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AARNO KAHMA

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Helsinki 1951. Valtioneuvoston kirjapaino

INTRODUCTION

The main part of the ancient rocks of Finland belongs to Archaean formations which have been involved in one or more orogenic cycles. In a few limited areas surrounded by metamorphic Archaean, the age of the rocks is also considered pre-Cambrian despite the fact that no traces of metamorphism are disclosed by the rocks concerned. This conclusion has been reached on the basis of the sedimentary rocks occurring in those areas. The rocks of these pre-Cambrian, and still post-Archaean regions, which occur also in Sweden and Eastern Fennoscandia, were collected under the designation »Jotnian formation» by Sederholm (1897, p. 36). The most complete and best preserved rock series of Jotnian age in Finland is presented by the Satakunta formation situated in southwestern Finland approximately in a triangle formed by Lake Pyhäjärvi and the two towns of Pori and Uusikaupunki (Fig. 1).

The Jotnian formation of Satakunta consists of three kinds of rocks, *viz.*, rapakivi granite, sandstone, and diabase. The rapakivi granite, a reddish, porphyritic, unoriented, potash-rich granite, forms a large pluton (so-called Laitila rapakivi massif) in the southern part of the Jotnian area into which the younger rapakivi varieties have intruded (see map Plate V). The rapakivi granite contains in abundance large ovoid orthoclase phenocrysts (Fig. 15 and 16, Pl. IV) sometimes surrounded by oligoclase mantles. The rapakivi granite cuts the Archaean rocks. This fact, together with the intrusive character of the contacts, clearly shows that the rapakivi is younger than the Archaean.

The arkosic sandstone, »the oldest red sandstone», occupies a wide area on the northwestern side of Lake Pyhäjärvi. On account of the vertical faulting which has probably taken place at its boundaries, the sandstone area has sunk with respect to its surroundings and thus, in spite of its friability, has been protected from erosion. The sandstone contains rounded quartz and feldspar grains with some mica cemented by siliceous material. The nearly horizontally stratified sandstone is usually medium-grained, containing thin inter-stratified layers of dark, pelitic material. Moreover, in the NW part of the sandstone area there are conglomerate varieties (Laitakari 1925, p. 14), the pebbles of which consist of pure vein quartz. In addition, near the town of Pori, sandstone conglomerate boulders are found, the pebbles of which are similar to the Archaean granite met in the surroundings (Sederholm, 1911, p. 103).

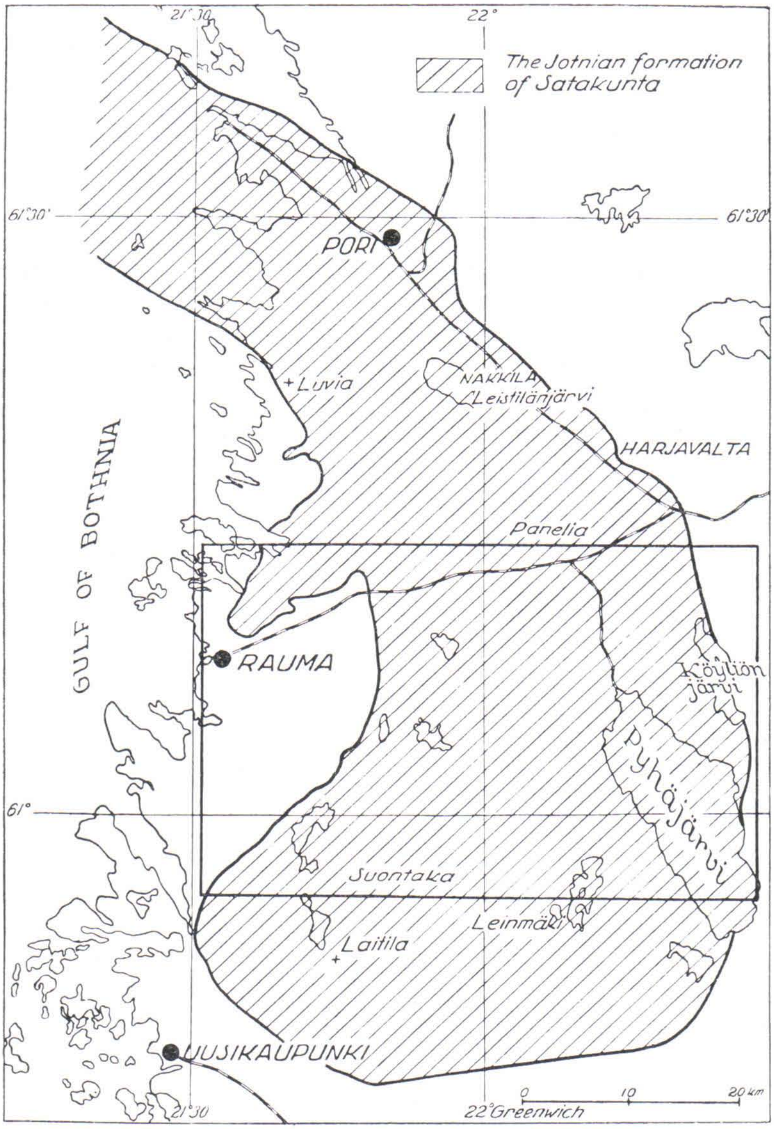

Fig. 1. Rectangle in the map shows the area investigated.

It is therefore likely that the sandstone in the NW part of the area is mainly the erosion product of Archaean rocks, while in the SE some of its material (concluded on the basis of pigmented feldspar) may originate from the rapakivi granite. Sandstone conglomerates, together with the grayish varieties containing ripple marks and current bedding, show that they probably belong to a fluviatile formation; the fine-grained red quartz-rich varieties, on the other hand, may have been formed under desert conditions. No definite fossils have been found in the Jotnian sandstone; a fact which is important evidence of its pre-Cambrian age. Finally, regarding the age relations, there is no direct proof in Satakunta that the sandstone is younger than the rapakivi granite. In Ångermanland in Sweden, however, on the opposite side of the Gulf of Bothnia, similar Jotnian sandstone lies on rapakivi granite. The age relations in Satakunta are most probably the same. The sandstone, on the other hand, is penetrated by dark olivine diabase which, from numerous contact observations, is the youngest rock of the formation.

The conceptions and the maps of the Jotnian formation of Satakunta have greatly changed with time. Tilas, 1737—38, and Gadd, 1780, were probably the first to write about the rocks of the Jotnian formation. In his general geological map of Finland Wiik (1877) roughly represents the distribution of the Jotnian rocks on the basis of the previous investigations of Bergroth (1801), Holmberg (1858) and of his own (1868). The maps of Moberg (1885) and Gylling (1887 b), showed a great improvement. In the map of the former author the sandstone area was extended up to the coast near the town of Pori. The latter gives a relatively detailed picture (in scale 1 : 200 000), especially of the distribution of the diabase in the southern part of the area. In his map of the northern part of the area in question Sederholm (1892), with the exception of the seven located sandstone areas, marked the large area between Lake Pyhäjärvi and Pori as olivine diabase, though it had been previously considered as sandstone. In the explanation to the map (1911) he thought it possible, however, that the sandstone may extend over a wider area beneath the glacial sediments. This was confirmed by the investigations of Laitakari (1925), who found several new outcrops of sandstone at the bottom of wells, in channels *etc.* On the basis of these observations the main part of the area between Lake Pyhäjärvi and Pori was marked as sandstone. The mapping made by the author in the summers of 1937—1939 in Southwestern Finland disclosed no reason to make essential changes in Laitakari's map. The map on Pl. V, in the scale 1 : 150 000, presents that part of the area investigated (in the rectangle marked in Fig. 1) where the contact phenomena described in this paper are encountered. The outcrops, located by the writer are marked on the map, the contacts of the different rocks have been drawn on this basis. The rest of the map is based on previous investigations, except for the western contact between the rapakivi granite and Archaean rock ground from the village of Lappi to Ihode. This contact has been also mapped by the writer, but the original map (scale 1 : 42 000) showing the outcrops was lost during the war.

Previous investigators have also described the contact influences resulting from the olivine diabase. Gylling (1887, p. 777) and Rosengren, 1886, describe a sandstone xenolith, 1.5 × 8 m. in size, which has been bent by the surrounding diabasic magma. It is regrettable that there are no recent observations available on this xenolith, situated at Kullankallio in the parish of Köyliö, since the later investigators (Sederholm, Laitakari and the writer) have not succeeded in finding it. Instead, Sederholm (1911, p. 109) and Laitakari (1925, p. 9 and 1928) describe similar phenomena at the contact between sandstone and diabase in Kiperjärvenoja and Leistilänjärvenoja and, in addition, more interesting contact phenomena in the N part of the Sorkka diabase massif (see map Pl. V). They regard these latter phenomena, which will be described in more detail on pp. 23—25, as a result of remelting — or palingenesis — of the rapakivi granite influenced by the adjacent diabasic magma.

PART I

GENERAL CHARACTER OF OLIVINE DIABASE

MODE OF OCCURRENCE

As may be seen from the map, Pl. V, olivine diabase occurs as long, narrow bands and as broader areas sometimes prolonged into bands as *e. g.* in the Suontaka and Lappi diabase areas (No. 12 and 5 on Pl. V). Numerous contact observations over the area investigated show that the contact surface between the diabase bands and the surrounding rocks is nearly vertical. Such contacts are known (Gylling 1891 b, Laitakari 1925 and Eskola 1925) for example in Kiperjärvenoja, Rivanmaa, Haukkavuori, (Nos. 7, 13 and 14 on Pl. V) and beyond the area covered by the map at Leinmäki in the parish of Laitila and at Leistilänjärvenoja in the parish of Nakkila (Gylling 1887 b, Sederholm 1911 and Eskola 1925). In the broader diabase areas, on the other hand, the contacts are nearly horizontal as, *e. g.*, in the Sorkka, Lappi, Tuiskula and Suontaka, diabase areas (Nos. 1, 2, 4, 5, 6, 9 and 12 on Pl. V).

Except for some so-called hybrid contacts, which will be discussed in Part IV, the diabase is fine-grained or aphanitic at the contact passing gradually into a medium-grained type over a distance of usually 1—2 m. from the contact. In addition, at many contacts, fine-grained or aphanitic diabase apophyses are found extending into the surrounding rocks. All these facts show that the olivine diabase is the youngest of the rocks concerned and has intruded into the sandstone, into the rapakivi granite, and into the Archaean rocks forming vertical dykes or sills.

The exact depth at which the diabase intrusion took place is unknown. The aphanitic contact zones of the diabase on the one hand and the lack of vitreous varieties on the other, however, show its hypabyssal character. It is also proved by the loose structure of the arkosic sandstone, which has obviously never been buried deep in the earth's crust. In Sweden, there are (v. Eckermann 1936, p. 331) sills of doleritic diabase in the Jotnian sandstone of the Dalecarlian formation which is about 800 m. thick. Their mode of occurrence, composition and texture corresponds to the olivine diabase of Satakunta. In Satakunta, where the relief is smoother, the estimation of the total thickness of the sandstone by geological means is more difficult. The deepest sections known at present are in the drill hole, 25 m. deep, near the power station of Harjavalta and in the well, 9 m. deep, of the farmhouse of Uusikatila in Panelia (beyond the map on Pl. V). The base of the sandstone has not been reached at either of these places. The results (at present unpublished) of the regional gravimetric measurements in West Finland of the Geodetic Institute seem to show that in some places also in Satakunta the sandstone formation can be of considerable thickness. For example, on the basis of the great negative anomaly in the vicinity of Lake Köyliönjärvi, found by Mr. T. Honkasalo, the sediment formation seems to be of considerable thickness.

As mentioned above, the relief in the sandstone areas is very smooth, but the wooded diabase chains are distinctly higher, having been more resistant to glacial erosion. In the rapakivi and Archaean areas, on the other hand, where the surrounding rocks have almost the same durability, the diabase areas can be often distinguished, by their richer vegetation, characteristic of areas of basic rocks.

Another conspicuous feature of the diabase areas is the distinct jointing of the rock. The diabase has a strong tendency to split into parallellepipedic pieces in such a way that one plane of the parallellepiped, usually the most distinct one, is parallel to the contact surface. This jointing plane is called in this paper the main joint plane. This phenomenon is clearly seen in Fig. 1, Pl. I, showing the upper contact of a diabase sill in the Suontaka area. The observations of the jointing of the diabase are of great importance, because they indicate the direction of the contact even in areas where no direct contact observations are available.

MINERAL COMPOSITION, TEXTURE AND STRUCTURE

The olivine diabase of Satakunta contains olivine, plagioclase, augite, and ore as main constituents and apatite, serpentine, and biotite as accessory minerals; in addition, it usually contains small amounts of quartz and alkali feldspar, which are often micrographically intergrown. The plagioclase occurs as lath-shaped crystals lying in all directions among the augite grains, giving rise to the ophitic texture, typical for this kind of rocks (Fig. 2 Pl. I).

In Sweden, Krokström (**1932**, **1936** a and **1936** b) has used for a similar kind of dyke rock the name dolerite, common in England, and v. Eckermann (**1936**, p. **309**) has compromised between the two names by calling the same type of the rocks doleritic diabase. Recently Johannsen (**1949** p. **312**), however, defined diabase as follow: »Diabase (United States usage) is a medium- to fine-grained rock, occurring in sills or dikes, having the mineral composition of basalts and usually an ophitic texture» in accordance with common usage in our country.

To obtain an idea of the quantitative and qualitative distribution of the minerals in the olivine diabase, let us examine the result of the statistical refractive index analysis (Fig. 13a), made by Mrs. Toini Mikkola of a sample near point Vb in Fig. 8 (p. 41) according to the method previously described by Kahma and Mikkola (1946). In column 1, Table I, are presented the percentages of minerals by volume according to the aforementioned method and in column 2 the results of the volumetric analysis after the Rosiwal method, also made by Mrs. Toini Mikkola. When comparing the two analyses it is noticed that a distinction between the minute grains of alkali feldspar and quartz from the labradoritic plagioclase by means of Rosiwal method without staining of the grains has not been possible. On the other hand, it is to be seen that, on account of the almost equal refractive indices, it has not been possible to distinguish between augite and olivine by the aid of refractive index analysis. It is to be noticed, moreover, that the amount of feldspars and quartz in column 2 is considerably greater than in column 1 while the sum of the augite and olivine in column 2 is less than in column 1. The deviations just mentioned are so great that they considerably exceed the errors caused by the limited number of grains or by the size of the sample. For example, the relative error in the value of plagioclase in column 2, for the reasons indicated, is about 11 %, calculated according to the method of Mader and Grengg quoted from Niggli (1948, pp. 125—127), while the errors in the statistical refractive index analysis are probably less than 5 %. For the most part, the deviation might depend upon the shape of the long plagioclase laths which have a cross-section relatively greater than that of the other more isometric grains of the same volume.

Table I. Mineral composition of the olivine diabase of Suontaka; (1) statistical refractive index analysis, (2) volumetric analysis.

	1 Vol. %		2 Vol. %	
Labradoritic plagioclase	44.0	57.0	71.4	71.5
Alkali feldspars	5.5			
Quartz	7.5		0.1	
Augite	34.0		13.4	21.9
Olivine			8.5	
Hornblende and serpentine	5.0		1.9	
Ore	4.0		4.8	
	100.0		100.1	

Since the aforementioned paper by Kahma and Mikkola *(op. cit.)* is presumably unknown to most readers, the main principles of the statistical refractive index analysis method are presented below together with the writer's present opinion concerning its possibilities of application.

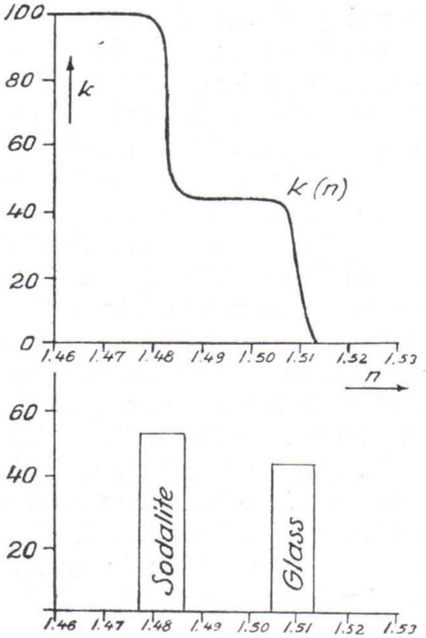

Fig. 2. Illustration of the results of the statistical refractive index analysis.

The purpose of this method is to measure, by means of the immersion method carried out on a crushed and sieved sample, the different refractive indices as well as their frequency distribution in the material to be investigated. The main subject is to determine the curve, k = k(n), (Fig. 2), which gives the percentage of a certain refractive index in the mixture under investigation plotted against the refractive index. The ordinate of any point on the curve shows how many per cent by volume, k, of the bulk of the grains have a refractive index greater than the abscissa of that point, n. Thus, according to Fig. 2 43 % of all grains of the corresponding sample have a refractive index greater than 1.492 and none have a refractive index less than 1.477.

The curve, k=k(n), may be obtained in the following way. The mixture in question is ground to a fine powder and homogenized. A small quantity of this homogeneous powder is then transferred on a glass plate, a drop of the immersion liquid is added and the whole covered with a cover glass. By means of a laterally adjustable stage, the glass plate is moved along a certain traverse. With the aid of the Becke line method, the grains are investigated and the percentages of those with a refractive index higher than the liquid is determined. The measurement is continued along a second, a third, *etc*., traverse until a sufficient number of grains has been counted. The corresponding percentages are calculated. The ordinate, k, corresponding to the refractive index of the liquid is thus obtained. The same procedure is repeated, using another immersion liquid and so forth. Each drop of the curve thus represents a certain refractive index corresponding to the steepest part of the drop. The amount of grains lying in this particular refractive index interval is numerically identical, expressed as a percentage of the total, with the difference between the two values of the ordinates on both sides of the drop in the curve.

If the sample to be measured contains some birefringent mineral with a zoned structure, either α' or γ' must be employed for the determination of the curve k(n) in the vicinity of the refractive index interval of that mineral. Instead of a steep drop, a more slanting part of the curve is obtained, the shape of which depends mainly upon the ratios between the main refractive indices α, β, and γ and upon the zoned structure of the mineral in question. A measurement carried out in this way requires, however, that in each liquid, belonging to this drop in the curve, every grain be tested in the two positions of extinction. This prolongs the time required for the determination of a single point in the curve from 10—30 to 40—80 minutes. For this reason and other reasons mentioned in the paper referred to, such a procedure was usually not performed, but the measurement has been made without turning the slide. Thus, the curve k(n) obtained corresponds to the distribution of both α' and γ' of the minerals in question. If no distinction between α' and γ' has been made, the existence of a zoned structure on a mineral may be ascertained with certainty in cases where the width of the drop is greater than γ—α of the corresponding mineral. Thus, for instance, on the basis of Fig. 13 a, it is evident that the plagioclase of that diabase is zoned and the composition varies at least between 48—77 per cent anorthite (Winchell, 1933) the maximum and minimum values of γ' and α' being 1.575 and 1.554 respectively.

The accuracy of the method depends mostly upon:

1. the size of the powdered sample,
2. the total number of the grains counted on every point of the curve,
3. to what extent the proportions of the different minerals in the powdered and sieved mixture correspond to the original mineral composition of the rock investigated.

In general, the errors depending upon points 1 and 2 may be eliminated relatively easily by increasing the size of the sample and the total number of grains counted. Except for analyses given in Figs. 13—15, which will be treated in more detail, condition 1 is satisfied for all the analyses of this paper. If the number of grains, counted for a single point on the curve k(n), varies between 500 and 2 000, the error of the mean square, caused by factor 2, does not exceed 2.5 per cent.

Finally, regarding point 3, it is to be admitted that the elimination of this error is very difficult. The writer cannot suggest at present any easy way to solve this problem. Fairly reliable control may, of course, be obtained by separating and chemically analysing the minerals of some rocks and subsequently calculating the amounts of the different minerals on the basis of the bulk composition of the rock. This method is, however, very arduous. In the paper by Kahma and Mikkola (*op. cit.* pp. 37—38), an attempt has been made to correct errors caused by point 3 with the aid of control mixtures. In this paper, however, the results are presented as originally obtained without similar corrections. This was done because the minerals used for the control mixtures are not quite the same as in the rock investigated. In addition, it is very difficult to prove whether or not the different minerals of the control mixture, made of loose material, are crushed exactly in the same way as the constituents of the hard rock. Therefore, the results of the statistical refractive index analyses have been employed only with care for conclusions concerning the quantitative proportions of the different constituents of the rock.

In this paper, a number of curves k(n) resulting from statistical refractive index analyses are given. In the corresponding figures presented below, the constituents of the rock in question are illustrated by columns. The width of these columns indicates the refractive index interval of the mineral and the height is proportional to the content of the mineral in the rock.

The olivine occurs as idiomorphic grains with serpentine as alteration product along the margins and cleavages. The composition of the olivine varies considerably. According to the determinations by Mrs. T. Mikkola and Mr. O. Waldén, the axial angle $2V_\alpha$ (using the universal stage) of the olivine in the Suontaka diabase area (No. 12 in the map Pl. V) varies between 78°—72°, and the α'-values 1.690 ± 0.003, 1.710 ± 0.003 and 1.729 ± 0.003 were obtained for 3 suitable grains separated from slides. According to Bowen and Schairer (1935), these (α) values correspond to 30, 39 and 52 % fayalite, respectively. On the basis of the diagram published by Deer and Wager (1939), the aforementioned axial angle range corresponds to a variation of the composition of the olivine between 34 and 50 % fayalite. According to Sahama and Torgeson (1948) the olivine of the olivine diabase at Lake Leistilänjärvi in the parish of Nakkila on the northern side of the area investigated contains 44 % fayalite. After Krokström (1936a, p. 153) and v. Eckermann (1936, p. 311) the axial angle of the olivine in the corresponding rocks in Sweden varies 72°—89° and 74°—84°, respectively. Thus, in the Swedish rocks the olivine varies in composition more than in the Satakunta rocks, higher contents in magnesia being reached in Sweden.

As has been mentioned in the foregoing, plagioclase generally occurs as long lath-shaped, idiomorphic crystals often with a zoned structure. According to the statistical refractive index analysis (Fig. 13a), the composition of the labradoritic plagioclase varies at least between 48—77 % An., but the range may be considerably greater. The plagioclase is usually quite fresh, but in the vicinity of the contacts it may contain saussurite or even chlorite strips in its cleavages. The occurrence of abundant plagioclase phenocrysts together with olivine pseudomorphs at the aphanitic contact zones of the diabase shows that the crystallization of plagioclase has started before the pyroxene.

The plagioclase laths are usually unoriented, but, on the island of Säppi, a horizontal orientation of plagioclase is seen on vertical surfaces, while horizontal surfaces show no orientation. To this phenomenon Eskola has suggested the explanation that the long plagioclase laths have sunk to the bottom of the magma basin and oriented themselves on the base. The writer has found the same texture in the diabase on the western side of the road from Honkilahti to Eura and between the Kauttua factory and Kiperjärvenoja.

