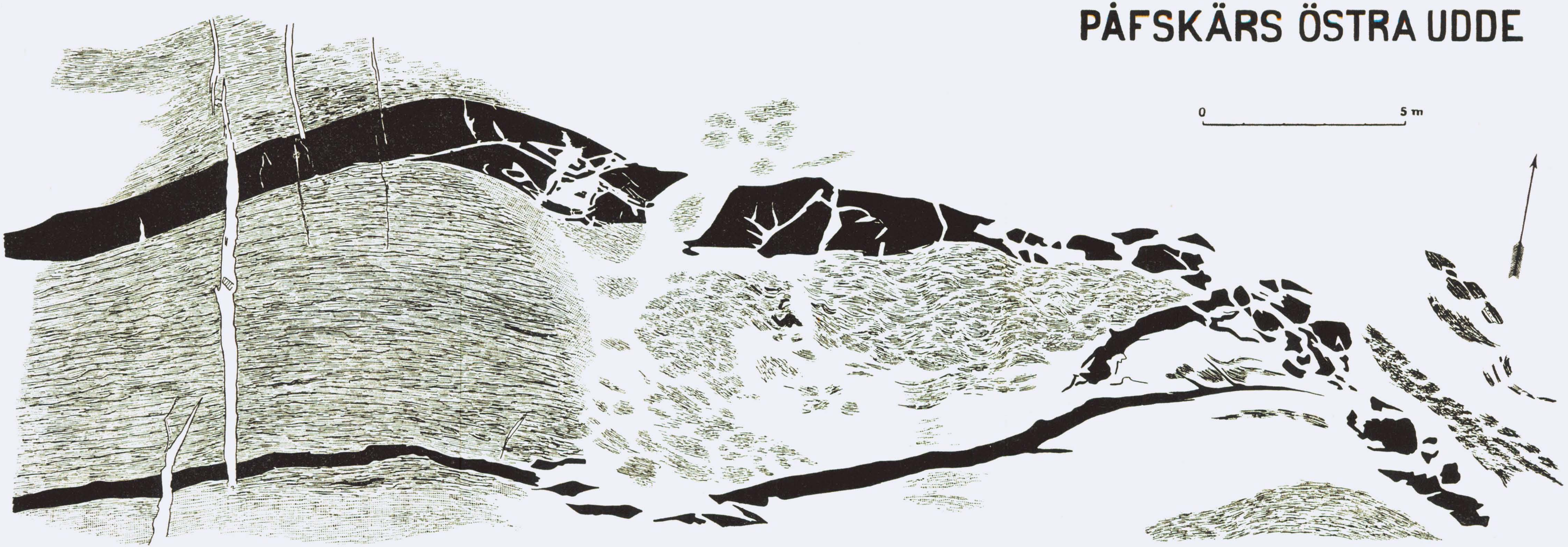

Fig. 1. A typical example of palingenesis. Map of rock surface at the eastern shore of Påvskär in Ingå. 1: 100 nat. size. Leptites (to the left), gneissose granite (shaded), metabasalt (black). Hangö granite (white).

J. J. Sederholm: On Migmatites II.

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