The pyroxene of the diabase is a gray-violet augite. The optical properties of the augite are $\alpha = 1.699$, $\gamma = 1.723$, $c/\gamma = 48°$ and $2\,V\gamma = 44°—47°$ (the axial angle determination was made by Mrs. T. Mikkola). After Winchell (1933), a pyroxene of the diopside-hedenbergite series, having these refractive indices, should show an extinction angle on (010) of about 43° instead of 48°.

At many places, knobs some centimeters in size can be seen on the weathered surfaces of the diabase exposures. Thin sections prepared from such a knob as well as its surrounding rock of diabase in the village of Pato show that the knobs are formed by large poikilitic augite crystals surrounded by plagioclase and olivine.

Most of the opaque grains are magnetite and ilmenite, usually intergrown. In addition there are some minute grains of pyrrhotite and calcopyrite.

As mentioned in the foregoing, the rock contains a small percentage of quartz and alkali feldspar, usually micrographically intergrown and filling the interstices of the main constituents of the rock. Eskola considers (1932, pp. 462—463) that these minerals represent the last crystallizing acidic constituent of the diabasic magma. On the basis of the contact phenomena, described in Parts III and IV, the writer, however, regards it probable that, at least near the contacts of the diabase, the quartz and alkali feldspar grains originate from the acidic country rock of the diabase.

CHEMICAL COMPOSITION

The chemical analyses of the olivine diabase of Satakunta are presented in Table II (Nos. 1—5). For the sake of comparison, three typical analyses of corresponding rocks from other parts of Fennoscandia are included as well as an average of 50 plateau basalts, according to Washington (1922).

Table II shows that the chemical composition of diabase in Satakunta is fairly homogeneous and fairly close to the average composition of the 50 plateau basalts. This fact, together with the mode of occurrence, thus makes it probable, as Eskola pointed out (1925, 1932), that the diabase dykes in Satakunta present the hypabyssal eruption channels and their horizontal extensions of a plateau basaltic extrusion (or extrusions).

Table II. Chemical composition of diabase and related rocks from Fennoscandia as well as of an average of 50 plateau basalts.

	1	2	3	4	5	6	7	8	9
SiO_2	45.90	46.20	46.43	46.68	47.73	48.84	45.80	46.00	48.46
TiO_2	2.00	1.90	2.18	2.18	1.96	3.78	1.99	2.40	2.55
Al_2O_3	15.13	17.20	16.24	15.94	15.06	12.70	15.62	15.39	13.80
Fe_2O_3	1.84	2.08	1.92	2.59	4.09	5.12	3.34	2.44	3.35
FeO	14.69	11.95	12.42	10.50	10.40	9.47	11.35	12.78	9.77
MnO	0.14	0.29	0.10	0.17	0.20	0.19	0.16	0.01	0.21
MgO	5.69	7.10	6.19	6.27	4.23	4.32	7.42	8.18	6.25
CaO	8.66	8.98	9.47	11.06	10.48	7.26	9.99	9.23	9.55
Na_2O	2.85	2.88	2.41	2.90	2.74	2.76	2.43	2.32	2.84
K_2O	0.96	0.89	0.69	1.02	1.46	1.96	0.96	0.91	0.98
P_2O_5	0.21	0.01	0.35	0.29	0.35	1.19	0.11	0.35	0.46
H_2O+	1.20	1.10	1.26	0.53	1.23	1.74	0.75	0.27	1.59
H_2O-	0.60	0.14	0.03	0.11	0.22	0.94		0.10	
	99.87	100.72	99.69	100.24	100.15	100.27	99.92[1])	100.38	99.81

1 Olivine diabase. Suontaka, Laitila (see No. 10 in Table VI). Anal. H. B. Wiik.
2 » » (Analysis from P. Eskola) Sorkka, Rauma. Anal. O. v. Knorring.
3 » » about 2 m. from the contact. Suontaka, Laitila. Anal. H. B. Wiik.
4 » » (Laitakari 1925, p. 20) From a boulder in Yläne. Anal. M. Aurousseau and P. Eskola.
5 » » Suontaka, Laitila (see No. 1 in Table VI). Anal. H. B. Wiik.
6 Quartz diabase. (Lokka, 1934. p. 41) Island Möykynsaari in Lake Laatokka. Anal. L. Lokka.
7 Mottled dolerite. (Krokström, 1936 p. 135) S. of Lake Holsjön, Sweden. Anal. N. Sahlbom.
8 Doleritic diabase. (v. Eckermann, 1936, p. 307) Stensjöberg Hill, Sweden. Anal. N. Sahlbom.
9 Average of 50 plateau basalts (11 anal. of the Deccan, 6 anal. of the Oregonian, and 33 anal. of the Thulean basalts) according to Washington (1922, p. 797).

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[1] The sum is in the original paper 100.01.

PART II

LOW GRADE CONTACT INFLUENCE

In most cases distinct exomorphic contact influences cannot be discovered with the naked eye or even with the aid of the microscope at contacts between olivine diabase and rapakivi granite. However, at some places, as for example in the upper contact of the diabase sill at Suontaka, the rapakivi granite is somewhat darker in color in the immediate vicinity of the contact. Under the microscope the rock is usually observed to contain great quantities of micropegmatite filling the interstices between the bigger orthoclase phenocrysts.

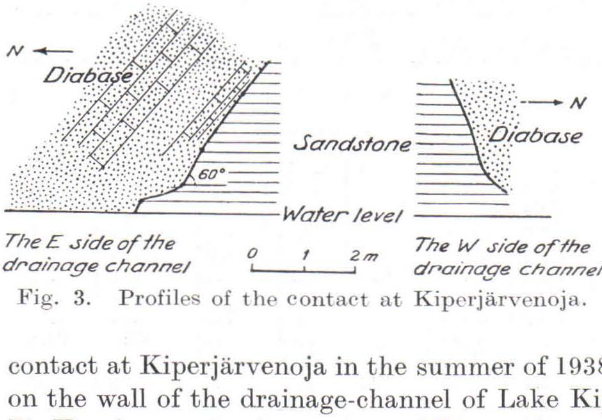

Fig. 3. Profiles of the contact at Kiperjärvenoja.

As mentioned on p. 8, Sederholm and Laitakari have described slightly metamorphozed sandstone in the vicinity of the diabase contact at Leistilänjärvenoja and Kiperjärvenoja. In order to get an idea of the phenomenon, the writer made observations and took specimens at the contact at Kiperjärvenoja in the summer of 1938. The contact is to be seen on the wall of the drainage-channel of Lake Kiperjärvi (No 7 on the map Pl. V). As seen in the sections of Fig. 3, the contact surface is somewhat uneven, but, on the average, it forms an angle of 45°—65° measured from the horizontal. Towards the contact the sandstone, though usually loose, becomes hard, the reddish color brighter and the lustre more vitreous. Thin sections have been made of sandstone specimens collected immediately from the contact and about 5 m. apart from it, as well as of a normal sandstone sample from a well near the Kauttua factory (No 8 on the map Pl. V). As seen in Fig. 3, Pl. I, the larger quartz grains have rather smooth surfaces in the normal sandstone, but, on approaching the contact, they become toothed (Fig. 4, Pl. I) while at the same time the fine-grained cement decreases. A fine-grained aggregate of quartz, pigmented feldspar muscovite and chlorite occurs between the larger quartz grains in the sandstone about 5 m. apart from the contact. This fine-grained aggregate has almost entirely vanished at the contact and instead the bigger quartz grains have become toothed, thus joining the constituents of the sandstone more firmly than normal. Neither sericite nor chlorite are found in the sandstone at the contact proper, but instead there are dirty shreds of biotite. Moreover neither twinning of the feldspar nor perthitic growth of potash feldspar can be detected in the contact zone under the microscope. This also seems to be a result of a contact influence.

It is difficult to say whether the hardening of the sandstone in the vicinity of the olivine diabase contact at Kiperjärvi is a result of the partial refusion of the minerals in the sandstone, or of more intense atomic movements in the crystal structures or perhaps of the consolidating influence of the water emanating from the crystallizing diabase. On the basis of similar phenomena in the sandstone at Tuiskula, to be described in the following chapter, the writer considers, however, the first factor probably most important at the contacts at Kiperjärvenoja and Suontaka.

PART III

PARTIAL REMELTING OF COUNTRY ROCK

PALINGENIC DYKES AT CONTACTS BETWEEN DIABASE AND SANDSTONE

At several places in the area investigated notably stronger contact influences than those described in the previous chapter may be discovered. Laitakari reports (1925) a sandstone xenolith, 10—12 cm. thick, situated on the path between the farm-house of Parkkila[1]) and Eura which seems to have been granitized by the diabase. Of the xenolith he says (*op. cit.* p. 11): »Dieses hat ebenso wie die anderen ziemlich kleinen Arkosebruchstücke grosse Ähnlichkeit mit Granit. Sie sind in fast gänzlich geschmolzenem Zustande in den Diabas hineingetragen und dann von neuem granitartig erstarrt». On mapping the north side of Lake Pyhäjärvi in the summer

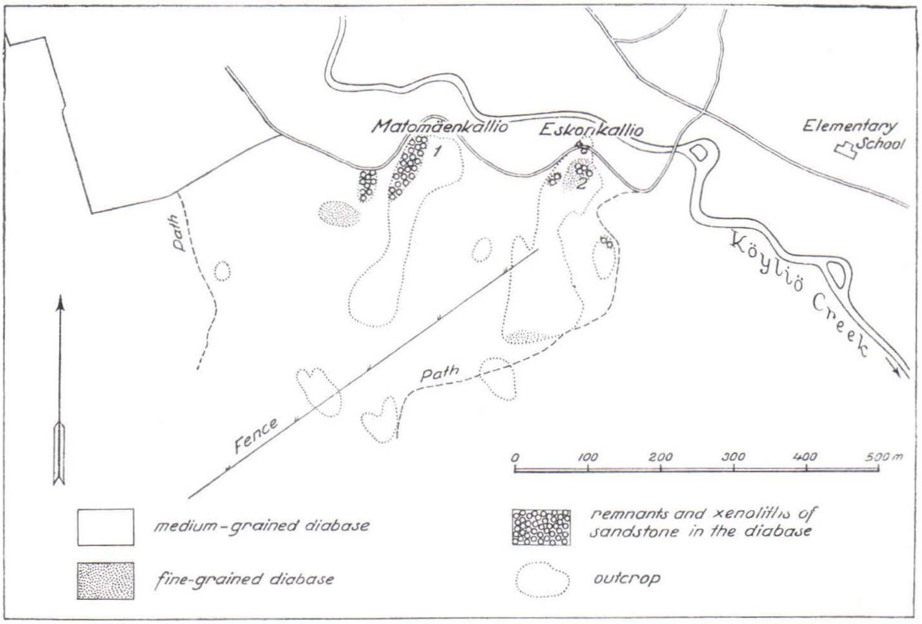

Fig. 4. Sketch map of the Tuiskula diabase.

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[1]) According to Laitakari (*op. cit.* p. 10) the farm-house was once situated near the outcrop of Eskonkallio.

of 1938 the writer unfortunately could not find this xenolith. However, it was possible to ascertain fairly strong contact influences between the diabase and sandstone on the exposures already discovered at Eskonkallio and Matomäenkallio (No. 9 on the map. Pl. V) on the west side of the Tuiskula elementary school.

In his note-book Th. Stolpe describeds in considerable detail the sandstone »xenoliths» he had found on the exposures of Eskonkallio and Matomäenkallio (Fig. 4) (after Stolpe Matokallio). Their extraordinary shape and the vermicular »cooling joints» of the aphanitic diabase seem to have awakened his interest. During the author's investigations in 1938 it nevertheless became apparent that, over most of the area covered by the strange »xenoliths», they are usually only a few centimeters thick, but as much as several meters wide, being remnants of sandstone formerly situated on the aphanitic diabase. The following facts may be presented as proof that the sandstone remnants on the exposure of Matomäenkallio, as well as on the exposures in its surroundings are not only relics of the huge sandstone xenoliths suspended in the diabasic magma, but most probably the remnants of a former sandstone layer:

1. Remnants and xenoliths of sandstone have been found in five different places (Fig. 4); while fine or aphanitic diabase, indicating the proximity of a relatively cold contact surface, has been found in seven places covering a rather wide area.

2. On the exposures of Matomäenkallio the sandstone remnants are almost horizontally stratified as in the sandstone outcrops of Kiperjärvenoja and Murronmäki in the southern part of the large sandstone area (Nos. 7 and 10 on the map Pl. V). This could hardly have happened if they had been remnants of loose sandstone inclusions in the diabase.

3. At all the places mentioned above, the transition of the aphanitic diabase into a medium-grained type takes place over the same distance (about 1—2 m.). This could not be expected if the aphanitic diabase varieties had been formed round loose sandstone xenoliths of different sizes and at varying distances from the main contact. On the outcrop of Eskonkallio there are, however, two genuine xenoliths of sandstone about 0.5 × 1 m. in size; the fine-grained contact cover round the one is only a few millimeters thick, while the other, situated farther apart from the main contact, probably 2—3 m., has a medium-grained and hybridized contact (p. 25) against the sandstone xenolith.

A detailed examination of the »cooling joints», which are 1—2 mm. thick, shows even with the naked eye that they contain a light reddish material which, proceeding from the sandstone remnants or xenoliths, continues at least 1—2 cm. into the aphanitic diabase. Thin sections prepared from these dykes show quartz, feldspar, greenish brown biotite, hornblende, chlorite, and iron ore. Quartz occurs as large toothed grains as well as small allotriomorphic grains between other minerals. Moreover, minute light green needles are found arranged in groups in the dykes. On account of their minute size, the needles cannot be identified with certainty. Hornblende, biotite, and chlorite occur as irregular shreds and, at the edges of some grains, hornblende has changed to biotite. The larger quartz grains and the texture of the groundmass is seen in the microphotograph Fig. 5, Pl. II.

On the contact, the distinct stratification and clastic texture of the thicker sandstone remnants are megascopically more difficult to perceive. Under the microscope, however, they can be observed fairly easily. It can also be seen how the rather smooth quartz grains become toothed, as on the contact at Kiperjärvi (p. 16). The interstices of the larger quartz and feldspar grains are filled with a fine-grained groundmass of quartz, feldspar, biotite, and chlorite, having the same micrographic texture as the reddish dykes proceeding from the contact into the aphanitic diabase.

Under the microscope, the diabase at the contact is either aphanitic or very fine-grained, becoming gradually coarser on proceeding away from the contact. It contains big, idiomorphic plagioclase phenocrysts and large olivine pseudomorphs inside of which sometimes relict olivine may be found. The long plagioclase phenocrysts are in some places beautifully oriented along the contact surface. They, like the olivine pseudomorphs in the aphanitic contact zone, show that the diabasic magma was not under a superheated condition, when the intrusion took place. In the contact zone of the diabase against the reddish dykes or sandstone, it is also seen that, especially where the rock is coarser, the grains of augite and olivine have changed into chlorite, biotite, and iron ore while the plagioclase laths have corroded. On the other hand, between the corroded plagioclase some minute allotriomorphic grains, that might be quartz are also to be observed.

On the basis of the observations described in the foregoing, it seems evident that the acidic dykes cutting the diabase cannot be interpreted as cooling joints in the diabase filled by loose sandstone that has been afterwards indurated nor as a separate granitic intrusion which had also penetrated the sandstone (such granitic intrusions are not known). The dykes apparently are of palingenic origin having intruded from the partially remelted contact zone of the sandstone generated by the thermal influence of the diabasic magma. The dykes being very narrow it was not possible to determine their chemical composition, but it did succeed for the neighboring outcrop at Eskonkallio.

The diabase at Eskonkallio (No. 2 in Fig. 4) is situated nearest the Köyliö Creek, about 350 m. from the elementary school of Tuiskula. The exposure is flat and measures about 3 m. in height. The bottom part of the outcrop is medium-grained, but the upper part is either a fine-grained or an aphanitic rock. The transition from fine-grained to medium-grained diabase takes place vertically over a distance of about 2 m. The uppermost part of the rock being fine-grained or aphanitic, the contact surface between the diabase and the sandstone evidently must have been in the immediate vicinity of a flat upper surface of the exposure.

Besides the two partially hybridized xenoliths, situated in the medium-grained diabase (p. 19) several xenoliths or remnants of sandstone are to be found in the aphanitic or fine-grained diabase (covering an area of about 1 000 m^2.) on the top of the outcrop of Eskonkallio. These xenoliths have also been described by Th. Stolpe in his notebook in the year of 1887. Also reddish dykes occur that are 0.5—8 cm. wide and several meters long (Fig. 6 Pl. II) some of which proceed from the xenoliths. Megascopically the texture appears clastic in these dykes. Under the microscope big (0.2—2 mm.), either rounded or toothed, quartz and feldspar grains may be seen (Fig. 7, Pl. II), the interstices being filled with a micrographic groundmass of minute (averaging 0.1 mm.) quartz, feldspar, biotite, chlorite, epidote, and ore grains. On account of the great differences in grain size and texture between the bigger quartz and feldspar grains and the groundmass, the bigger grains are probably remnants of the sandstone grains which have intruded into the diabase with the partially remelted sandstone material. In the contact zone of the diabase products of similar reactions occur between the granitic melt and the diabase as described on p. 20. It is probable that the amphibole, chlorite, epidote, and ore grains, encountered in the granitic dykes, are results of such reactions.

According to the method described on pp. 12—13 statistical refractive index analyses have been made of a sandstone remnant on the outcrop of Matomäenkallio and of a granitic dyke on the outcrop of Eskonkallio. The results of these measurements and the chemical analyses made from the same rocks and other sandstone specimens, are presented in Figs. 5 a and 5 a′ and in Table III, columns 1, 2, 7. It is to be noted that, although the chemical and modal analyses are made of the same rocks, they are not made of identical, homogenized powder. This may cause small differences in the results. Nevertheless the great difference between the modal and normative orthoclase in the palingenic dyke seems to be real. It indicates that, in the palingenic dyke, only a minor part of the potash content combined in the feldspar forms orthoclase, while the major part occurs as anorthoclase or, to a lesser extent, is contained in the albitic plagioclase. The most interesting feature, however, is the difference between the composition of the dykes and the parent rocks. It greatly supports the conclusion presented above of the partial remelting of the sandstone and the intrusion of this melt into the cooling joints of the diabase.

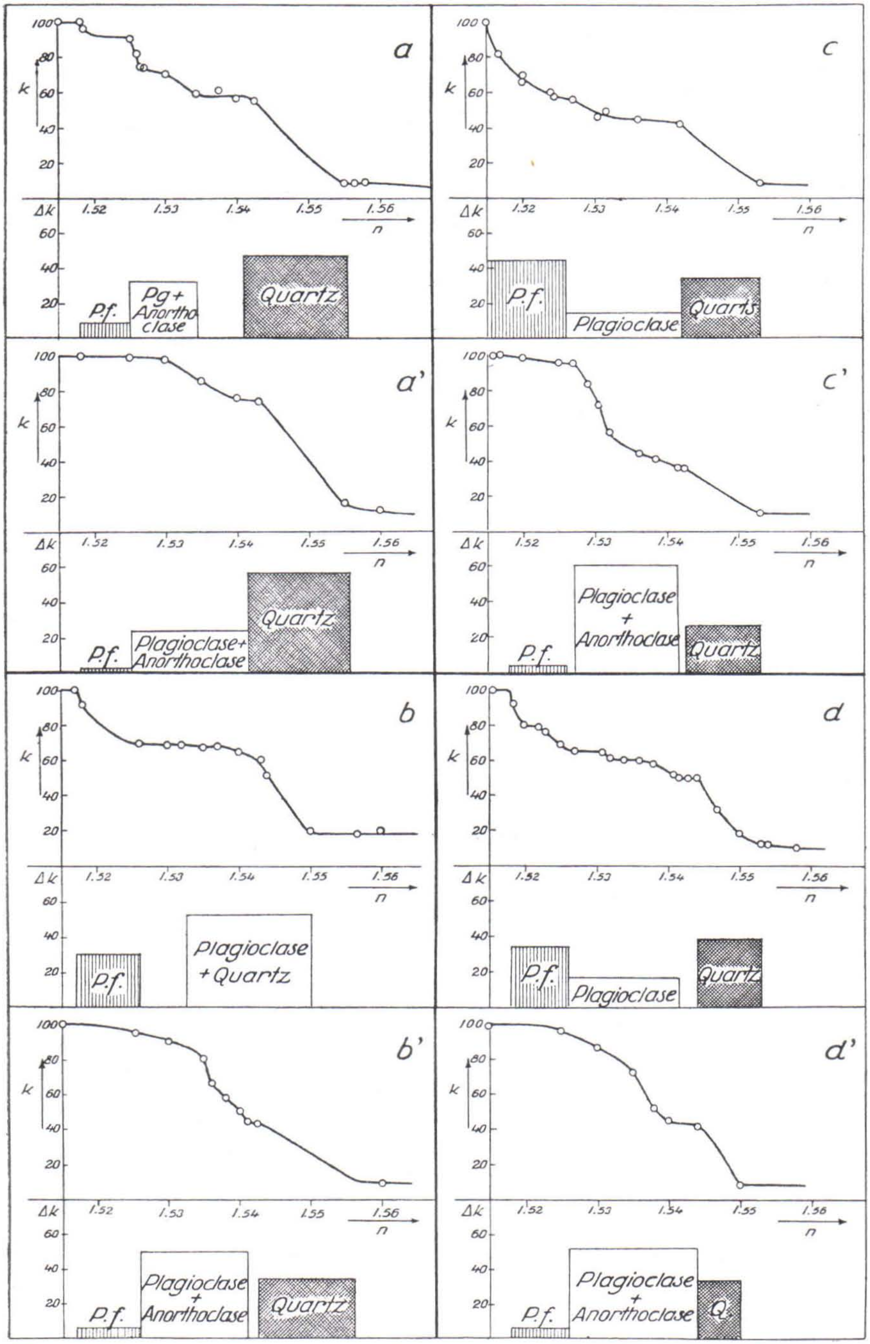

Fig. 5. Results of the statistical refractive index analyses of the palingenic dykes from: the sandstone (a′), the Tarkki granite (b′), the spotted granite (c′), and the normal rapakivi granite (d′) as well as their corresponding parent rocks (a, b, c, d). Abbreviations: P. f. = potash feldspar, Pg = plagioclase, Q = quartz.

As mentioned above (p. 19), on the E and NE side of the exposure of Eskonkallio there occur two sandstone xenoliths measuring about 0.5 × 1 m. in size. Round the eastern xenolith there is a fine-grained contact cover, a few millimeters in thickness, which, however, is neither diabase nor sandstone, but a rock which together with the micrographically intergrown quartz and feldspar grains contains serpentine, some biotite, and ore. Some centimeters from the contact towards the center of the xenolith, the rock contains large rounded grains of feldspar and toothed quartz, the interstices of which are filled with a groundmass of the same composition and texture as the contact cover above. In the vicinity of the contact, the olivine and, to some extent, the augite, also of the medium-grained diabase, have been altered into iron ore and serpentine which occur in place of the original grains and fill the cleavages of the large plagioclase laths. On account of the heating up of the sandstone by the intruding diabasic magma the sandstone xenolith has been partially remelted and the granitic liquid thus formed has reacted with the thin contact mantle of the diabase forming the fine-grained intermediate zone between the xenolith and the surrounding diabase. In the case of the other xenolith on the NE side of the exposure, situated probably 2—3 m. from the main contact, the heating and thus also the reactions have been so intense that the sharp boundary between the two rocks has entirely disappeared.

PALINGENIC DYKES AT CONTACTS BETWEEN DIABASE AND RAPAKIVI GRANITE

PALINGENIC DYKES PROCEEDING FROM THE TARKKI GRANITE

Remelting phenomena, similar to those described in the preceding chapter are also encountered in the northwestern part of the area investigated at the contacts between the olivine diabase of Sorkka and the reddish, even-grained rapakivi variety, called Tarkki granite. Sederholm (1911, p. 121), who first studied these contacts, writes as follows (in transition):

»I have encountered a very strange xenolith of rapakivi granite in the diabase on the northeastern boundary of the small diabase area near the town of Rauma, SE from Haukila [1]. The xenolith only about two meters in diameter, is the same medium-grained, red rapakivi granite which is common in the surroundings. In the immediate vicinity of this xenolith, the diabase has an aphanitic or almost glassy texture. In spite of the fact that the diabase has solidified later, small dykes rich in feldspar proceed, however, from the xenolith into the diabase just as if the granite were younger. This apparently contradictory relation, which I have also observed at the contact between the rapakivi granite and the olivine diabase

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[1] must be Hankkila.

at Ulfön, Ångermanland, in Sweden and which one can consider as a reciprocal contact influence, is to be explained in such a way that, on account of the influence of the surrounding eruptive magma the constituents of the xenolith have been partially remelted. Since now also the rest of the diabasic magma, which was solidified last has been a quartz and feldspar solution, it is easy to understand that a part of the constituents of the granitic xenoliths could remain in a molten state after the diabase was solidified and in this way penetrated it.»

In his publication Laitakari (1928) describes the palingenic contact phenomena at the »old contact of Heikkilä» (No. 2 on the map Pl. V). The contact is well exposed on the outcrop, the upper surface of which slopes gently in a NW direction. The reddish brown, medium-grained Tarkki granite forms there an irregular network of dykes in the diabase (Fig. 6 reproduced from Laitakari 1928). At suitable places, however, it can be observed that many of the diabase »xenoliths» like those seen in Fig. 6, are not really xenoliths, but shallow remnants of an earlier diabase sill, the contact surface against the Tarkki granite of which lies near the present surface of the outcrop. It is difficult to determine the age relations at this contact on account of the position of the contact and of the more intense reactions between the medium-grained diabase and the granite than those described on pp. 20—21 which have formed transitional contacts between these two rocks. For the same reasons it is not easy to decide which granitic dykes are real, which are only windows of the granite base, and which are partially assimilated granite xenoliths in the diabase.

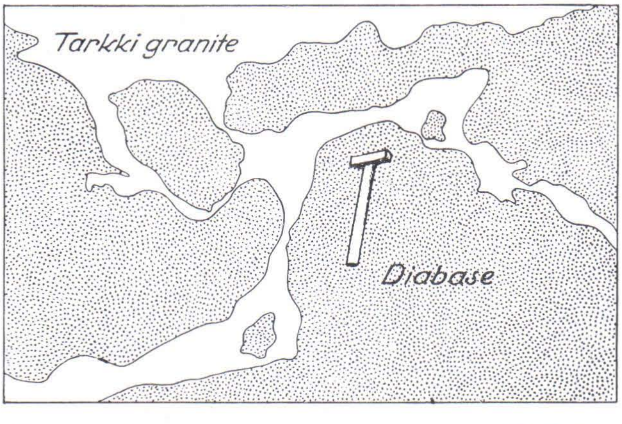

Fig. 6. Sketch of the »old contact of Heikkilä», Eurajoki, from photograph by Laitakari (1928).

In order to cast new light on this problem, the writer examined during field work in the summer of 1937 the northern boundary of the diabase area of Sorkka. Two new contacts were found between the diabase and the Tarkki granite (Nos. 3 and 4 on the map Pl. V).

The most illuminating of these is the so-called »new contact of Heikkilä» (No. 3 on the map Pl. V) situated about 300 m. east of the »old contact of Heikkilä» and about 50 m. south of the road between the villages of Lapinkylä and Hankkila. The contact between the diabase and the Tarkki granite is exposed on a slope facing north, for a distance of some ten meters, the lower part of the slope being Tarkki granite, above which diabase exposures are found. On the basis of data previously presented by Laitakari (1925), the general course of the contact between the diabase sill and its base is nearly horizontal, as also found at the new contacts (Nos. 1 and 4, Pl. V). In this place the contact, however, seems to be steeper but, as there is not a sufficiently long section against the contact surface, it is not possible to ascertain its direction accurately.

The Tarkki granite, forming a horseshoeshaped area between the Sorkka diabase and the village of Auvinkylä (see the map Pl. V), is a medium-grained, reddish brown, unoriented rock which, on account of its composition, mode of occurrence, and texture, is to be regarded as a rapakivi variety. It contains red pigmented orthoclase, partially altered plagioclase and, in addition to the allotriomorphic quartz, also idiomorphic quartz grains typical of all rapakivi varieties. As dark constituents the rock contains dark-green or brown hornblende and extremely pleochroic biotite, as well as apatite, ore and, according to Laitakari, also some fluorite as accessory minerals. The chemical composition of the Tarkki granite appears in column 8 in Table III.

The Tarkki granite described above continues unaltered almost up to the diabase-contact. Thin sections made of a specimen from the contact and 8—9 m. from it, reveal that the amount of allotriomorphic quartz in the granite is perhaps somewhat greater in the contact zone.

The olivine diabase is quite aphanitic at the contact, but a few meters away it becomes medium-grained. From the diabase a great number of apophyses proceed into the granite, their thickness ranging from a few centimeters to some 20—30 cm. The edges of the diabase dykes are aphanitic, but the central part of the wider dykes is fine-grained. These sharpedged and relatively straight diabase apophyses are cut, again, by red, fine-grained, granitic dykes which proceed from the Tarkki granite (Figs. 8 Pl. II and 9 Pl. III). The thickness of these granitic dykes varies from 1 to 20 mm. and they are sinuous and irregular in form.

These dykes contain potash feldspar, plagioclase, quartz, and biotite as main constituents and some hornblende, especially near the contacts of the diabase. The texture is micrographic (Fig. 10, Pl. III). When comparing the statistical refractive index analysis (Fig. 5 b',) with the norms of analyses Nos. 3 and 4 in Table III, made of the dykes, it may be observed, as in the case of the palingenic dykes from the sandstone (p. 21), that a considerable amount of potash is combined either in the albitic plagioclase or in the anorthoclase. On account of the overlapping of the refractive index of anorthoclase, after Winchell (1933) $\beta = 1.528$ and Chudoba, 1932, $\beta = 1.526—1.549$, with the albitic plagioclase after Winchell (1933) $\beta = 1.529$, and on account of the lack of suitable grains for the determination of the axial angle in the thin sections, made of the dykes, it was not possible to identify with certainty the sodium-rich feldspar. Taking into consideration the large amount of potash component, it is probable, however, that anorthoclase is also present.

Some granitic dykes continue to a certain extent, though vaguer in form, into the Tarkki granite. As shown in Fig. 9, Pl. III the dyke on the side of the granite becomes a little broader (indicated by the broken arrow) and less distinct, disappearing at a distance of 10—20 cm. from the diabase dyke. In addition, parallel with the diabase apophyses, and apart from the granitic dykes cutting them, fine-grained granitic dykes are met, a few millimeters thick and several meters long. They contain quartz and alkali feldspars as their main constituents and, in addition, some biotite and hornblende near the contact to the Tarkki granite. The micrographic texture is similar to that in the dykes mentioned above. At the contact of the dyke, minute apophyses can be observed, a few millimeters long, proceeding from these dykes between the quartz and feldspar grains of the surrounding Tarkki granite.

In addition to the sinuous, granitic dykes which cut diabase apophyses, similar fine-grained, reddish dykes (1—2 cm. broad and about 0.5—1 m. long) are encountered at the main contact proceeding from the contact of the Tarkki granite into the fine-grained diabase. Moreover, granitic dykes, 1—30 mm. thick, and some ten centimeters long, may be seen coming from the xenoliths of Tarkki granite (0.5—2 m. in diameter) situated in the medium-grained diabase a few meters from the main contact. On the surface of the outcrop one of these xenoliths seems to be almost typical Tarkki granite, but in specimens it appears that the rock is darker and there are transitional contacts between the xenolith and the diabase. These fine-grained granitic dykes show an appearence like that described above, continuing, although vaguer, into the xenoliths, and vanishing at some distance.

At the contact between the diabase and the granitic dykes the results of reactions similar to those described on p. 20 are seen. Just at the contact between the diabase and dyke, as well as around the small diabase xenoliths in the dyke, there is a margin of green hornblende. It is probable that the hornblende grains encountered here and there in the dyke have been separated from this margin. Away from the contact the laths of plagioclase of the diabase are well developed and beautifully oriented, but, some millimeters from it, they become unoriented and corroded. At many places the corrosion has proceeded to such an extent that there are only shreds of the original plagioclase left. The interstices of the plagioclase laths are filled with a groundmass of hornblende, serpentine and iron ore, which are difficult to identify on account of their turbidy and minute grain size.

As regards the age relations between these two rocks, the fact that the medium-grained diabase shows aphanitic contacts against the granite should in itself prove that the diabase is younger than the Tarkki granite. This becomes, however, quite evident from the granite xenoliths in the diabase, and in the diabase apophyses which have aphanitic edges and coarser centers and proceed from the diabase to the granite. It is possible to explain in the following manner the fine-grained granitic dykes penetrating the diabase apophyses and the aphanitic contact zone of the diabase of the main contact as well as the phenomena at the contact between the diabase and sandstone. The thermal influence of the diabasic magma has caused a part of the minerals of the Tarkki granite to remelt and the intergranular liquid thus formed has been intruded as palingenic dykes into the cooling joints of the previously solidified diabase, or filled the joints of the somewhat plastic Tarkki granite. The comparison of the chemical analyses of the palingenic dykes Nos. 3 and 4 in Table III. with the analysis of the Tarkki granite No. 8 in Table III. shows that the remelting of the Tarkki granite has not proceeded very far.

PALINGENIC DYKES PROCEEDING FROM SPOTTED GRANITE

Another rapakivi variety, spotted granite, occurs in the Suontaka diabase area (see Fig. 8 on p. 41) at three different places. Remelting phenomena are encountered also at its contacts against the olivine diabase.

The usually even-grained spotted granite, containing quartz, orthoclase, plagioclase, and biotite as main constituents, has been named after the black biotite spots abundant in the rock. Microscopically the dark-brown pleochroic centers of the biotite spots are surrounded by dark ragged biotite; in addition, there are also light green biotite laths which do not have the dark margins mentioned above. As accessory minerals the spotted granite contains fluorite, apatite, chlorite, and muscovite.

On account of turbidity and lack of twinning, it is difficult to identify the different feldspars in thin sections. According to statistical refractive index analyses given in Fig. 5c, the feldspar seems to be mainly potash feldspar. As is usual in rapakivi granites, the spotted granite contains quartz of two generations, *viz.*, idiomorphic drops, and allotriomorphic grains between the other minerals. Moreover, the SW part of the even-grained spotted granite area (No. 2 in Fig. 8) contains large, ovoid orthoclase phenocrysts the amount of which gradually increases towards the west until the rock becomes a normal rapakivi granite. In the NE part of the small massif, on the other hand, the amount of the phenocrysts decreases and a sharp contact exists between the even-grained spotted granite and the normal rapakivi. At the contacts mentioned above, no direct evidence (*e. g.* apophyses or inclusions) of the age relations between these two rocks has been traced. It is, however, highly probable that the spotted granite, as well as the other rapakivi varieties, is younger than the normal type. If the opposite view is accepted, it becomes difficult to understand how the small spotted granite massif has been preserved unaffected inside such an enormous rapakivi granite massif of the normal type which has intrusive contacts against its surroundings.

Two contacts have been found between the spotted granite and olivine diabase in the Suontaka diabase area, *viz.*, Nos. 2 and 9 in Fig. 8. At place No. 9, where the spotted granite is above the olivine diabase, the direction of the contact is N 30° E dipping 20° WNW. As usual, the olivine diabase is aphanitic at the contact containing phenocrysts of plagioclase and pseudomorphs of olivine or augite phenocrysts.

The medium-grained spotted granite containing no orthoclase phenocrysts, continues almost unchanged up to the contact. At some places against the diabase contact, however, a micrographic groundmass of fine-grained quartz and feldspar is seen under the microscope. From such a place fine-grained, reddish dykes, 0.1—2 mm. thick and several centimeters long extend into the aphanitic diabase. These dykes have the same mineral composition, texture and similar reaction zones against the diabase as described in the connection with the other palingenic dykes. On account of the narrowness of the dykes, it was not possible to determine their chemical composition at this place, but it did succeed for contact No. 2 in the SW part of the Suontaka diabase area.

The upper surface of the diabase outcrop at the contact No. 2 (Fig. 8) mentioned above, sloping 45° WNW, consists of fine-grained or aphanitic diabase which becomes coarser downwards. The contact surface had obviously lain on the upper surface of the aphanitic diabase parallel to the main jointing of the rock. The spotted granite outcrops are only 1—2 m. from the diabase. It is highly probable that the spotted granite had been lying above the aphanitic diabase, and then eroded away. On the aphanitic diabase surface, however, red granitic dykes 5—10 cm. thick are found continuing on the steeper side of the outcrop about one meter from the contact. As the granitic part of the contact has been eroded away, it is not possible to decide conclusively whether palingenic dykes from the spotted granite are in question or whether they represents a separate granitic intrusion of later date than the diabase. The fact that no granitic dykes are found farther in the diabase or even in the spotted granite makes the palingenic origin of the dykes highly probable. The texture and composition of the dykes also points to this interpretation.

The dykes contain quartz, alkali feldspars, greenish brown biotite, and light brown biotite, with chlorite, some fluorite, and zircon as accessories. A part of the quartz occurs as idiomorphic drops which may originate from the spotted granite, but the greatest part of it forms a micrographic intergrowth with the potash feldspar forming sun-like aggregates. Sometimes such an aggregate is banded only in two directions perpendicular to each other giving raise to a time-glass texture. When comparing the mineral composition, obtained by statistical refractive index analysis (Fig. 5c′), with the normative composition No. 5 in Table III, it is to be noted again that a considerable amount of the potash content of the dyke is combined either in the anorthoclase or albitic plagioclase. On the curve (Fig. 5c′) between the pure albite ($\beta = 1.529$) and orthoclase a notable drop exists which coincides with the refractive index interval of the anorthoclase. It is most probable that the rock also contains this mineral. Biotite occurs as greenish brown strongly pleochroic plates and green acicular needles inside of which traces of the original amphibole or pyroxene grains are sometimes seen. The brown ragged biotite as well as the idiomorphic quartz drops of the dyke may originate from the spotted granite in the same way as the rounded quartz grains in the palingenic dykes from the sandstone (p. 21). Regarding the acicular biotite needles and chlorite grains, into which the greatest part of the considerable MgO content of the dyke is combined (see analyses Nos. 5 and 9 in Table III), it is probable that they are results of similar reactions between the granitic liquid and the diabase as described on pp. 20 and 24.

PALINGENIC DYKES PROCEEDING FROM NORMAL RAPAKIVI GRANITE

At several places in the Suontaka diabase area contacts between the diabase sills and the normal rapakivi granite (Nos. 3, 4, and 6 in Fig. 8) are found. In addition, on the steep slope in the SW part of the area it is possible to follow the contact between the undulating diabase sill and the normal rapakivi granite above it almost continuously for a distance of 600 m. (section Ib—Id in Fig. 9). The medium- or coarse-grained diabase is aphanitic at the contacts and in many places there are small apophyses penetrating the rapakivi granite. As usual, the aphanitic contact margin of the diabase contains phenocrysts of plagioclase and olivine or augite pseudomorphs.

The normal rapakivi granite contains in abundance large, reddish, ovoid orthoclase phenocrysts, 3—8 cm. in diameter, between which there are dark idiomorphic quartz grains together with oligoclase, hornblende, biotite, and allotriomorphic quartz. At some places near the contact of the diabase the rapakivi granite is somewhat darker in color with more micropegmatite than usual. Especially at such a point fine-grained, reddish, sinuous, granitic dykes, 1—20 mm. thick, proceed from the granite into the diabase. It must be pointed out that in spite of much searching, these dykes have never been observed to continue farther than 1—2 m. into the fine-grained diabase.

The mineral composition and texture of the dykes is similar to that of the other palingenic dykes, *e. g.* the Tarkki granite. On the basis of the statistical refractive index and chemical analyses (Fig. 5d′ and No. 6 in Table III) a part of the potash content seems to be combined either in the anorthoclase or in the albitic plagioclase. In the vicinity of the dykes the olivine has been altered into iddingsite, chlorite and iron ore while pyroxene may occur together with hornblende even in the dyke itself. As usual, the plagioclase laths of the diabase have been corroded near the dyke, and between them and other grains there are minute allotriomorphic grains which might be quartz.

PALINGENIC DYKES AT A CONTACT BETWEEN DIABASE AND ARCHAEAN

Most of the diabase sheet of Sorkka is surrounded by Archaean rocks. In the NW side of the diabase sheet an illuminating contact between the diabase and Archaean rock is seen about 150 m. south of the Mäntylä farm-house (No. 1 on the map Pl. V). The undermost part of the exposure is composed of migmatite gneiss rich in biotite streaks, above which lies the bed of olivine diabase. The contact is nearly horizontal, dipping 15° to the east; the medium-grained diabase becomes fine-grained or aphanitic towards the contact. Palingenic dykes, 1—2 mm. thick and a few centimeters long, proceeding from the gneiss to the diabase have been found especially in places where the migmatite gneiss is rich in quartz and in reddish potash feldspar which, on the basis of its cross-hatched structure, is microcline. They contain quartz and alkali feldspars as main constituents, with some hornblende, serpentine, and a small amount of biotite in addition. The texture is micrographic, rich in micropegmatite aggregates. At the contacts between the fine-grained diabase and the palingenic dykes there are similar, though not so intense, reaction zones as those described in connection with the other palingenic dykes. On account of the narrowness of the dykes it was not possible to separate sufficient material for chemical and statistical refractive index analysis.

In addition to the palingenic dykes just described straight, grayish dykes, 0.5—2.0 cm. in thickness, cut the medium-grained diabase a few meters from the contact. These dykes contain ordinary greenish brown hornblende, bluish green fibrous amphibole, chlorite, biotite, turbid plagioclase, and potash feldspar, and some ore. The lighter minerals are often enriched in the central part of the dykes, thus giving rise to a banded structure. It may be noted that these dykes are apart from the palingenic dykes and do not continue up to the contact surface. Moreover, their mineral composition and texture is quite different from that of the palingenic dykes. As to their genesis, the writer cannot express anything definite on the basis of rather limited observations. Perhaps they represents the last crystallized residual solution of the diabasic magma, as assumed by Wahl (1908, p. 60) with respect to the acidic dykes in the Svir-diabase, although they differ from the latter in being practically quartz free.

CHEMICAL COMPOSITION OF THE PALINGENIC DYKES AND PARENT ROCKS

When examining the analyses in Table III in more detail we find that, except for the MgO and CaO content, the composition of the palingenic dykes (Nos. 1—6) generally varies within a considerably narrower range than that of the parent rocks (Nos. 7—10). Thus for example the SiO_2 content, varying in the parent rocks from 64.96 to 81.10 %, in the palingenic dykes ranges only from 69.50 to 74.28 %. In the palingenic dykes the content of Al_2O_3 is in general somewhat smaller than in the parent rocks, and this is probably due to the fact that the palingenic dykes contain plagioclase which is more albitic and poorer in aluminium than that of the parent rocks. The percentages of FeO, CaO and MgO, combined in the amphibole, chlorite and biotite in the palingenic dykes, vary considerably even in analyses made from the same kind of rocks as *e. g.* the palingenic dykes from sandstone (Nos. 1 and 2) and Tarkki granite (Nos. 3 and 4). In addition, all palingenic dykes contain more MgO than their parent rocks, and usually the amounts of FeO and CaO are also greater. All palingenic dykes contain more Na_2O owing to a greater albitic plagioclase content whereas the amounts of potash are smaller than in the corresponding parent rocks.

In Table III the sums of normative quartz, orthoclase and albite range from 69.43 % to 90.72 % of the total composition of the palingenic dykes and parent rocks. In order to illustrate the distribution of these characteristic constituents, the position of each analysis has been calculated on the basis of the normative Q, or, and ab values in the triangle SiO_2—$NaAlSiO_4$—$KAlSiO_4$ in Fig. 7 where the main features of the equilibrium diagram of the dry alkali-alumina silicate system are reproduced after Schairer and Bowen (1935). The numerical values of the coordinates of the points are included in Table III after the norms. This operation is, as Bowen (1937) writes, »tantamount to projecting the composition of the rock out of polydimensional space upon that triangle, or more simply, to projecting it out of a tetrahedron which has that triangle as its base and the sum of all the other normative constituents as its apex, the eye-point being the apex». When comparing the constituents of the parent rocks with those of the palingenic dykes, the points of which are connected by broken lines, it is seen that in the dykes the amount of albitic plagioclase increases at the expense of potash feldspar. In addition, the SiO_2 is fairly similar in all palingenic dykes from rapakivi granite (Nos. 3, 4, 5, 6) and shows an increase as compared with the parent rocks. But the amounts of SiO_2 in the palingenic dykes from sandstone (Nos. 1 and 2) on the other hand, deviate clearly from the others. According to the description given on page 21, the palingenic dykes from sandstone contain large, usually rounded quartz and feldspar grains in addition to the fine-grained, micrographic groundmass. These large grains are interpreted by the writer as remnants of the original sandstone grains. To eliminate the influence of these large grains, volumetric analyses have been made, and, on the basis of this and the norms, the composition of the groundmass has been calculated. The position of the calculated groundmass, 1_r in Fig. 7, is considerably closer to that of the other palingenic dykes, with respect to the SiO_2 content. A detailed description of the method and the results obtained are presented in the following.

With the aid of the intergration stage, the proportions between the large rounded quartz and feldspar grains and the groundmass have been determined. On the basis of three thin sections, corresponding to analysis N:o 1, and a total line-sum of 725 mm., the rock contains:

	Vol. %
Large rounded quartz grains	16.9
» » feldspar »	12.4
Groundmass	70.7
	100.0

Table III. The analyzed palingenic dykes and their parent rocks.

Oxide percentages

	1	2	3	4	5	6	7	8	9	10
SiO_2	70.92	71.98	74.28	72.04	72.58	69.50	81.10	64.96	72.98	68.16
TiO_2	0.25	0.53	0.16	0.27	0.17	0.63	0.09	0.85	0.25	0.46
Al_2O_3	11.69	11.54	11.69	9.20	10.97	11.33	9.64	14.26	12.28	14.37
Fe_2O_3	1.04	0.89	0.91	1.29	1.68	1.01	0.28	1.25	1.64	1.95
FeO	2.67	3.38	2.28	3.30	1.44	4.00	0.65	6.02	1.67	2.07
MnO	0.04	0.07	0.03	0.05	0.04	0.05	0.03	0.10	0.03	0.04
MgO	2.17	2.28	0.67	1.00	1.38	1.39	0.76	0.54	0.21	0.50
CaO	3.78	1.29	0.96	4.58	0.60	2.79	0.80	2.45	1.02	1.45
Na_2O	2.50	2.81	3.60	3.20	2.54	2.29	1.78	2.80	2.04	1.83
K_2O	2.02	2.36	4.43	3.23	5.62	5.01	3.79	5.23	7.12	6.89
P_2O_5	—	0.11	—	0.11	—	0.10	0.08	0.05	—	0.11
H_2O+	2.31	2.01	0.80	1.03	1.90	1.60	0.77	1.20	0.80	1.20
H_2O-	0.53	0.37	0.20	0.30	0.84	0.48	0.17	0.13	0.16	0.32
F	—	—	—	—	[1])0.34	0.37	—	[1])0.21	[1])0.33	0.23
	99.92	99.62	100.01	99.60	100.10	100.55	99.94	100.05	100.53	99.58
—0					0.14	0.16		0.09	0.14	0.10
					99.96	100.39		99.96	100.39	99.48

1. Palingenic dyke from sandstone	Tuiskula, Köyliö	Anal.	Elsa Ståhlberg
2. » » » »	» »	»	H. B. Wiik
3. » » » Tarkki granite	»New contact of Heikkilä», Eurajoki	»	Elsa Ståhlberg
4. » » » » »	» »	»	H. B. Wiik
5. » » » spotted granite	Suontaka, Laitila	»	Elsa Ståhlberg [1])
6. » » » normal rapakivi granite	» »	»	O. von Knorring
7. Sandstone near the contact of the diabase	Tuiskula, Köyliö	»	H. B. Wiik
8. Tarkki granite (Laitakari, 1925 p. 11)	Eurajoki	»	E. Nordenswan [1])
9. Spotted granite	Suontaka, Laitila	»	Elsa Ståhlberg [1])
10. Normal rapakivi granite	» »	»	O. von Knorring

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[1] The fluorine determinations, which were not performed from the identical sample material, were made later by H. B. Wiik.

All the feldspar grains have been counted together, because the identification of the grains without staining was not possible, owing to turbidity and lack of twinning lamellae.

Provided that the ratios between the different feldspar components of the large feldspar grains is equal to that of the groundmass, the composition of the groundmass is obtained by subtracting the weight percentages of the large quartz and feldspar grains from the norms. The exact density values of the feldspars and the groundmass not being known and, further, the deviations caused thereby being relatively small with respect to the other errors, the author has used in Table IV the volume percentages, instead of weight percentages obtained by the volumetric analysis.

Table IV. Composition of the groundmass of a palingenic dyke from Sandstone. Eskonkallio, Tuiskula, Köyliö.

	Normative comp.	Large grains	Calculated groundmass
Quartz	36.8%	16.9%	19.9
Orthoclase and albite	32.6	8.5	24.1

The calculated groundmass contains consequently $SiO_2 = 69.5$ %, $KAlSiO_4 = 10.9$ % and $NaAlSiO_4 = 19.6$ %. As mentioned above, the plotted point 1_r is

Table III continued.

		1	2	3	4	5	6	7	8	9	10
Normative compositions[1]	Q	36.78	38.94	32.40	32.52	32.64	28.32	53.28	18.90	31.02	27.24
	or	11.68	13.90	26.13	18.90	33.36	30.02	22.24	31.14	42.26	40.59
	ab	20.96	23.58	30.39	27.25	21.48	19.39	15.20	23.58	17.29	15.72
	an	15.01	5.56	2.78	1.11	1.95	5.56	3.06	10.84	3.34	5.56
	C	—	2.35	—	—	—	—	1.43	—	—	1.84
	sal	84.43	84.33	91.70	79.78	89.43	83.29	95.21	84.46	93.91	90.95
	di	3.19	—	1.64	14.08	0.89	5.13	—	1.21	1.43	—
	wo	—	—	—	1.74	—	—	—	—	—	—
	hy	7.40	10.19	4.04	—	3.99	6.59	3.09	9.35	1.09	2.75
	mt	1.39	1.39	1.39	1.86	2.55	1.39	—	1.86	2.32	2.78
	il	0.46	1.06	0.30	0.46	0.30	1.22	0.15	1.67	0.46	0.91
	ap	—	0.34	—	0.34	—	0.34	0.34	—	—	0.34
	fr	—	—	—	—	—	0.78	—	—	—	—
	fem	12.44	12.98	7.37	18.48	7.73	15.45	3.58	14.09	5.30	6.78
Position in the triangle of Fig. 7	SiO_2	74.1	73.0	64.8	67.6	65.0	64.6	77.0	58.6	63.2	62.2
	$KAlSiO_4$	9.6	10.3	16.7	13.6	21.7	21.9	13.9	24.0	26.5	27.6
	$NaAlSiO_4$	16.3	16.7	18.5	18.8	13.3	13.5	9.1	17.4	10.3	10.2
		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Niggli numbers	si	341	372	414	347	407	327	647	271	411	338
	ti	0.9	2.2	0.7	0.9	0.7	2.3	0.5	2.8	1.0	1.8
	al	33.1	35.0	38.5	26.0	36.4	31.3	45.0	35.0	40.9	42.0
	fm	29.7	36.2	20.7	25.4	25.9	29.3	15.3	28.7	16.2	19.6
	C	19.6	7.1	5.7	23.7	3.7	14.1	6.7	11.0	6.1	7.7
	alk	17.6	21.7	35.1	24.9	34.0	25.3	33.0	25.3	36.8	30.7
	qz	170	185	174	148	171	126	415	70	164	115
	k	0.34	0.36	0.45	0.40	0.59	0.59	0.58	0.56	0.70	0.71
	mg	0.52	0.49	0.27	0.28	0.46	0.34	0.59	0.12	0.10	0.20
	c/fm	0.66	0.20	0.27	0.23	0.14	0.48	0.44	0.38	0.38	0.39

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[1] The norms and the Niggli numbers have been calculated using the tables, Johannsen I (1939) quoted from Prof. Paper 99, U.S.G.S.

situated considerably closer to the other palingenic dykes with respect to the SiO_2 content. As to the K/Na ratio of the reduced point 1_r, it is not as accurate as the value of SiO_2, because it is not known how far the foregoing assumption of the constant relation between the different feldspars is valid.

DISCUSSION OF RESULTS

To sum up the most essential features of the observations in the field and under the microscope concerning the palingenic contact phenomena described in the foregoing paragraphs, the following facts may be presented:

1. As a rule, the olivine diabase has aphanitic contacts against its country rock, in which apophyses are found with aphanitic edges and coarser centers. Exceptions to this rule are the »old contact of Heikkilä» (p. 24), as well as some xenoliths of the country rock situated farther from the main contact and some exceptional contacts which will be described in detail in Part IV.
2. At the aphanitic contact margin of the diabase, all over the area in question, large plagioclase phenocrysts and, very often, pseudomorphs of olivine or pyroxene phenocrysts are met.
3. Especially in places where the olivine diabase has a sill-like character, there are in the aphanitic or fine-grained diabase fine-grained, reddish granitic dykes called palingenic dykes, 0.1—8 cm. thick. These dykes cut the diabase apophyses or penetrate up to 2—3 m. into the diabase from the contacts. The different country rocks, also called parent rocks, are: sandstone, three varieties of rapakivi granite, and Archaean gneiss.
4. The above mentioned palingenic dykes, are usually sinuous and irregular in form. At the »new contact of Heikkilä» (p. 26) where they penetrate the diabase apophyses, some of these dykes continue, though vaguer and broader in form, even to some extent into the granite.
5. Palingenic dykes contain orthoclase, anorthoclase, albitic plagioclase, amphibole, chlorite, and biotite as main constituents; micrographic texture is characteristic of them all.
6. In the narrow contact zone (1—5 mm. thick) of the diabase against the palingenic dykes and the parent rocks, the olivine and augite grains of the diabase have disappeared and altered into serpentine, amphibole, chlorite, and iron ore while the plagioclase laths have been corroded.
7. Fine-grained granitic dykes in the parent rock near the palingenic dykes are not observed except at the »new contact of Heikkilä». Here, parallel with the diabase apophyses, some granitic dykes are encountered which, though occurring quite apart from the palingenic dykes, have a mineral composition and texture similar to theirs. In addition, proceeding from these granitic dykes, apophyses a few millimeters long are noticed between the quartz and feldspar grains of the surrounding Tarkki granite.

8. According to Laitakari in the diabase sill of Sorkka, some reddish granitic dykes, ten centimeters broad and several hundred meters long, occur. Against these dykes in the contact zone of the diabase, the olivine and augite have been altered into hornblende, serpentine, biotite, and iron ore.

To avoid repetition, the genetic aspects of the phenomena have been treated in the previous paragraphs only to an extent necessary to make the descriptions clear. On the basis of the foregoing facts, the writer will now try to present his conception of the remelting phenomena of the country rock at the olivine diabase contact.

As previously described at numerous contacts in the area investigated, where it is possible to determine the age relations by means of the aphanitic contact margins of the diabase or of the diabase apophyses, it is obvious that the olivine diabase is younger than the sandstone, rapakivi granites and Archaean rocks. The diabase, now seen on the erosion surface, has been solidified at a depth, that cannot be determined exactly (see p. 9). However, the chilled margins on the one hand and the lack of vitreous contact varieties on the other clearly show the hypabyssal character of the intrusion. In addition, the olivine pseudomorphs and plagioclase phenocrysts which occur in the aphanitic contact zone of the diabase

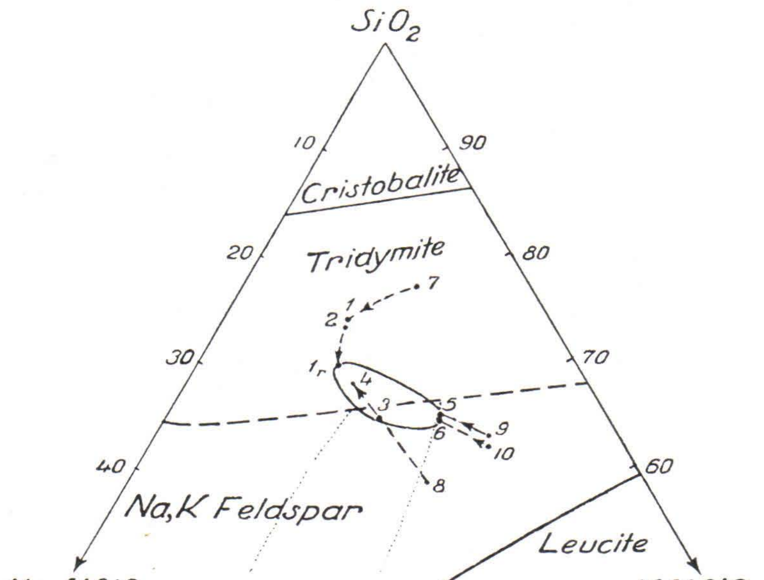

Fig. 7. Plot of the salic normative composition (except anorthite) of the palingenic dykes and their parent rocks in Table III in the equilibrium diagram of the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2 after Schairer and Bowen (1935). Dashed lines show the side boundaries of the temperature through after Bowen (1937).

are not resorbed except in the narrow reaction zone at the contact surface proper. This shows that the diabasic magma was not under superheated conditions when intrusion took place.

According to the experiments made by Eskola (1925) at the Geophysical Laboratory of the Garnegie Institute in Washington, a dry silicate melt, prepared from the olivine diabase of Satakunta, passed through its crystallization interval approximately between 1 200°—1 050°C under the pressure of one atmosphere. According to Schairer and Bowen (1935), on the other hand, the area of lowest temperature on the boundary line between tridymite and alkali feldspars in the dry system SiO_2—$NaAlSiO_4$—$KAlSiO_4$ is about 1 000° C.

On account of these differences in the crystallization intervals between dry diabasic and granitic liquids it is easy to understand that the heat flowing from the diabasic magma through the aphanitic contact has caused the temperature of the country rock to rise high enough to remelt part of its minerals. This has happened especially in places where the heat influence has been greater than usual as *e. g.*, below diabase sills or, also, at the upper contacts of the diabase in places where other hot diabase sills above the present erosion surface might have been present. It is obvious that the composition of the first intergranular liquid was situated in that part of the space in the polydimensional system which corresponds to the lowest temperature range in the prevailing pressure and concentration (including water) of the country rock. When the temperature arose, the composition of this intergranular liquid shifted somewhat towards the bulk composition of the country rock.

During the cooling of the contact zone of the diabase, cooling joints formed, into which intergranular, granitic liquid, crystallizing at a lower temperature, intruded as palingenic dykes. The sinuous form of these dykes, together with the fact that they do not continue more than 2—3 m. from the main contact into the diabase, shows that the diabase was not completely solidified at the time of their formation. That these palingenic dykes extend also vaguely into the Tarkki granite (p. 26) and that there are fine-grained dykes in the Tarkki granite, of almost the same mineral composition and texture can be explained as an extension of the cooling joints from the diabase into the relatively basic Tarkki granite, these joints having been filled with intergranular liquid. A separate post-diabasic granitic intrusion, not genetically connected with the diabase intrusion, would be very artificial, because only a part of the palingenic dykes of the »new contact of Heikkilä» extends indefinitely into the granite. Neither have any fine-grained granitic dykes been found in connection with palingenic dykes of other contacts.

The extension of some palingenic dykes into the granite, together with the micrographic groundmass between the original minerals of the parent rocks encountered near the diabase contacts, shows that the remelting of the parent rock during the formation of the palingenic dykes had not advanced very far. This is also shown by the great differences between the chemical composition of the palingenic dykes and parent rocks in Table III. Despite the great variety of the parent rocks, the positions of the palingenic dykes lie in a rather limited area, encircled in Fig. 7, near the temperature valley of the boundary curve between tridymite and alkali feldspars in the dry alkali-alumina silicate system under normal pressure. This fact seems to show that the conditions at the diabase contacts have not deviated considerably from that of the dry system. It is difficult to decide which one of the following points has been most important in causing the differences in the compositions of the palingenic dykes in Fig. 7.

1. On account of the remelting of the minerals of the parent rocks with rising temperature, the composition of the originally similar intergranular liquid has changed towards the composition of the parent rocks.
2. Different pressure and concentration (including water) have caused differences in the composition of the first drops of the intergranular liquid.
3. The original unresorbed minerals of the parent rocks carried by the intergranular liquid have altered the total composition of the dykes.

The straight lines drawn through the points representing parent rocks of the rapakivi granites and the corresponding palingenic dykes in Fig. 7, intersect between points Nos. 4 and 1_r. In addition, the palingenic dyke from the Tarkki granite, corresponding to analysis No. 4, Table III, contains considerably more micropegmatite than the other dyke from the same rock, corresponding to analysis No. 3. On the basis of these facts the writer regards the first and third factors to be dominant. If this is correct, then the position of the first drops of the intergranular liquid between quartz and alkali feldspar grains should lie approximately between points No. 4 and 1_r in Fig. 7.

Let us follow, then, the crystallization of the liquid which has intruded into the joints of the diabase and which may contain some quantity of the original minerals of the parent rocks. When the temperature of the liquid begins to fall, it is probable that such minerals, being in excess over the composition of the primary intergranular liquid, will crystallize first; after that the quartz, alkali feldspars and perhaps also biotite will crystallize simultaneously, forming a micrographic texture (Vogt, 1921, pp. 323—324), typical of all palingenic dykes. Another characteristic feature, probably resulting from the extraordinary conditions in the formation of the palingenic dykes, is their considerable anorthoclase content. According to their composition the anorthoclases coincide with perthite. In view of this fact, Alling (1921) writes: »It is quite reasonable, therefore, to consider that many anorthoclases are undercooled metastable solid solutions of the two alkali components». Taking the fact into account that anorthoclases occur mainly in volcanic rocks, this explanation may also be valid with respect to the formation of the anorthoclases of the palingenic dykes. Then it must be conceded that conditions were favorable for the formation of undercooled, metastable minerals from a liquid the temperature of which was relatively high, and which certainly must have cooled rapidly as compared with plutonic conditions.

On the basis of the reaction principle of Bowen (1928), the formation of the dark minerals of the palingenic dykes becomes understandable as do the reactions at the immediate contacts between the aphanitic or fine-grained diabase and the palingenic dyke or parent rock. According to this principle, as soon as a liquid in the parent rock has been created through the thermal influence of the diabase, the olivine, augite, and labradoritic plagioclase in the contact mantle of the diabase become unstable in the granitic liquid striving for the acid end of the reaction series. The intergranular liquid, containing mainly quartz and alkali feldspar, could not remelt the plagioclase of the diabase richer in anorthite, but began to react with it and convert it into a more acid plagioclase, while at the same time more albitic plagioclase, with which the granitic liquid is saturated, crystallized from it. On the other hand, olivine and augite, with which the liquid is supersaturated, disintergrate and a part of their constituents forms serpentine, hornblende, and iron ore in the immediate vicinity of the disintergrating grains, while the rest, as Mg-, Fe- and Ca-rich solutions, migrate through the intergranular liquid towards the palingenic dyke or parent rock to form hornblende, chlorite, and biotite. As has been pointed, it is possible, however, that a part of the biotite, and perhaps also hornblende, in the palingenic dykes originates from the material of the parent rocks. As to the quartz grains, encountered in the reaction zone on the side of the diabase, the writer assumes that their material, like the solutions containing ferrous iron and magnesium, migrates through the intergranular solution formed by the reaction of the acidic intergranular liquid with the constituents of the olivine diabase.

Depending upon the position and width of the dyke in relation to the main contact and upon the thermal conditions, the reactions between the diabase and granitic liquid have attained different stages at different points and thus it is possible to understand the great differences, occurring even in the dykes from the same parent rocks, in the contents of FeO, MgO, and CaO, which for the most part have come from the diabase. Especially the magnesium content of the palingenic dykes is considerably greater (as much as 4—6 times) than in the parent rocks. This seems to show that the magnesium ion has the greatest mobility of the three, Mg, Fe and Ca. This fact is consistent with the results which will be presented on pp. 70 and 75.

On the basis of the phenomena described above, it is also easy to comprehend that under more favorable thermal conditions, as *e. g.* round the xenoliths in the diabase farther from the main contact (p. 23), the reactions between the partially remelted xenolith and the thin diabase mantle around it have been so intense that the distinct boundary between the rocks has vanished.

The writer has no personal observations regarding the genesis of the acidic dykes in the diabase area of Sorkka, reported by Laitakari (1928, pp. 16—18), and will accordingly not express any definite opinion in the matter. Considering, however, the intense remelting phenomena observed in the Suontaka diabase area to be described later in more detail, as well as the texture of the dykes in question together with the reactions between the diabase and the dykes encountered at the contacts, the writer regards it possible that they might have intruded from parts below the Sorkka diabase sheet, which on account of the stronger heat influence have been remelted more completely.

From the observations at the contacts of the olivine diabase of Satakunta, the writer considers it evident that the hypabyssal diabase, especially in areas where it occurs as sills, has been able partially to remelt its country rocks and form intergranular liquids. Despite the great deviations in the composition of the parent rocks, that of the liquids ranges in a fairly narrow area near the temperature valley along the boundary curve between tridymite and alkali feldspars in the dry alkali-alumina silicate system. It is noteworthy that, although the rapakivi granites are rich in potash, the intergranular liquids, squeezed out from the different kinds of parent rocks, contain considerably more sodium. However, contact phenomena will be described later (pp. 57 and 76) that can be explained by assuming that the residual solution of the almost completely remelted and recrystallized rapakivi granite has been enriched in potash.

It is difficult to say how far the results can be applied to phenomena taking place deaper in the earth's crust, where the temperature undoubtedly corresponds to the contact conditions of the diabase, but where the pressure and concentration of components, especially the water content, are different. In any case the foregoing contact observations tend to support the conception, presented by Eskola (1932, 1934, 1950), of the genesis of a granitic magma by partial refusion of the igneous rocks, most basic ones excepted, and argillaceous or arkosic sediments. The investigation of the composition of the intergranular liquid, formed under plutonic conditions, by the aid of the aforementioned methods, is probably more difficult than at the contact of the Satakunta diabase. Hence, it is possible that suitable laboratory experiments will more easily give a satisfactory answer to this and other related questions.

PART IV

MORE COMPLETE REMELTING OF COUNTRY ROCK AND FORMATION OF HYBRID ROCKS

HYBRIDIZATION PHENOMENA IN THE SUONTAKA DIABASE AREA

POSITION OF THE HYBRIDS

Previous chapters have described how the minerals of country rock have, on account of the heat flowing from the diabasic magma, been partially remelted near the contact forming an intergranular liquid which may have intruded as palingenic dykes into the contact zone of the diabase. Also the endomorphic contact influences in the diabase, caused by the intergranular liquid, have been described. Moreover, on p. 23 mention has been made of the reactions between the partially remelted xenoliths and the surrounding fine-grained diabase which have been so intense that any distinct boundary between the two rocks has vanished. Similar hybridization phenomena are encountered also at the main contacts of the diabase sills in many places over the area investigated, but they have been extraordinarily intense in the Suontaka diabase area (No. 12 in appended map) in the parish of Laitila.

In the Suontaka diabase area several wave-like diabase sills occur, at the upper contacts of which (Nos. 2, 3, 4, and 9 in Fig. 8) palingenic dykes described in Part III are encountered. The map (Fig. 8) shows that, in connection with the diabase and rapakivi area, there are also hybrid rocks which may contain either features of diabase or of rapakivi granite; but on the basis of the texture as well as the mineral and chemical composition these hybrid rocks belong to neither one of the two rocks. In the vertical sections IIa—IId and IIIa—IIId in Fig. 9, drawn through the drill hole (No 1 in Fig. 8), 24 m. deep, it can be seen that the southern hybrid rock area is situated between two nearly horizontal diabase sills. The contacts Nos. 6 and 9 near the vertical section IVa—IVb (Fig. 9) and the outcrops Nos. 7 and 8, in which the upper part of the outcrop is medium-grained diabase while the lower part is of a hybrid rock, show that the hybrid rock occurs also in the northern part of the Suontaka diabase area below a diabase sill. It is hard to say how thick the

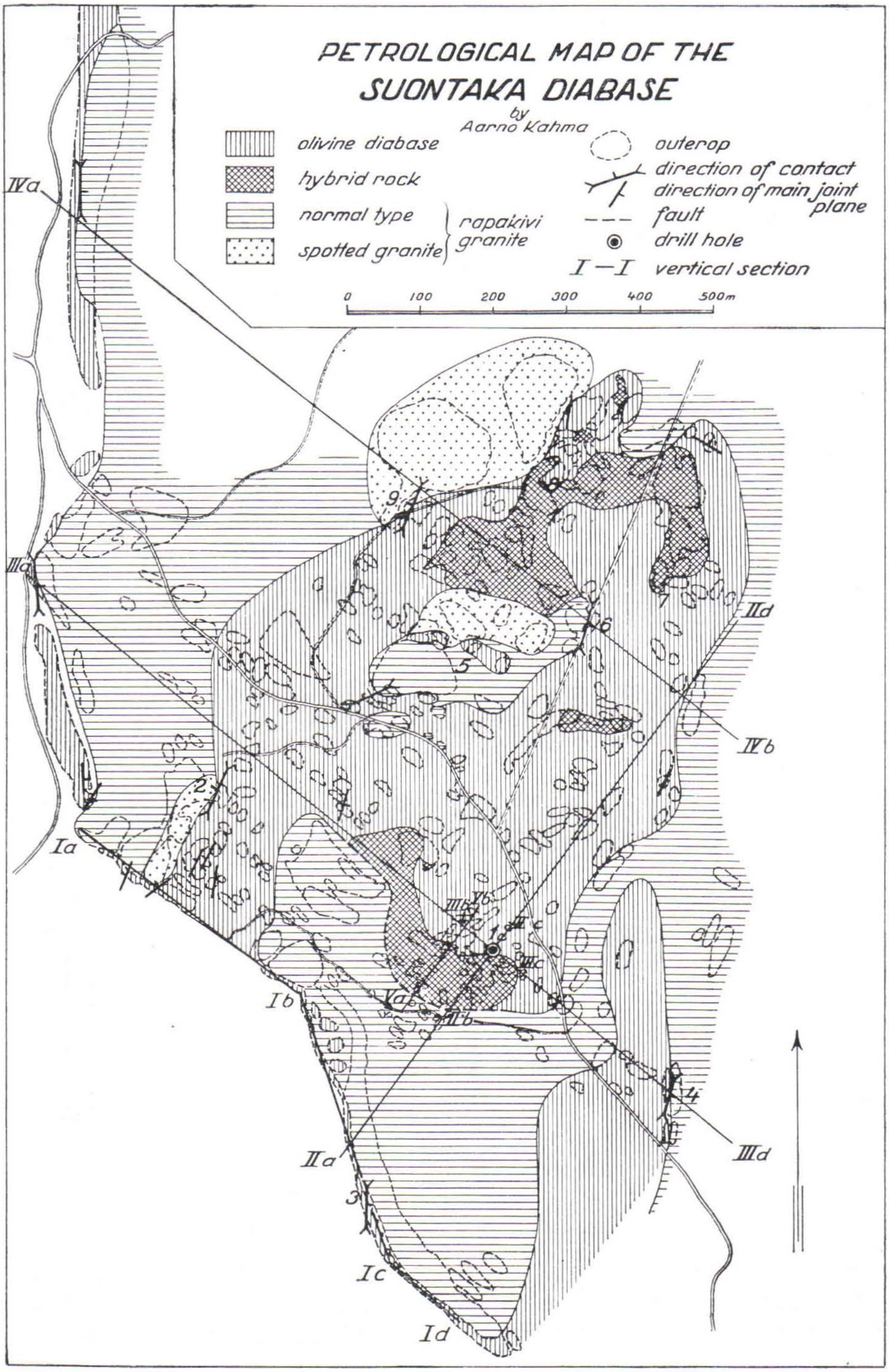

Fig. 8. Petrological map of the Suontaka diabase area.

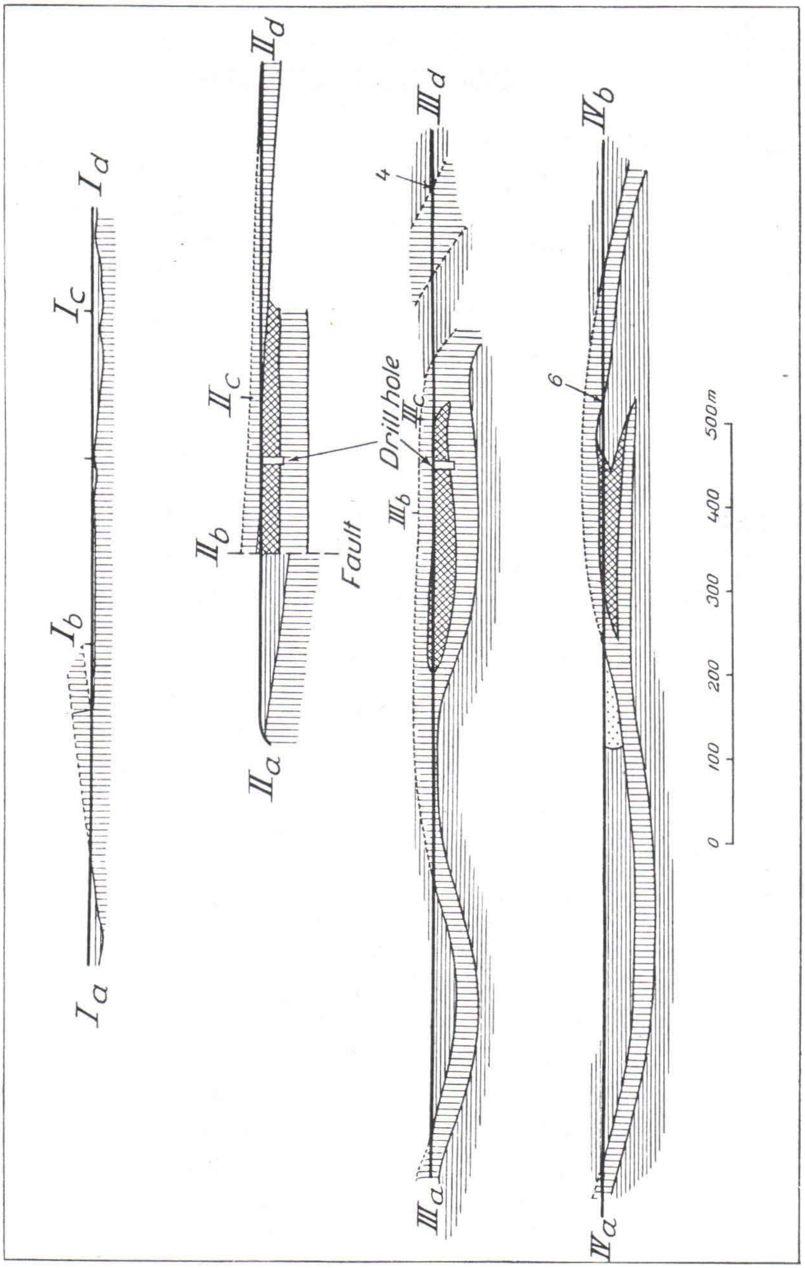

Fig. 9. Vertical sections for the map of the Suontaka area, Fig. 8. The thick horizontal lines represent the present erosion surface, the other symbols are the same as in Fig. 8.

hybrid formation here is and whether there is another diabase sill below, as is assumed in section IVa—IVb (Fig. 9). It is also difficult to decide whether the diabase outcrops (No. 5), situated in the rapakivi window, are remnants of the main diabase sill, or only remnants of the thinner branch, parallel with it.

The upper diabase sill once existed all over the area above the hybrids, but it is difficult to estimate its total thickness. Rough estimates range from 10 to 25 meters, being based chiefly on sections Ia—Ib [1]) and IVa—IVb (Fig. 9). In following chapters the description will be limited to the hybrid formation of the southern part of the Suontaka area, where a reliable picture can be obtained of the occurrence of the different rocks and conditions of formation from more detailed surface investigations and drill hole No. 1.

DENSITY AND CHEMICAL COMPOSITION OF THE HYBRIDS

In order to get an idea of the character of the southern hybrid contact in the Suontaka area, let us first examine the density determinations. Curve $C_s(Z)$ in Fig. 10 represents the densities in the vertical drill hole [2]), which is 23.9 m. deep (No. 1 in Fig. 8). The determinations were made from the halved drill cores with a sample interval of 0.5 m. The density curve in Fig. 10 is drawn in the interval —Z=10—23.9 m. through the points corresponding to the average densities in the sample interval —Z=10—12, 12—14, 14—16, 16—20 and 20—23.9.

The practical density determinations of the samples in the drill hole, as well as of the other samples mentioned in this chapter, have been made by Mrs. T. Mikkola using the ordinary method of weighing the samples in air and in water. Regarding the accuracy of the determinations it can be seen in Fig. 10 that the points, corresponding to the sample interval of 0.5 m., deviate only 0.01—0.03 g/cm^3 from the curve in the upper part of the drill hole, but in the lower part the deviations may be even 0.12 g/cm^3 from the average densities of greater sample intervals. In Table V we see that the average grain size of the plagioclase rapidly increases with increasing depth. Thus any fortuitous variation in the number of the different mineral grains may cause notable deviations in the density at the relatively short sample interval.

Table V. The average grain size of the plagioclase grains in drill hole No. 1. Suontaka.

—Z	The average grain diameter
0.01 m.	1.86 mm.
0.81	1.11
6.0	0.25
6.5	0.25
21.0	2.03
23.87	3.15

---

[1]) The course of the contact in section Ia—Id has been made by levelling.

[2]) The co-ordinates of the drill hole are: X = **449.5**, Y = **143.7**, Z = 0.00; the Y — axis is parallel with traverse IIa—IId in Fig. 8.

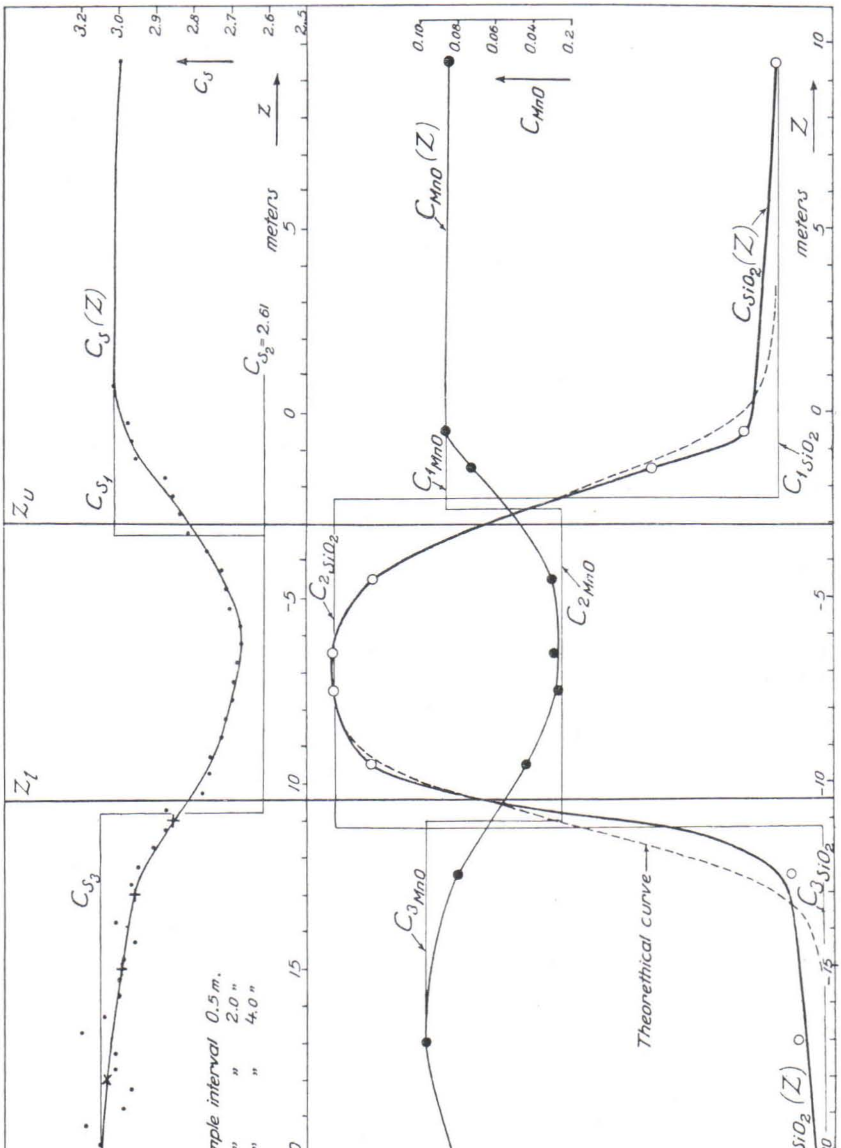

Fig. 10. The distribution of density[1]) (s) and the concentration of SiO_2 and MnO in drill hole No. 1. Suontaka.

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[1]) Instead of C_{s_1}, C_{s_2} and C_{s_3} in Fig. 10 read C_{1S}, and C_{2S} and C_{3S} respectively.

The density determinations made of the samples from drill hole No. 1 show that when passing either from the upper or the lower diabase sill into the middle of the hybrid formation the density of the rock con-

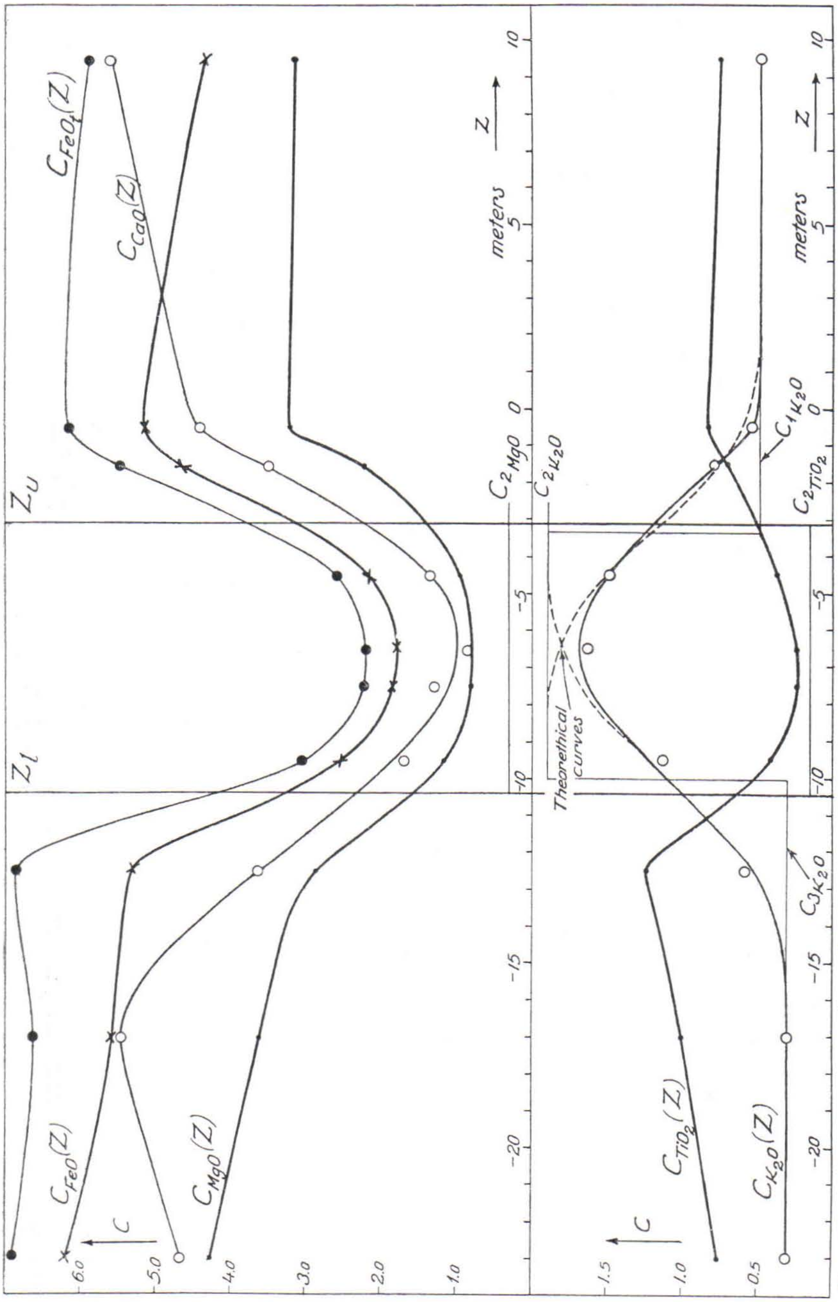

Fig. 11. The concentration distribution of K_2O, TiO_2, MgO, CaO, FeO, and FeO_t in drill hole No. 1. Suontaka.

tinuously decreases, reaching a minimum s = 2.67 g/cm³ at about Z = —6.0. The density curves in Fig. 18_{a_2} and 18_{b_2}, obtained from the determinations of surface samples along the traverses IIb—IIc and

Table VI. Chemical composition, molecular proportions, concentrations and Niggli numbers of the rocks in or near drill hole No. 1. in the Suontaka area.

		1	2	3	4	5	6	7	8	9	10	11	12	13
	Sample interval in m.		0—1	1—2	4—5	6—7	7—8	9—10	12—13	16—18	22—23.9			
Oxide percentages	SiO_2	47.73	49.08	52.50	64.56	66.71	66.18	63.67	47.98	46.57	45.90	65.35	66.71	68.16
	TiO_2	1.96	2.22	1.90	1.09	0.72	0.72	1.20	3.33	2.66	2.00	1.00	0.61	0.46
	Al_2O_3	15.06	14.32	14.40	14.52	13.52	13.21	13.46	12.60	14.76	15.13	13.38	13.77	14.37
	Fe_2O_3	4.09	2.71	2.28	1.16	1.36	1.12	1.45	4.12	3.01	1.84	2.28	3.32	1.95
	FeO	10.40	12.42	11.45	5.69	4.79	4.97	6.62	12.96	13.24	14.69	4.75	2.38	2.07
	MnO	0.20	0.21	0.18	0.08	0.08	0.07	0.11	0.19	0.23	0.14	0.07	0.06	0.04
	MgO	4.23	4.35	3.07	1.38	1.27	1.12	1.69	3.93	4.80	5.69	1.39	0.83	0.50
	CaO	10.48	8.37	6.71	2.74	1.82	2.69	3.43	6.90	10.08	8.66	2.70	1.11	1.45
	Na_2O	2.74	2.35	1.97	2.25	1.81	2.20	2.54	2.58	2.30	2.85	2.26	2.00	1.83
	K_2O	1.46	1.66	2.68	5.17	5.78	5.89	3.90	1.90	0.95	0.96	5.29	7.07	6.89
	P_2O_5	0.35	0.30	0.29	0.14	0.12	0.20	0.26	0.20	0.23	0.21	0.15	0.18	0.11
	H_2O+	1.23	1.24	1.85	1.22	1.57	1.07	1.53	2.08	1.25	1.20	0.87	1.41	1.20
	H_2O-	0.22	0.41	0.55	0.44	0.11	0.43	0.55	0.90	0.42	0.60	0.14	0.62	0.32
	F		0.03											0.23
		100.15	99.67	99.83	100.44	99.66	99.87	100.41	99.67	100.50	99.87	99.63	100.07	99.58
	—O		0.01											0.10
			99.66											99.48
Density		2.99	2.96	2.91	2.71	2.67	2.69	2.75	2.95	3.03	3.03	2.72	2.59	2.61

1. Olivine diabase	Point L in Fig. 18	Anal. H. B. Wiik
2. Diabase hybrid	Drill hole No 1 in Fig. 8, —Z = 0—1	»
3. » »	» , —Z = 1—2	»
4. Rapakivi hybrid	» , —Z = 4—5	»
5. » »	» , —Z = 6—7	»
6. » »	» , —Z = 7—8	»
7. » »	» , —Z = 9—10	»
8. Diabase »	» , —Z = 12—13	»
9. » »	» , —Z = 16—18	»
10. » » (practically pure oliv. diabase)	» , —Z = 22—23.9	»
11. Rapakivi »	Point G in Fig. 18.	»
12. » »	» E_2 in Fig. 18.	»
13. Normal rapakivi granite	Near I_b in Fig. 8.	Anal. O. von Knorring

Table VI. continued.

		1	2	3	4	5	6	7	8	9	10	11	12	13
Molecular proportions	SiO_2	.795	.817	.874	1.075	1.111	1.102	1.060	.799	.775	.764	1.088	1.111	1.135
	TiO_2	.025	.028	.024	.014	.009	.009	.015	.042	.033	.025	.013	.008	.006
	Al_2O_3	.148	.140	.141	.142	.133	.130	.132	.124	.145	.148	.131	.135	.141
	Fe_2O_3	.026	.017	.014	.007	.009	.007	.009	.026	.019	.012	.014	.021	.012
	FeO	.145	.173	.159	.079	.067	.069	.092	.180	.184	.204	.066	.033	.029
	FeO_t 1)	.196	.207	.188	.094	.084	.083	.110	.232	.218	.228	.094	.075	.053
	MnO	.003	.003	.003	.001	.001	.001	.002	.003	.003	.002	.001	.001	.001
	MgO	.105	.108	.076	.034	.031	.028	.042	.097	.119	.141	.034	.021	.012
	CaO	.187	.149	.120	.049	.032	.048	.061	.123	.180	.154	.048	.020	.026
	Na_2O	.044	.038	.032	.036	.029	.035	.041	.042	.037	.046	.036	.032	.030
	K_2O	.016	.018	.028	.055	.061	.063	.041	.020	.010	.010	.056	.075	.073
	P_2O_5	.002	.002	.002	.001	.001	.001	.002	.001	.001	.001	.001	.001	.001
	$H_2O +$	.068	.069	.103	.068	.087	.059	.085	.115	.069	.067	.048	.078	.067
Concentration	SiO_2	23.77	24.18	25.43	29.13	29.66	29.64	29.15	23.57	23.48	23.15	29.59	28.77	29.62
	TiO_2	0.748	0.829	0.698	0.379	0.240	0.242	0.413	1.239	1.000	0.758	0.354	0.207	0.157
	Al_2O_3	4.43	4.14	4.10	3.85	3.55	3.50	3.63	3.66	4.39	4.48	3.56	3.50	3.68
	Fe_2O_3	0.777	0.503	0.407	0.190	0.240	0.188	0.248	0.767	0.576	0.364	0.381	0.544	0.313
	FeO	4.34	5.12	4.63	2.14	1.79	1.86	2.53	5.31	5.58	6.18	1.80	0.855	0.757
	FeO_t	5.86	6.13	5.47	2.55	2.24	2.23	3.03	6.84	6.61	6.91	2.56	1.94	1.38
	MnO	0.084	0.086	0.073	0.030	0.029	0.027	0.044	0.080	0.097	0.061	0.027	0.026	0.026
	MgO	3.14	3.20	2.21	0.921	0.828	0.753	1.16	2.86	3.61	4.27	0.925	0.544	0.313
	CaO	5.59	4.41	3.49	1.33	0.854	1.29	1.68	3.63	5.45	4.67	1.31	0.518	0.679
	Na_2O	1.32	1.12	0.931	0.976	0.774	0.942	1.13	1.24	1.12	1.39	0.979	0.829	0.783
	K_2O	0.478	0.533	0.815	1.49	1.63	1.69	1.13	0.590	0.303	0.303	1.52	1.94	1.91
	P_2O_5	0.060	0.059	0.058	0.027	0.027	0.027	0.055	0.030	0.030	0.030	0.027	0.026	0.026
Niggli numbers	si	113.5	123.2	148.9	262.2	298.6	284.0	247.1	124.6	108.2	104.8	272.0	309.5	337.8
	ti	3.6	4.2	4.1	3.4	2.4	2.3	3.5	6.6	4.6	3.4	3.3	2.2	1.8
	al	21.1	21.1	24.0	34.6	35.7	33.5	30.8	—19.3	20.3	20.3	32.7	37.6	42.0
	fm	43.6	48.0	45.3	31.2	31.5	28.8	35.9	51.8	48.0	50.9	32.3	27.0	19.6
	c	26.7	22.5	20.5	12.0	8.6	12.4	14.2	19.2	25.1	21.1	12.0	5.6	7.7
	alk	8.6	8.4	10.2	22.2	24.2	25.3	19.1	9.7	6.6	—7.7	23.0	29.8	30.7
	qz	—20.9	—10.4	8.1	73.4	101.8	82.8	70.7	—14.2	—18.2	—26.0	80.0	90.3	115.0
	k	0.27	0.32	0.47	0.60	0.68	0.64	0.50	0.32	0.21	0.18	0.61	0.70	0.71
	mg	0.34	0.34	0.29	0.27	0.26	0.25	0.27	0.29	0.35	0.38	0.26	0.22	0.18
	c/fm	0.61	0.47	0.45	0.38	0.27	0.43	0.40	0.37	0.52	0.42	0.37	0.21	0.39

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1) total iron $FeO + 0.8998 \times Fe_2O_3$

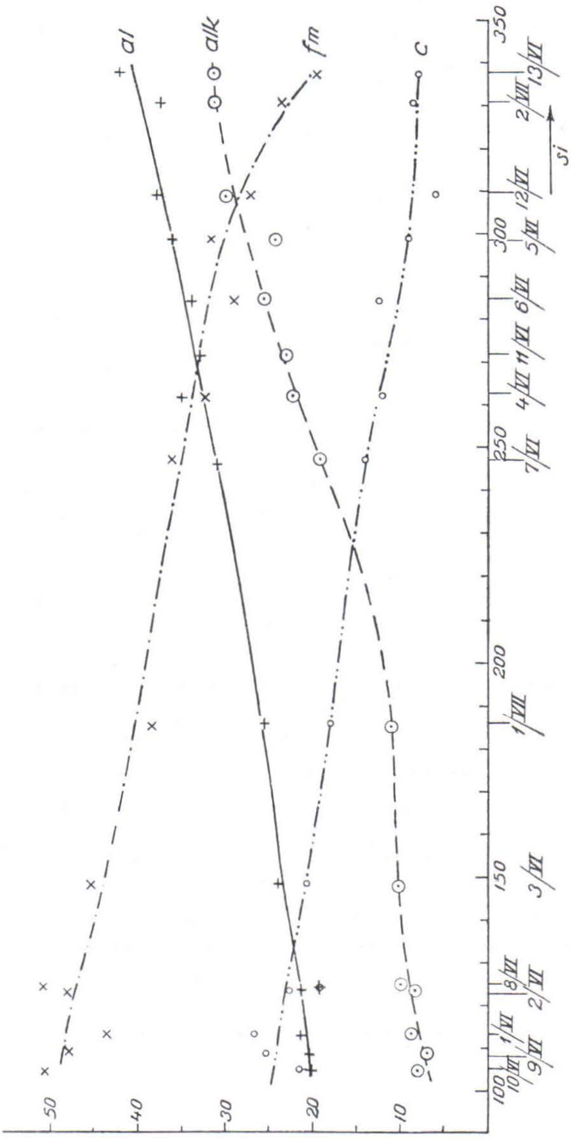

Fig. 12. The al-, fm-, c- and alk-values of rocks in Suontaka as a function of si. The numbers, *e. g.* 2/VII refer to the corresponding analysis and table respectively.

Va—Vb in Fig. 8 show almost the same character. In addition Fig. 18_{a_2} shows that lower on the slope the hybrid formation reached its minimum $s = 2.59$ g/cm^3 at point E_2, which is 3.86 m. higher[1]) than the corresponding point in the drill hole. On the traverse Va—Vb, on the other hand, the hybrid formation reaches its minimum density $s = 2.58$ near point e in Fig. 18_{b_2}, which is 1.55 m. higher than the minimum point in the drill hole.

The variation in the chemical composition of the hybrid rocks is given in Table VI. Analyses Nos. 2—10 have been made of samples from the drill hole and Nos. 1 and 11—13 of surface samples. To avoid the aforementioned errors owing to grain size, analyses Nos. 2—8 have been made with sample intervals of 1.0 m. in length, and analyses Nos. 9 and 10 with sample intervals of 2.0 m. In addition to the oxide percentages and molecular proportions Table VI contains the Niggli values and concentration (in moles per liter) $C_A = \frac{10^3 \cdot s \cdot m_A}{10^2} = 10 \cdot s \cdot m_A$ where m_A is the molecular proportion of an oxide A and s the density of the sample. As fluorine determinations have not been made of all the samples and as the H_2O values may vary greatly on account of accidental factors, the concentrations of fluorine and H_2O are omitted.

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[1]) The profiles in Fig. 18 have been made by levelling.

Figs. 10 and 11 give a better idea of the variation of the chemical composition in the drill hole, the concentration of the most characteristic oxides of analyses Nos. 2—10 being presented as the function of the average depth (or Z-coordinate) of the sample intervals. For reasons to be described on p. 65, analysis No. 1 (Anal. No. 5 in Table II) is included, corresponding to the Z-value +9.5, a point which lies 9.5 m. above the upper end of the drill hole. As in the density curve, we can see in Figs. 10 and 11 that the hybrid formation consists of a continuous series of rocks lying between the composition of the olivine diabase (Nos. 1 and 10) and the granite (Nos. 5 and 6), which has almost the same composition as the normal rapakivi granite, in the Suontaka area (No. 13). The comparison of analysis No. 12 (made of a surface sample on the slope) with the analyses Nos. 5 and 6 in the drill hole shows that the former is more acid than the latter — — a fact which is in agreement with the density determinations, made of the same rocks.

Fig. 12 presents the values of al, fm, c and alk in Table VI as a function of si. In addition, the hybrid analyses Nos. 1 and 2 in Table VII, made of surface samples not far from the drill hole have been included. As the samples for these analyses were taken before the detailed mapping of the area, their location on the map is not as accurate as for the others.

Table VII. Chemical composition and Niggli numbers of hybrid and dyke rocks in the vicinity of drill hole No. 1 in the Suontaka area.

	1	2	3
SiO_2	57.44	69.02	70.28
TiO_2	2.37	0.63	0.40
Al_2O_3	13.32	13.11	12.90
Fe_2O_3	3.00	1.44	2.80
FeO	8.35	3.02	1.69
MnO	0.15	0.06	0.04
MgO	2.17	0.79	0.69
CaO	5.00	1.60	0.69
Na_2O	2.82	2.34	2.33
K_2O	3.75	6.64	6.12
P_2O_5	0.04	—	tr.
H_2O +	1.46	1.12	1.25
H_2O—	0.46	0.22	0.53
	100.33	99.99	99.72
si	185.6	331.1	365.6
ti	5.8	2.3	1.6
al	25.4	37.2	39.7
fm	40.8	23.3	24.4
c	17.3	8.4	3.7
alk	16.5	31.1	32.2
qz	19.6	106.7	136.8
k	0.47	0.65	0.63
mg	0.26	0.25	0.22
c/fm	0.42	0.36	0.15

1. Hybrid. Anal. Elsa Ståhlberg
2. » » » »
3. Aplitic dyke. Anal. H. B. Wiik

MINERAL COMPOSITION, TEXTURE AND STRUCTURE OF THE HYBRIDS

DIABASE HYBRIDS

On the basis of arguments to be presented later (pp. 72—86), the hybrid rocks of the drill hole (No. 1 in Fig. 8) in the Suontaka area are divided into two groups, *viz.*, the diabase and the rapakivi hybrids. Among rapakivi hybrids are included the rocks occurring in the drill hole at the depth interval —Z = 3.1—10.4 m. and among diabase hybrids the rocks extending on either side of the foregoing limites to the normal olivine diabase.

If the specimens of hybrid rock from the interval —Z = 0—1 m. are examined megascopically, no differences can be detected between them and the normal olivine diabase. Even the densities and the chemical compositions are similar. Microscopically, however, in addition to the main minerals of the olivine diabase (plagioclase, augite, olivine and iron ore) also quartz and alkali feldspar can be detected. The large plagioclase laths, together with the gray-violet augite, form a similar ophitic texture as in the normal olivine diabase (Fig. 11 Pl. III). The olivine occurs as idiomorphic grains, with green serpentine as an alteration product on the margins and fissures. In many cases the olivine grains have been completely altered into serpentine or more rarely into reddish-brown iddingsite, and iron ore.

There are micrographic intergrowths of quartz and alkali feldspar in the form of veinlets or aggregates between the aforementioned main minerals. Adjoining minerals have altered to a slight extent: grains of augite show rims of hornblende or even biotite; the plagioclase laths, usually fresh, contain epidote, whilst only the margins of olivine grains have altered to serpentine.

The depth interval of —Z = 21—23.9 m. is more coarse-grained than the former (see Table V) but very similar in mineral and chemical composition, the most important difference being the smaller amount of quartz and alkali feldspar not micrographically intergrown. The differences between this type of diabase hybrid and the normal olivine diabase are so small that it can be considered normal olivine diabase. The plagioclase contains abundant alteration products in the vicinity of the alkali feldspar grains. Small apatite grains are fairly abundant throughout the rock as inclusions in the augite, plagioclase, and alkali feldspar grains.

Figs. 13 b and 15 c give a general idea of the minerals which occur in the depth interval of —Z = 0—1 m. and —Z = 21—23.9 m. They present the statistical refractive-index analyses (pp. 12—13) made of the sample intervals of —Z = 0.00—0.08 m. and —Z = 23.00—23.08 m. These analyses has been made by Mr. O. Waldén. In the upper part of the figures are the curves k = k(n), on the basis of which the columns below are drawn. When the composition of certain minerals, like plagio-

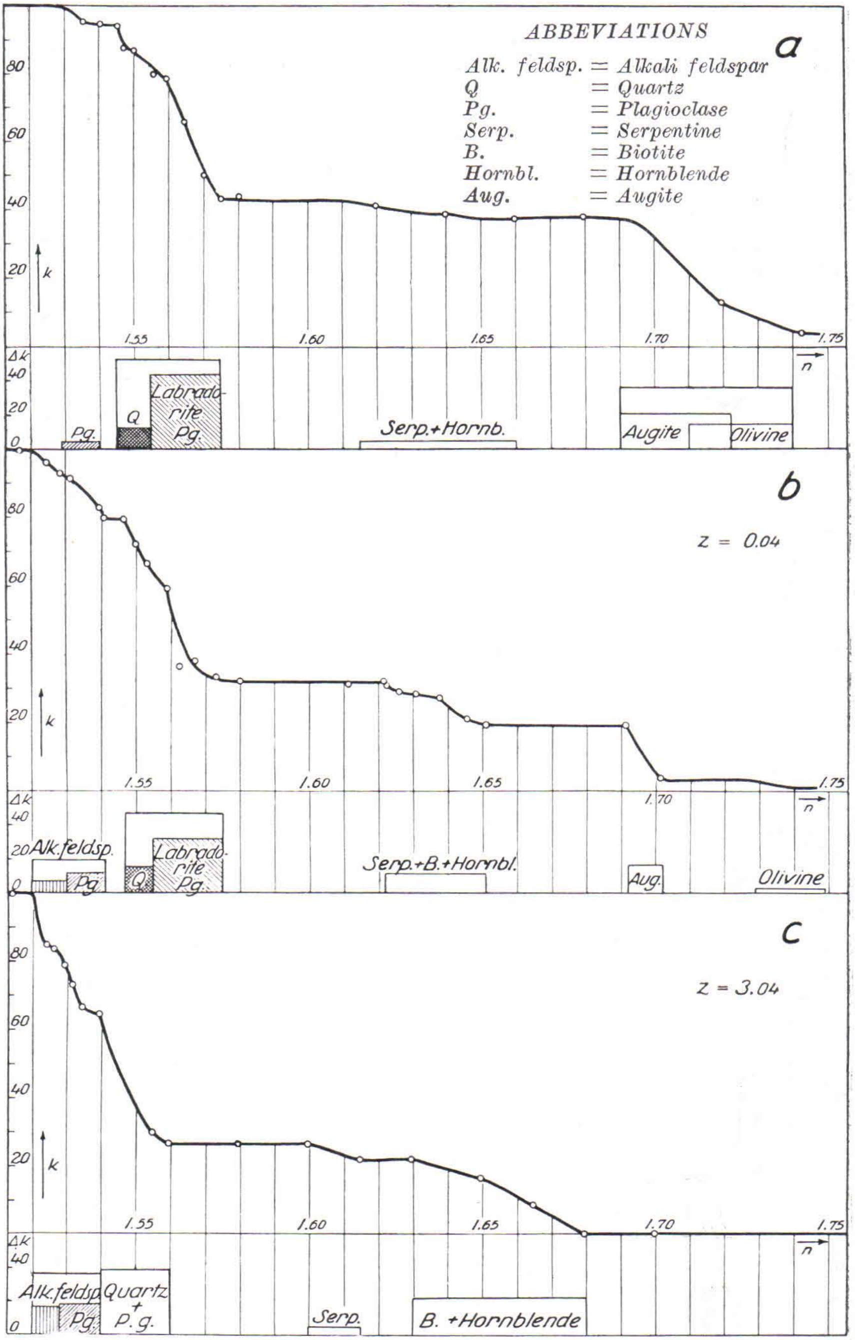

Fig. 13. Results of the statistical refractive index analyses of the olivine diabase (a), and diabase hybrids (b and c) in drill hole No. 1. Suontaka.

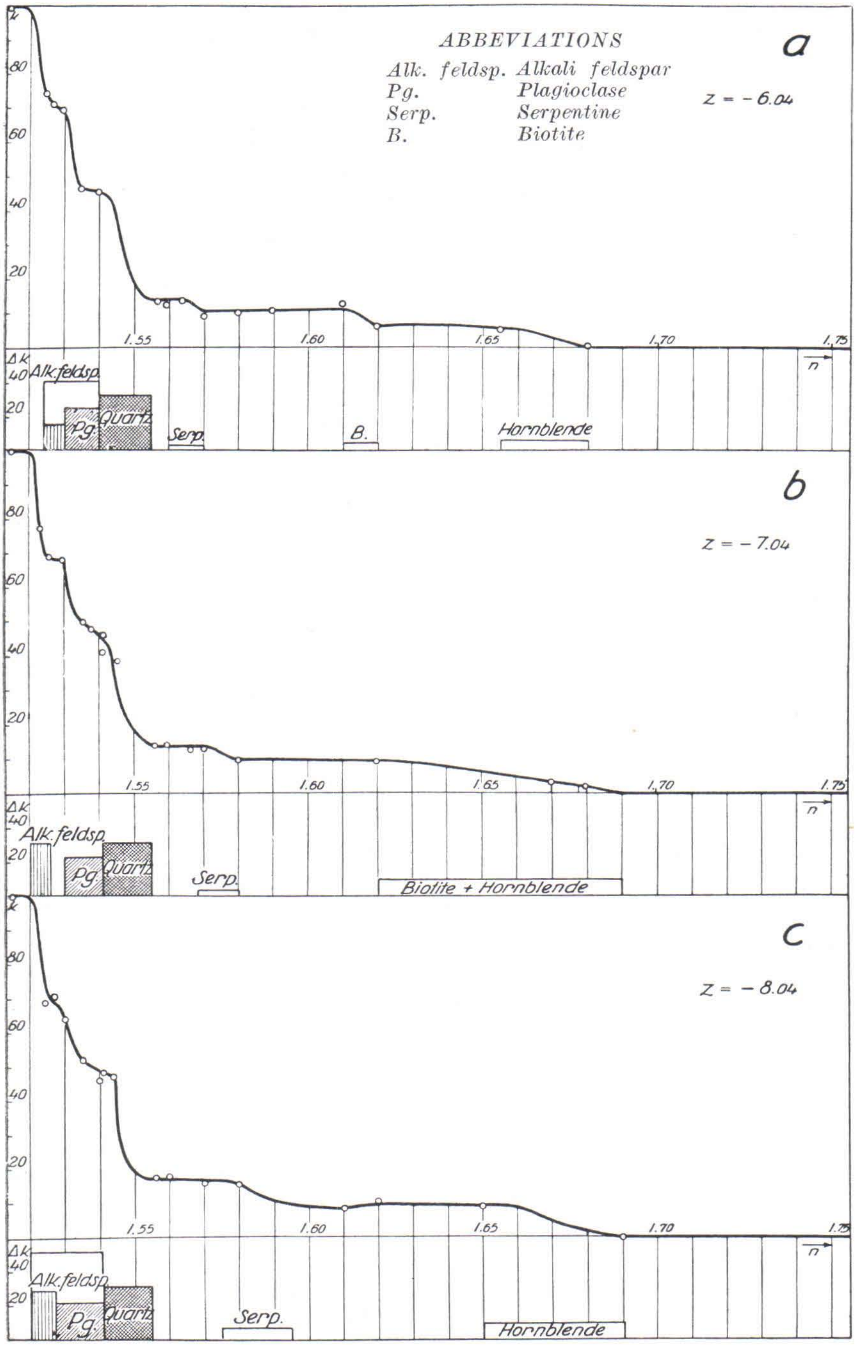

Fig. 14. Results of the statistical refractive index analyses of rapakivi hybrids in drill hole No. 1. Suontaka.

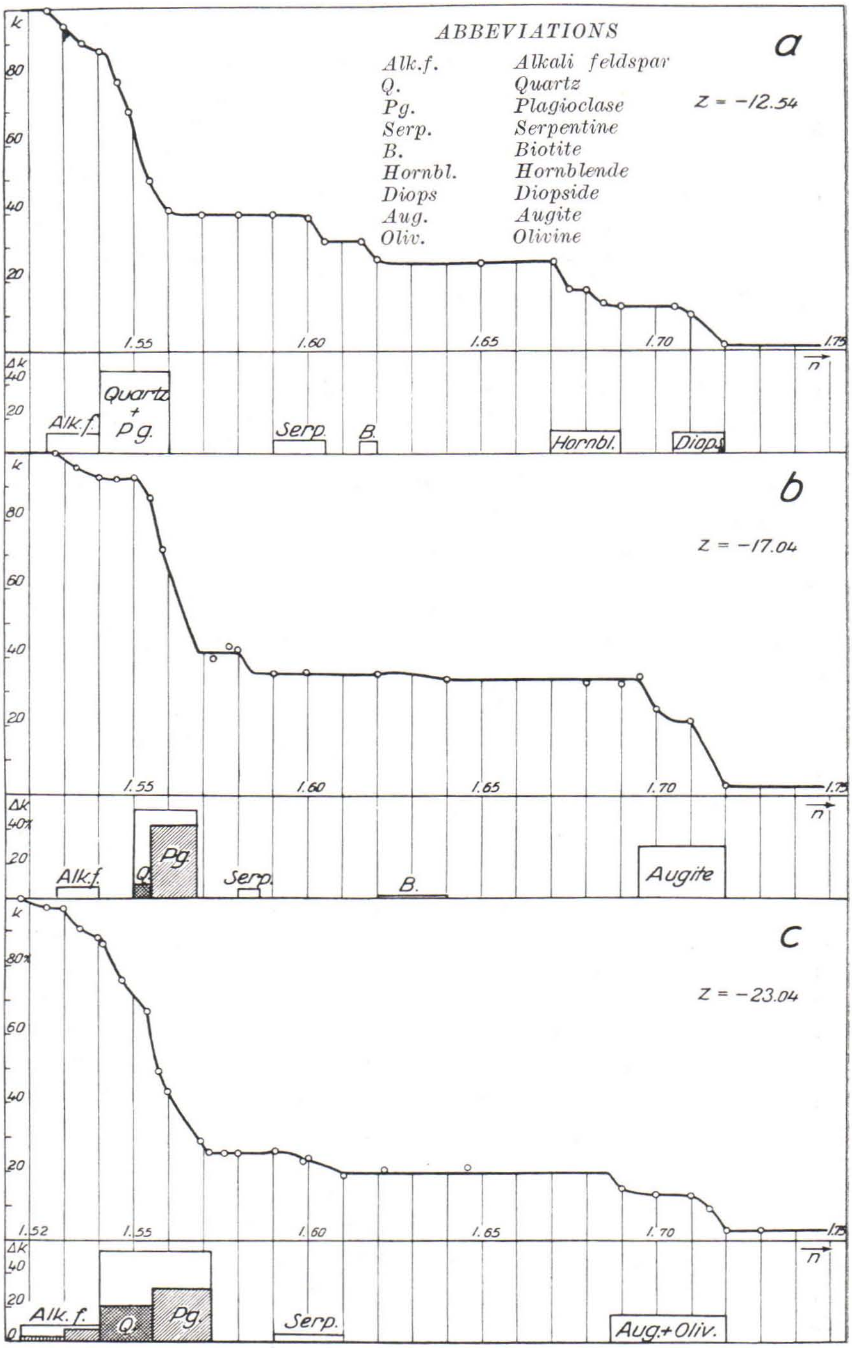

Fig. 15. Results of the statistical refractive index analyses of diabase hybrids in drill hole No. 1. Suontaka.

clase, varies considerably in a relatively short depth interval it was necessary to use a very short sample interval. It follows from this and the relatively coarse grain size of the samples (see Table V) that the height of the columns represent only roughly the proportions of the different minerals. Owing to the method used, it is difficult to draw a sharp boundary between two minerals when the refractive indices overlap, as is very often the case of plagioclase and quartz. When identifying the different minerals from the curve k = k(n), the microscopical observations, made on the thin sections have, of course, been taken into consideration.

The comparison of Figs. 13 b and 15 c shows that the augites are almost the same in both samples, but the refractive indices of the olivines deviate considerably. To confirm these facts, axial angle determinations have been made of the thin sections and, in addition, individual grains have been picked out of the slides or powder for refractive index determinations. The values presented in Table VIII have been collected from determinations made by Mrs. T. Mikkola, Mr. O. Waldén and the writer. Figs. 13 b and 15 c, and Table VIII show that, on the basis of refractive indices, the olivine in the depth interval of 0—1 m. is richer in iron, containing (*cf.* the diagram by Bowen and Schairer, 1935) about 46 % fayalite, whereas in the interval of 21—23.9 m. the olivine contains only about 27 % fayalite. In addition it is interesting to note that serpentine, the alteration product of olivine, seems to have higher refractive index in the sample interval of 0.00—0.08 m. than in the interval of 23.00—23.08 m. This seems to show that the serpentine also in the former sample is richer in iron (probably delessite) than in the latter sample, where the serpentine is likely to be penninite. These facts are in agreement with the higher mg-value of analysis No. 10. in Table VI. A comparison of Figs. 13 b and 15 c with Fig. 13 a, which is made of an almost pure olivine diabase sample, situated about 50 m. from the drill hole (near point V b in Fig. 8), reveals that the labradorite plagioclase begins in all these three cases at almost the same point, corresponding to the refractive index of 1.572—1.575; but the amount of labradorite in the diabase hybrids is slightly less than in the olivine diabase. On the other hand, the diabase hybrids contain considerably more alkali feldspar than the olivine diabase.

Megascopically most of the rocks which are situated in the depth intervals of —Z = 1.0—3.1 m. and 21.0—10.4 m. and which change into the rocks described above without any sharp boundaries deviate considerably from the olivine diabase as well as from the rapakivi granite. Also their densities and chemical composition differ noticeably from the ordinary rocks of the area.

Regarding mineral composition, the depth intervals of —Z = 1.0—3.1 m. and 21.0—10.4 m. do not contain olivine, but especially near the boundaries with the previous intervals there are serpentine and iron ore aggregates which are probably alteration products of former olivine grains. Instead of olivine, grey-violet poikilitic augite grains, typical of the normal olivine diabase, are seen near the olivine-bearing zone of the diabase hybrids. It is to be noted, however, that the borders of the augite grains have altered into hornblende and biotite. When approaching the boundary of the rapakivi hybrids the augite grains disappear and, instead, colorless or yellowish prisms of pyroxene occur, very often twinned on (100). Sometimes such pyroxene prisms have grown crosswise but, on account of the alteration products, it is difficult to decide with certainty whether it is a twinning phenomenon or not. The determination of the extinction angle ($c \wedge \gamma$) on a prism, the section of which lies parallel to the plane (010), gives the value 42°. After removing this prism from the thin section its refractive indices by the ordinary immersion method were found to be $\alpha' = 1.693$, $\gamma' = 1.718$, corresponding after Winchell (1933) to a pyroxene in the series diopside-hedenbergite, containing 37 % hedenbergite. Comparing it with the augite of the diabase hybrid in Table VIII, the refractive indices are found to be almost the same; but the extinction angle of the augite is considerably greater. Note, however, that the foregoing determinations have been made earlier from surface samples situated near the drill hole, corresponding the diabase hybrid met later in the drill hole.

Figs. 13 c, 15 a and 15 b present the statistical refractive index analyses of samples from the depth intervals of $-Z = 3.00-3.08$ m., $12.00-12.08$ m. and $17.00-17.08$ m. the first two made by Mrs. T. Mikkola and the third by Mr. O. Waldén. Fig. 15 b shows that, together with the colorless pyroxene, the rock contains abundant hornblende ($c \wedge \gamma = 12°$), which, according to its refractive index, is rich in iron, while at depths of 3.00—3.08 m. (Fig. 13 c), with practically no augite, the iron content of the hornblende seems to be less. When approaching the boundaries of the rapakivi hybrids (Figs. 13 c and 15 a), the upper limit of the refractive index interval of the labradorite plagioclase decreases at the same time as the amount of alkali feldspar and quartz increases. In the thin section we can see that the alkali feldspars and quartz no longer occur as small aggregates or veinlets between the other minerals, but form wider, micrographically intergrown areas between the darker minerals and the larger square plagioclase grains.

RAPAKIVI HYBRIDS

The rapakivi hybrids of the depth interval of 3.1—10.4 m. grade without sharp boundaries into the diabase hybrids. Fig. 14 shows the main minerals of the rapakivi hybrids and their proportions. The curves in Fig. 14 are based on the statistical refractive index analyses of the samples of the depth intervals of $-Z = 6.00-6.08$, $7.00-7.08$ and

Table VIII. Optical determinations of the olivines and pyroxenes in the rocks of the Suontaka area.

Mineral	α'	γ'	2 V	$c \wedge \gamma$	Type of rock and locality
Olivine	1.703	1.734	—74°		Olivine diabase, near drill hole No. 1
»	1.723	1.762	—72°, (—78°)[1]		Diabase hybrid, —Z = 0.2—0.4, drill hole No. 1
»	1.689	1.722			Diabase hybrid, —Z = 23.9, drill hole No. 1
Augite	1.699	1.723	44°—47°	48°	Hybrid[2], near drill hole No. 1 (see p. 14)
Diopsidic augite	1.693	1.718		42°	Hybrid, near drill hole

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[1] The determinations of α', γ' and 2 V have not been made of the same grains.
[2] Corresponding to the diabase hybrids in the drill hole.

8.00—8.08 m. made by Mrs. T. Mikkola. As shown by Fig. 14 the rock in the depth interval of 6—8 m. contains almost equal amounts of quartz, oligoclase, and potash feldspar (probably orthoclase). It is to be noted that no labradorite occurs. The refractive index intervals of the serpentine are in Fig. 14 a and b between 1,560 and 1,570, corresponding closely to the composition of antigorite, rich in magnesium Winchell (1933). The refractive index intervals of hornblende are also slightly less than that of hornblende in the diabase hybrids. This may depend upon their greater magnesium content.

Characteristic of the rock in the depth interval of 4—8 m. are the long hornblende needles (Fig. 12. Pl. III) inside of which minute colorless cores, probably consisting of pyroxene, may be detected. When approaching the boundary of the diabase hybrids, the proportion of hornblende and pyroxene increases, while the rock gradually changes into a diabase hybrid.

Of particular interest in the rapakivi hybrids are the quartz blebs (0.5—1 cm. in diameter) and the large orthoclase ovoids (3—5 cm. in diameter), the latter being more abundant in the depth interval of —Z = 4.5—5.5 m. As seen in Fig. 14 Pl. IV the potash feldspar ovoids in the hybrids greatly resemble those of the rapakivi granite (Figs. 15 and 16 Pl. IV), in shape and size, even though some ovoids in the rapakivi hybrid seem to have been partly assimilated. Under the microscope it can also be seen that the potash feldspar ovoids of the hybrids contain a great amount of small quartz inclusions instead of the large quartz inclusions in the orthoclase ovoids of the normal rapakivi granite.

The quartz blebs in the rapakivi hybrids also resemble to some extent the idiomorphic quartz grains of the normal rapakivi granite, but they are somewhat larger and more rounded than in the normal rapakivi granite and, in addition, they are often surrounded by a margin of hornblende (Fig. 13 Pl. IV). The micrographic groundmass between the large potash feldspar, quartz, and acicular amphibole grains mainly consists of quartz, oligoclase, potash feldspar, and biotite.

The transition of the red rapakivi hybrid into a dark diabase hybrid takes place gradually in the drill hole without any breccia formations. This is also partly shown by the upper part of the density curve in Fig. 10., which is based on the density determinations of a sample interval 0.5 m. in length.

Also in the vicinity of the drill hole the transition of the rapakivi hybrid into the diabase hybrid or diabase takes place gradually. The only heterogeneties found are at a place about 8 m. SE of the drill hole where a rapakivi hybrid, rich in potash feldspar ovoids, is cut by an aplitic vein, 2—3 cm. in thickness. About 6 m. W of the drill hole was found a similar vein in a loose block, probably formerly situated at the bottom of the well near the drill hole.

The first mentioned vein contains quartz, pigmented potash feldspar, oligoclase ($\gamma' >$ Canada balsam $> \alpha'$), pleochroic greenish brown biotite and yellow green mineral shreds which are probably serpentine. Quartz occurs as rounded inclusions in the potash feldspar, and it is also encountered in the interstices of the other grains and in many places it forms micrographic intergrowths with the potash feldspar, as in the palingenic dykes and in the rapakivi hybrids. The chemical composition of the aplitic dyke is seen in Table VII. Comparison with Table VI shows that the dyke contains more SiO_2 than the rapakivi hybrids, but less TiO_2, FeO, MnO, MgO, and CaO differing from the palingenic dykes mostly on account of its greater potash and smaller FeO, MgO and CaO content.

THE PROBABLE COURSE OF THE HYBRIDIZATION PROCESS

DISCUSSION OF THE GENERAL OUTLINE OF THE PROCESS

In examining the analyses of the hybrid rocks in Table VI or Fig. 12 and only knowing that they are made of specimens from the same area, the idea is easily obtained that there is a group of rocks between gabbro and granite, belonging to the same rock series of magmatic differentiation by crystallization. For instance, that part of the section, corresponding to the depth interval $-Z = 9-23.9$ m. may give the impression that the differences in the composition of the rocks depend upon gravitative differentiation of the diabase; but quite the reverse sequence of the rocks in the upper part of the drill hole makes this impossible. Moreover, it is very improbable that the hybrid formation could have been formed through hybridization between the diabasic magma and a granitic magma, intruded in connection with the diabasic intrusion, or through the hybridization of the solidified diabase sills and a granitic magma intruded later, for the following reasons.

1. Excepting the small palingenic dykes and the dyke situated in the rapakivi hybrid (p. 57), no granitic intrusions are known in the Suontaka area as being postdiabasic or contemporaneous with the diabasic intrusion.

2. It is difficult to understand why the contemporaneous diabasic and granitic magmas have not been able to mix earlier and how the mixing of a diabasic and granitic magma could give rise to a rock which, together with the characteristic minerals of the olivine diabase, contains at the same time a great amount of quartz and alkali feldspars.

3. Finally, if we assume that the hybrids have been formed through the assimilation of the cold olivine diabase by the granitic magma, it is difficult to understand how a granitic magma containing large orthoclase and quartz phenocrysts can assimilate diabase to such an extent, and moreover why the partially assimilated orthoclase phenocrysts, as well as the quartz blebs, are situated in a fairly limited zone, corresponding to the depth interval of $-Z = 4-6.5$ m. in the drill hole.

On the basis of the foregoing discussion, and taking into consideration the fact that the diabase sills have been able, even under normal contact conditions, to melt the country rocks, as shown by the numerous palingenic dykes in the Suontaka area, the writer regards it as very probable that the hybrid formation is a result of hybridization between the rapakivi granite lens and the two olivine diabase sills which have intruded contemporaneously, or nearly so, on both sides of the granite lens.

Let us consider the last point of this hypothesis that both diabase sills have intruded contemporaneously — — or nearly so. If this were not so, we should have no reason to assume more intense influences at the contacts than those encountered in other parts of the area (pp. 27—30). If, on the other hand, the diabasic intrusions have been contemporaneous, or have followed closely upon one another, the heat influences will have reinforced each other, and it is easy to understand the intense hybridization at the upper as well as the lower contacts of the granite lens.

DETERMINATION OF THE ORIGINAL CONTACT SURFACES

THEORETICAL CONSIDERATIONS

In order to understand the hybridization process it is very important to know the original position of the contacts between the diabase sills and the rapakivi lens when the diabase-intrusion took place. On the basis of the hypothesis presented in the foregoing chapter, and the density and concentration curves in Figs. 10 and 11 we shall try to locate the original contacts in the following way.

Let us first examine a theoretical case, Fig. 16, where the plane BB′ (perpendicular to the z-axis and the plane of the figure) divides two

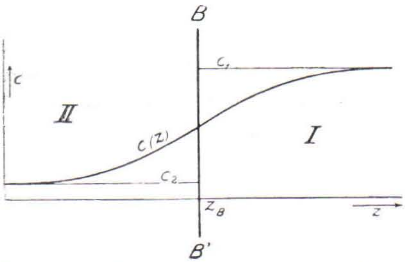

Fig. 16. Curve C(z) shows the distribution of concentration in the vicinity of the boundary plane BB′ at moment t.

substances I and II (*e. g.* diabase and granite) from each other. The concentrations of an oxide in the substances I and II are C_1 and C_2 respectively. In addition, let us assume that from the moment $t = 0$ the concentration of this oxide has had opportunity to equalize through migration either in the liquid or solid state, and the curve C(z) represents the distribution of concentration along the direction of the z-axis at the moment t. Provided that the total amount of the oxide in question remains constant, and provided, moreover, that after the migration there exist no differences in concentration in the planes parallel with BB′, we get the equation

$$(1) \qquad \int_{-\infty}^{z_B} q\,[\,|C(z) - C_2|\,]\,dz = \int_{z_B}^{+\infty} q\,[\,|C(z) - C_1|\,]\,dz,$$

where q dz is the volume element, which has the cross-section q and the concentration C(z), and where z_B is the point of intersection of the plane BB′ with the z-axis. On the other hand, if, in the aforementioned system the original concentrations C_1 and C_2 and the curve C(z) are known, the position of the original boundary plane z_B can be estimated from equation (1). Even in case one knows the concentration curve C(z′) along the z'-axes, which forms an angle φ with the normal of the contact plane, the value of z_B can be computed by subtituting C(z′) for C(z) in equation (1). If desired, the curve C(z′) can be transformed into C(z), using $z = z' \cos \varphi$. When angle φ is relatively small *e. g.* smaller than 10° the values of z and z′ deviate 1.5 % at the most.

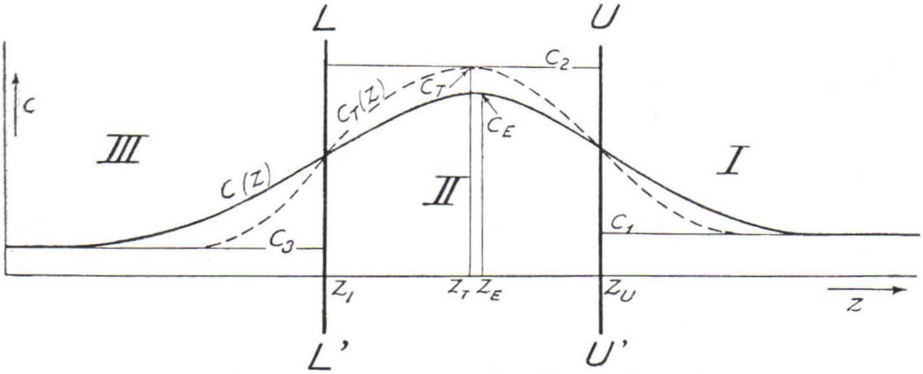

Fig. 17. Curves C(z) and $C_T(z)$ show the distribution of concentration in the vicinity of the boundary planes UU′ and LL′ at moment $t = t_E$ and $t = t_T$ respectively.

Let us now examine a system, Fig. 17, where the two boundary planes UU′ and LL′, perpendicular to the z-axis and the plane of the figure, divide the concentration field at the moment $t = 0$ so that

$$\begin{aligned} C &= C_1 \quad \text{when} \quad z > z_u \\ C &= C_2 \quad \text{»} \quad z_1 \leq z \leq z_u \\ C &= C_3 \quad \text{»} \quad z < z_1, \end{aligned}$$

where z_u and z_1 are the points of intersection of the plane UU′ and LL′ with the z-axis. Let us assume again that from the moment $t = 0$ the concentration differences have had opportunity to equalize. Let the broken curve $C_T(z)$ in Fig. 17 represent the concentration in the direction of the z-axis at the moment $t = t_T$, when the straight line $C = C_2$ can be taken as tangential to the concentration curve at the point of its extreme value C_T, or, in other words, the difference $|C_2—C_T| < \varepsilon$, where ε is a small number (*e. g.* 1 % from $|C_2—C_1|$ or $|C_2—C_3|$). Let the curve $C(z)$ represent the final concentration distribution after the time $t = t_E$. Providing the concentration is equal in the planes parallel with the boundary planes UU′ and LL′, we get

$$(2) \quad \int_{-\infty}^{z_1} q\,[\,|C(z) — C_3|\,]\,dz + \int_{z_u}^{+\infty} q\,[\,|C(z) — C_1|\,]\,dz = \int_{z_1}^{z_u} q\,[\,|C(z) — C_2|\,]\,dz$$

If $|C_T—C_E|$ is small compared with $|C_2—C_3|$ and $|C_2—C_1|$ (C_E is the extreme value in curve $C(z)$), and, in addition, the straight line $z = z_E$ divides curve $C(z)$ into two almost symmetrical parts *i. e.* $z_E \approx z_T$ (see Fig. 17), we can write thus

$$(3\,a) \qquad \int_{-\infty}^{z} q\,[\,|C(z) — C_3|\,]\,dz \approx \int_{z_1}^{z_E} q\,[\,|C(z) — C_2|\,]\,dz \qquad \text{and}$$

$$(3\,b) \qquad \int_{z_E}^{z_u} q\,[\,|C(z) — C_2|\,]\,dz \approx \int_{z_u}^{+\infty} q\,[\,|C(z) — C_1|\,]\,dz$$

If, on the other hand, curve $C(z)$, and the original concentrations C_1, C_2 and C_3 are known, the original contact planes z_u and z_1 can be calculated using equations (3 a) and (3 b), provided the foregoing conditions are satisfied.

POSITION OF THE CONTACTS IN THE IDEAL CASE AND THE EXAMINATION OF ERRORS

Examining again the map in Fig. 8., the profiles in Fig. 9. and the concentration curves in Figs. 10 and 11, it can be seen that the southern contact of the Suontaka area considerably resembles the theoretical case, presented on p. 60 and in Fig. 17. How far the positions of the calculated contacts (according to equations 3 a and 3 b on p. 60) correspond to the real conditions depends mostly on the extent to which the following conditions are satisfied.

1. The migration of the constituents after hybridization has not been great enough to cause essential changes in the concentration curves.
2. The upper and lower diabase sills, as well as the granite lens between them, must have had a sufficiently constant composition, at least with respect to some oxides (or density), to allow a relatively reliable estimate of C_1, C_2 and C_3.
3. The error caused by the deviation between the Z_T- and Z_E- values must be small.
4. The original contact surfaces between the diabase sills and the rapakivi lens must be parallel planes, or the deviations such that the errors caused can be taken into consideration.
5. Not much migration could have taken place in the direction of the contact planes — — or only in such a way as to cause no differences in concentration in the direction of the contact planes.

Regarding point 1, the olivine diabase is the youngest rock of the Jotnian formation, and so has not been involved in any orogenic cycles, where the diabase and the rapakivi granite might have exchanged material. Also, except for insignificant surface weathering, there is no known instance of water solutions having caused alterations in the composition of the diabase and granite. Hence it is very probable that the concentration values, in Table VI, present a sufficiently accurate concentration distribution of the hybrid formation after the hybridization process.

Table VI shows that the composition of the olivine diabase varies considerably, especially with respect to the values of TiO_2, FeO, MnO, MgO and CaO. Indeed it is not easy to decide whether the variation of these oxides in the depth interval of $-Z = 12.0$—23.9 m. depends upon the hybridization process or upon the original variation in the composition of the olivine diabase. On the other hand the values of C_1 and C_3 with respect to the K_2O, SiO_2, FeO, and the density can be relatively accurately estimated. Also the determination of C_1 in the upper system with respect to the values of MgO, TiO_2 and MnO seems reliable. It is to be noted also that, according to the density determinations by Mrs. T. Mikkola, the density (3.05) of the aphanitic diabase from the contact proper (No. 2 in Fig. 8). is within the limits of error equal to the fine- or medium-grained diabases 0.5 m. (corresponding to anal. No 3 in Table II) and farther from the contact. It is regrettable that no other direct information is available concerning the composition of the original rapakivi lens than analyses Nos. 5 and 6 in Table VI corresponding to the depth interval of 6—8 m. in the drill hole, and the analyses Nos. 11 and 12, which have been made of the samples on the slope. Analysis No. 13 of the normal rapakivi granite (near point Ib in Fig. 8 on p. 41) is very similar to the rapakivi hybrid analyses Nos. 11 and 12, so analysis No. 13 can be considered to represent the values of C_2 sufficiently accurately. The contacts can also be estimated using the values of C_2, from analysis No. 12 instead of No. 13. On p. 63 we can see that the results of the calculations with respect to $C_{K_2O}(Z)$ and $C_s(Z)$ deviate only a little from each other.

In Figs. 10 and 11, condition 3 is satisfied at least with respect to the SiO_2 and CaO. As to the other oxides and the density, it may be seen on p. 63 that the corrections in the positions of the contacts, resulting from the deviations in the Z_E- and Z_T- values, are relatively small.

Whether or not conditions 4 and 5 are satisfied will be examined on pp. 63—67 after Table IX which presents the calculated positions of the contacts on the basis of the concentration curves and the equations (3 a) and (3 b) on p. 60. The column Z_u in Table IX presents the calculated contact positions in the upper concentration system ($Z > Z_E$), where the integration is performed from Z_E to Z_u and from Z_u to Zc_1, where Zc_1 is the Z-value for $C = C_1$. Correspondingly, in column Z_1 are presented the contact positions in the lower concentration system ($Z \leq Z_E$), when the integration is performed from Zc_3 to Z_1 and from Z_1 to Z_E.

Table IX. Calculated positions of the contacts in the drill hole.

Group		Z_u	Z_1	Z_{C_1}	Z_{C_3}	Z_E
I	SiO_2	—2.2	—11.2	9.5	—23.0	—6.5
	K_2O	—3.3	—10.0	0.5	—17.0	»
	S	—3.4	—10.8	1.0	—22.0	»
	Mean	—3.0	—10.7			»
II	FeO	—3.7	—9.7	—0.5	—14.0	»
	FeOt	—3.4	—9.9	»	—12.5	»
	TiO_2	—3.5	—10.3	»	»	»
	MnO	—2.6	—11.0	»	—17.0	»
	MgO	—2.9		»		»
	Mean	—3.2	—10.2			
III	MgO		—10.3		—14.0	»
	CaO	—3.1	—10.4	—0.9	—13.5	»
	Mean I and II	**—3.13**	**—10.41**			

Table IX is divided into three groups *viz.*, I, II and III depending upon the reliability of the calculations. In the group I are those oxides (and the density), in which the C_1- and C_3- values are relatively reliable, owing to the regular shape of the C(Z) curves. The determination of C_1 and C_3 of the oxides belonging to group II is slightly less accurate, but it is to be noted, however, that the results obtained, and especially the means of the two first groups, do not deviate much from each other. In group III are CaO and MgO (of the lower system), with respect to which the determination of C_1 and C_3 is rather questionable. Finally, Al_2O_3, Fe_2O_3, Na_2O, P_2O_5 and H_2O form their own group which has not been presented in Figs. 10 and 11 or in Table IX. Taking into consideration the accuracy of the chemical analysis, the differences in these oxides between the diabase and rapakivi hybrids are so small that calculations serve no purpose.

Let us then consider the basis for the assumption $Z_E = -6.5$, and further what differences a variation in the Z_E-value will cause in the values of Z_u and Z_1. In Table VI, the concentrations of analyses Nos. 5 and 6 deviate only a little from each other. On the basis of Figs. 10 and 11 $Z_E \approx -7.0$ should be taken as the mean value. According to the density curve (Fig. 10), which has been made from sample intervals of 0.5 m., however, the value Z_E —6.0 is obtained. As the density depends to some extent on the proportions of the lighter and heavier oxides in the rock, the mean value $Z_E = -6.5$ has been chosen.

Fig. 10 shows that the value of C_E in curve $C_{SiO_2}(Z)$ is approximately the same as C_2. So, if Z_u and Z_1 are calculated on the basis of the curve $C_{SiO_2}(Z)$, using $Z_E = -6.0$ or $Z_E = -7.5$ instead of $Z_E = -6.5$, no changes in the values in Table IX are obtained. If, on the other hand, curve $C_{K_2O}(Z)$ instead of $C_{SiO_2}(Z)$ is used, the Z_u- and Z_l- values, thus obtained, will deviate only 0.1 m. from those in Table IX. Thus deviations of 0.5—0.1 m. in the values of Z_E cause only relatively small changes in the calculated positions of the contact plane.

How much the values of Z_u and Z_1 would change, if C_2 is taken from analysis No. 12 instead of No. 13 in Table VI (or the density $s = 2.59$ instead of 2.61). If $C_{2_{K_2O}}$ is increased by 0.03, it causes a change of 0.1 m. in the values of Z_u and Z_1, and an alteration from 2.61 to 2.59 in C_{2_S} causes a deviation of 0.2 m. Taking into consideration the accuracy of the values of C_1, C_2 and C_3 it can be considered probable that the deviations in the values of Z_u and Z_1 in Table IX depend for the most part upon the errors in C_1, C_2 and C_3, provided that conditions 4 and 5 are satisfied. On the other hand, the means of the different calculations probably correspond to a greater accuracy, than is to be expected solely on the basis of Table IX, as the deviations most probably compensate each other, because the sums of the oxides, from which the calculations are made, are nearly equal. For example the sums of the concentrations (presented in Table IX) of analyses Nos. 12 and 13 deviate only 0.01 from each other.

Let us now consider the errors in the position of the contact when condition 4 on p. 61 is not satisfied. As the contacts between the diabase and rapakivi granite are transitional, it is not possible to determine their direction in the usual way, but we have again to use the density estimations and chemical analyses, made from the drill core or from the samples in its surroundings.

The density curves in Figs. 10 and 18 a_2 show that the density has its minimum in the drill hole at about $Z = -6.0$, while on the traverse II b—II c the minimum is reached at point E_2 in Fig. 18 a_2, where $Z = -2.14$. The straight line E_1E_2, drawn through these points in Fig. 18 a_1, forms an angle of $\varphi_1 = 6.2°$ with the horizontal. It is, however, probable that the actual minimum density on traverse II b—II c is reached near point E'_2, which would divide the density curve more symmetrically. This point is reasonable because the error in the density calculations on this traverse may be 0.02 g/cm^3, and when the density curve in Fig. 10 is fairly symmetrical with respect to the straight line $Z = -6.0$. Thus the line $E_2'E_1$, connecting the minimum values, should make an angle $\varphi'_1 = 2.5°$ with the horizontal.

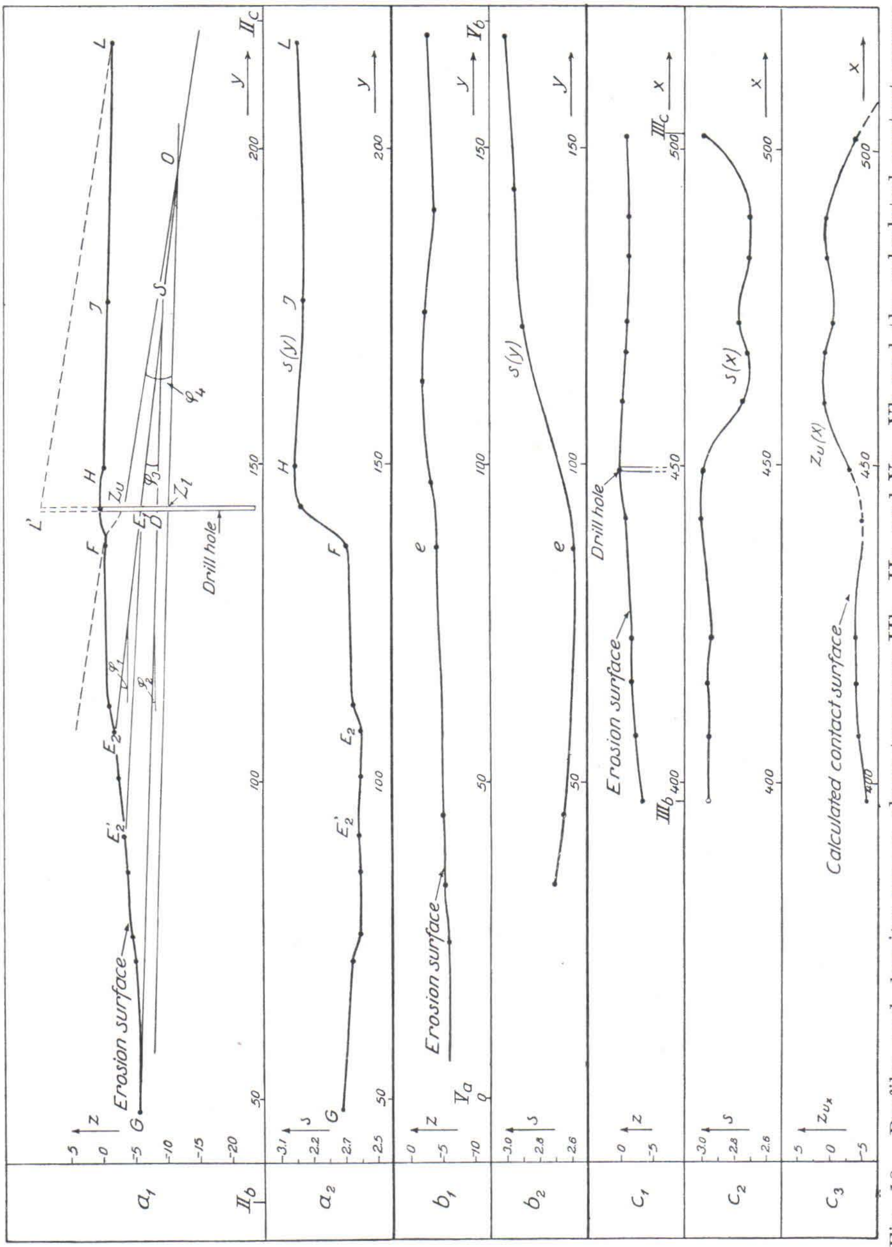

Fig. 18. Profiles and density curves along traverses IIb—IIc, and Va—Vb and the calculated contact curve along traverse IIIb—IIIc.

Point G in Fig. 18 a on traverse II b—II c has the same density (s = 2.72 g/cm³) as point D in the drill hole, corresponding to a depth Z = —8.6 m. On the other hand, analysis No. 11 in Table VI, made of the sample at point G, corresponds on the average (according to the calculation of all the components in Table IX) to a depth of z = —8.5 m. If line GD is assumed to be parallel to the lower contact and to form an angle of φ_2 with the horizontal, then $\varphi_3 = \varphi_1 - \varphi_2$ would represent the angle between the lower contact and the line connecting the minimum values. Depending upon what value of φ_1 is used (6.2° or 2.5°) φ_3 varies 4.5°—0.8°. This would mean that the distance between the contact surfaces is greater on the lower slope than in the drill hole. This is supported by analysis No. 12, which lies between analyses Nos. 5 and 13, and the fact that the density ($s = 2.67$ g/cm^3) at a depth of $Z = -6.0$ in the drill hole is distinctly greater than at point E_2 ($s = 2.59$ g/cm^3) where the density is equal, within the limit of error, to that of the normal rapakivi granite ($s = 2.61$ g/cm^3).

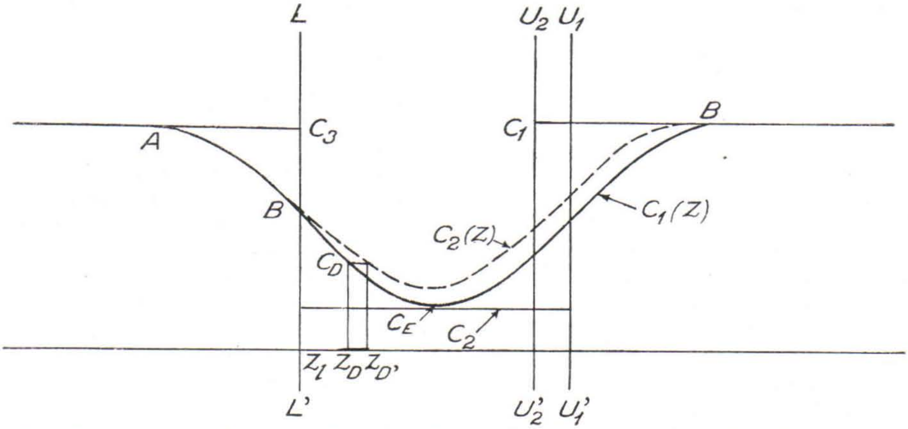

Fig. 19. Curves $C_1(z)$ and $C_2(z)$ show the concentration distribution at moment t in systems I and II, which have the boundary planes U_1U_1', LL' and U_2U_2', LL' respectively.

It has been stated that φ_1 is probably too great. It will be made clear below that the angle φ_2 used above is probably too small and thus $\varphi_3 = 4.5°$ too great. By analogy with Fig. 17 the curve $C_1(z)$ in Fig. 19 presents at the moment t the concentration (or density) curve in a system I, where the contact planes are $U_1U'_1$ and LL'. In addition, let us assume that $|C_E - C_2|$ is small compared with $|C_1 - C_2|$. If the other contact is moved to the position U_2U_2', the curve $C_2(z)$ (broken line) and the original curve $C_1(z)$ in the interval of AB presents the distribution of the concentration at moment t in this new system II. Depending upon the differences between the two curves, the concentration C_D in system I will be reached at point $Z = Z_D'$ in system II. When $Z_D' - Z_1 \geq Z_D - Z_1$, angle φ_2 in Fig. 18 a_1 is either equal or greater than the angle between the lower contact and the horizontal. Thus the angle between the straight line E_2E_1 and the lower contact (φ_3) probably would be 4.5° at the most.

In Table VI and Figs. 10 and 11 we can see that $|C_E - C_2|$ is relatively small compared with $|C_2 - C_1|$ and $|C_2 - C_3|$, and with respect to SiO_2 the value of $C_E \approx C_2$. Thus it is to be expected that direction E_1E_2, connecting the extreme values, will not have changed much at the end of the hybridization process. We can then approximately estimate that angle φ_4 in Fig. 18 a_1 between the upper and lower contact is about 7°, and a line parallel to the direction of the upper contact through point L in Fig. 18 a_1 cuts the drill hole extension at point L', with $Z = 9.5$.

That φ_4 is probably too great rather than too small is shown by the density curve in Fig. 18 a_2, where the density ($s = 2.95$ g/cm^3) at point J in Fig. 18 a_1, indicates a smaller distance from the upper contact surface than indicated by

Fig. 18 a_1. This is also proved by the fact that angle $\varphi_2 + \varphi_4 \simeq 9°$, between the upper contact and the horizontal, seems to be too great on the basis of the detailed map and profiles from the area (Figs. 8 and 9). As mentioned on p. 59, this angle widens the curve C(Z) in the vicinity of the upper contact by an amount of cos 7° or about 1 % wider than in the direction of the normal of the upper contact plane, but this has no effect on the position of the contact. In the vicinity of the extreme values of the concentration curve, on the other hand, where the theoretical curves of the upper and lower concentration systems overlap, as Fig. 11 shows, deviation from the parallel contact system causes errors in the contact positions calculated on the basis of the ideal case. But when $| C_E—C_2 |$ is small compared with $| C_2—C_3 |$ and $| C_2—C_1 |$, and when, moreover, the values of the integrals

$$\int_{Z_1}^{Z_E} q\,[\,|C(z) — C_2|\,]\,dz \quad \text{and} \quad \int_{Z_E}^{Z_u} q\,[\,|C(z) — C_2|\,]\,dz$$

and thus also Z_u and Z_1, change very slowly with the small alteration of Z_E as has been shown on p. 63, there is reason to believe that the errors, depending upon the angle φ_4 between the contact planes, are insignificant with respect to the other errors. Even if φ_4 were as great as 15—30° the last mentioned error would be relatively small, provided that the foregoing condition is satisfied.

It has been stated in the foregoing that the general course of the upper and lower contact surfaces in the direction of II b—II c deviate from the ideal course only so slightly as to be negligible. On the basis of the detailed geological map (Fig. 8) and the curves in Fig. 18 it can be ascertained that, while the upper contact slopes gently (3—5°) in the NW direction, the general shape of the upper and lower contacts probably does not deviate more from the ideal case than that in the direction II b—II c.

As to the deviation of the contacts from the ideal case[2]) in the immediate vicinity of the drill hole, it can not be determined accurately at least with respect to the lower contact owing to lack of more drill holes. In any case, on the basis of the curves in Fig. 18 it is obvious that the upper contact curves upwards into the direction SW and SE, the radius of the curvature being of an order of 10 and 40 m. respectively. The latter value is obtained from the curve $Z_u(X)$ (Fig. 18 c_3). This curve, which characterizes to some extent the course of the upper contact surface in the direction of $III_b—III_c$[1]), is obtained by means of the equation $Z_{u_x} = Z_u + (Z_x — Z_{s_x})$ where Z_{u_x} and Z_x denote the z-co-ordinates of the calculated contact and the erosion surface respectively at point x, Z_{s_x} representing the Z-co-ordinate in the drill hole which corresponds to the density s_x in the upper concentration system, and $Z_u = 3.1$ is the Z-co-ordinate of the calculated contact in the drill hole. Depending the contact surface curvatures, q (see p. 88) is not constant but q(Z), which causes deviations in the Z_u-values in Table IX, as calculated on the assumption that q is constant. If the radius of the curvature is 5, 10 and 40 m. the deviations (downwards) would be 0.8, 0.4 and 0.1 m. respectively, provided the concentration field is spherically symmetric. Now since analysis No. 1 in Table VI probably does not perfectly correspond to the composition of the upper diabase sill and since the errors caused thereby tend to move the value of Z_u upwards, both the foregoing effects will compensate each other and can thus be omitted.

As to the lower contact, it can be stated that should the detailed course in the vicinity of the drill hole deviate from the ideal case more than the upper contact, a considerable difference in the calculated contact positions of the different compo-

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[1]) The traverse III_b — III_c forms an anxle of about 3° with the X-axis.

[2]) See Fig. 17.

nents would result, because the concentration curves deviate to some extent from each other in shape. As the deviations in the calculated contact positions of the lower concentration system in Table IX are not greater than those in the upper, we have reason to believe that the errors resulting from the irregular shape of the lower contact surface do not appreciably exceed those in the upper system.

Finally, regarding condition 5 (p. 61), it can be ascertained that the migration of some components in the direction of the contact plane will give rise to values of Z_u and Z_1 that greatly deviate from each other. This is in conflict with the values in Table IX.

On the basis of the foregoing examination of errors the author is of the opinion that the true contact positions in the drill hole probably do not deviate from the values of $Z_u = -3.1$ and $Z_1 = -10.4$ more than 0.5—1.0 m.

CHARACTER OF THE MIGRATION AND MIGRATION ABILITIES

In the previous chapter an attempt was made to determine the positions of the original contacts. Let us then examine the concentration distribution, assuming that hybridization between diabase and granite has taken place by material diffusion either in the liquid or solid state. Further let us examine how the concentration curves thus obtained deviate from the curves in Figs. 10 and 11.

Diffusion follows Fick's second law:

$$\frac{\partial c}{\partial t} = D \Delta c = D \left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2} \right); \tag{1 a}$$

where $\frac{\partial c}{\partial t}$ is the differential of the concentration with respect to the time and D the constant of the diffusion which has been assumed to be independent of the concentration. For an infinite system in the direction of the z-axis we get:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial z^2} \tag{1 b}$$

If:

$c = C$ when $z \leqq 0$ and $t = 0$

and

$c = 0$ » $z > 0$ » $t = 0$,

the partial integral of equation (1 b) is after Jost (1937, pp. 14—15)

$$c = \frac{C}{2} \left\{ 1 - \psi(\xi) \right\},$$

$$\text{where } \xi = \frac{z}{2\sqrt{DT}} \text{ and } \psi(\xi) = \frac{2}{\sqrt{\pi}} \int_0^{\xi} e^{-\eta^2} d\eta \tag{4}$$

The values of the latter function can be obtained *e. g.* from the appended table by Jost *(op. cit)*.

The total amount of material that has flowed during the time from 0 to T through the cross-section q at point $z = O$ is:

$$S = \int_{o}^{T} s_Z \, dt, \tag{5}$$

where according to Fick's first law:

$$s_Z = - \frac{\partial c}{\partial z} \, q \, D \tag{6}$$

Equation (5) together with eq. (4) gives (Jost *op. cit.*, p. 16):

$$S = qC \sqrt{\frac{DT}{\pi}}, \text{ and} \tag{7 a}$$

$$\sqrt{DT} = \frac{S}{C\,q} \sqrt{\pi} \tag{7 b}$$

If S be considered as the amount of material flowing through the unit cross-section on the contact plane, and in addition C as $| C_2—C_1 |$ or $| C_2—C_3 |$ in the curves C(Z) in Figs. 10 and 11 the values of $\sqrt{DT}$ can be calculated by the aid of equation (7 b). Substituting the values of $\sqrt{DT}$ and C, thus obtained, in equation (4) and in addition considering that $z = Z—Z_u$ and $z = Z—Z_1$ (see p. 60), we get for K_2O and SiO_2 the dotted curves in Figs. 10 and 11, which follow the original curves fairly well. This seems to show that migration in the hybridization has taken place, at least with respect to the components, K_2O and SiO_2, in a way which approximately follows Fick's second law.

In Fig. 10 curve $C_{SiO_2}(Z)$ and the theoretical curves overlap in the vicinity of Z_E. Fig. 11 shows, on the other hand, that the intersection of the theoretical curves is approximately above the maximum values ($Z = —6.5$) of the curve $C_{K_2O}(Z)$. If the upper and lower system had the same values of DT at the beginning of the hybridization process, the two concentration curves would »meet» approximately in the middle of the upper and lower contact *viz.*, at point $Z_T = —6.75$, which deviate only 0.25 m. from the average Z_E -value (p. 63) and thus the errors, caused by the deviation in the value of Z_T and Z_E, are so small that it is not necessary to take these into consideration when calculating the position of the original contacts as well their directions.

What conclusions, then, can be drawn concerning the constant of diffusion on both sides of the contact and the relative diffusion constants of the different oxides on the basis of the curves in Figs. 10 and 11? Examination of the theoretical curves which have been calculated on the basis that DT is constant on both sides of the contact, shows that the inflexion points are situated on the contact line, and the curves are symmetrical with respect to these points. On the other hand, the inflexion point in Fig. 20 has moved considerably towards the upper side and the curve is not symmetrical with respect to the inflexion point; this figure represents the experimental concentration curve in the liquid plagioclase-diopside system after Bowen (1921, p. 303), the diffusion constant on the lower (diopside) side of the contact being about three times that on the upper side. When looking at curves in Figs. 10 and 11, we find that the mean values of the contacts $Z_u = -3.1$ and $Z_1 = -10.4$ are situated, within their limits of error (probably less than 0.5—1.0 m), so near the inflexion points of the curves that the diffusion constant on both sides of the hybrid contacts can be regarded as almost equal, provided that the time of diffusion (T) is the same.

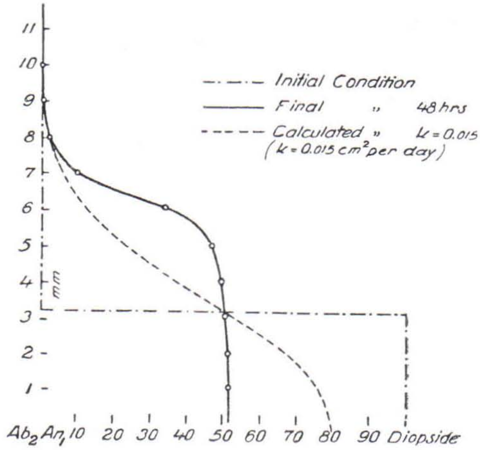

Fig. 20. Concentration curve in the system liquid plagioclase-diopside after Bowen (1921).

Let us now examine the relative diffusion constant of the different oxides. Although a glance at the curves in Figs. 10 and 11 is enough to show that there are no great differences in the migration ability of the different oxides, a more accurate comparison is not possible at once, owing to the considerable deviation in the values of C_1, C_2 and C_3 of the different oxides. When now the experimental and theoretical concentration curves correspond so closely, as Figs. 10 and 11 show, it is possible to obtain some measure of the migration abilities by calculating the values of DT for such theoretical curves, in which the values of S and C (p. 68) are equal to the values of

$$S = \int_{-\infty}^{Z_1} q\,[\,|\,C(Z) - C_3\,|\,]\,dZ \quad \text{or} \quad S = \int_{Z_u}^{+\infty} q\,[\,|\,C(Z) - C_1\,|\,]\,dZ$$

and $C = |\,C_2 - C_1\,|$ or $|\,C_2 - C_3\,|$, obtained from the experimental curves C(Z) in Figs. 10 and 11. As q can be regarded as equal for all oxides, we get, according to equation (7b):

$$\frac{D\ T}{D_o\ T_o} = \left(\frac{S\ C_o}{S_o\ C}\right)^2 \tag{8}$$

If we assume the different oxides to have the same migration time (T), the values of DT/D_0T_0 would represent the relative diffusion constants. However, it is possible that some oxides may be able to migrate at lower temperatures than others, and so the times of migration cannot be regarded as equal. Thus the author will use the term »migration ability» (DT) (instead of diffusion constant) to include as factors both the diffusion constant as well as time.

Table X. Calculated migration abilities of some of the components at the southern hybrid contact in the Suontaka area.

	C_1—C_2	C_2—C_3	Su moles/m²	S_1 moles/m²	DT/D_0T_0		
					Upper system	Lower system	Mean
K_2O	1.43	1.60	$1.19 \cdot 10^3$	$1.50 \cdot 10^3$	1.00	1.00	1.00
SiO_2	5.85	6.46	4.09	3.58	0.68	0.35	0.52
MgO	2.83	2.94	2.41	2.54	1.04	(0.85)	0.95
FeO	4.36	4.69	3.61	4.05	0.99	(0.80)	0.90
FeO_t	4.75	5.46	3.55	3.83	0.80	0.56	0.68
TiO_2	0.672	1.082	0.533	0.674	0.90	0.44	0.67
MnO	0.060	0.071	0.0311	0.0612	0.39	0.85	0.62

Table X presents the relative migration abilities of SiO_2, MgO, FeO, FeO_t, TiO_2 and MnO compared with K_2O. We see first that the migration abilities are of the same order varying from 0.35 to 1.04. Although the values of DT/D_0T_0 in the upper and lower system deviate to some extent, the fact that for example the migration ability of K_2O in the upper and lower system is considerably greater than that of SiO_2 seems to be real and not fortuitous. For the same reasons, the migration ability of MgO seems to be almost equal to that of FeO, but perhaps a little greater than that of FeO_t.

When comparing the migration abilities of K_2O and SiO_2 with those of MgO, FeO and FeO_t, we must take into consideration the fact that the concentrations on the side of the diabase do not necessarily represent the concentrations in the dispersed phase, especially with respect to the components migrating from the diabase into the granite (*e. g.* MgO, FeO and FeO_t), because a part of the material has probably been in a crystalline state and the rest liquid, as we shall see on pp. 72—74. In addition, it is to be noted that Fick's law is strictly valid for dilute solutions only and not for such a concentration as, for example, with respect to SiO_2. When, however, the experimental curves $C_{K_2O}(Z)$ and $C_{SiO_2}(Z)$ correspond fairly well to the theoretical curves, in the absence of any better method the foregoing manner of presentation seems reasonable.

MORE DETAILED DESCRIPTION OF THE HYBRIDIZATION PROCESS

The general outlines of the hybridization process have been discussed on pp. 57—58, and in the same connection the conclusion has been reached that the hybrid formation most probably has been formed in the present position immediately after the diabasic intrusion, through the hybridization of the diabase and the rapakivi granite. On the basis of this assumption the author has tried to determine the exact position of the original contact surfaces. On pp. 68—69 the migration abilities of the oxides on both sides of the original contacts have been ascertained to be almost equal and the course of the migration to follow approximately the laws of material diffusion, at least with respect to some oxides. Moreover, on this basis, the author has calculated some values of the relative migration ability of some oxides under the contact conditions of the olivine diabase.

Though the general outlines of the hybridization process have been drawn, the mechanism of hybridization has not yet been discussed in detail. Thus, let us first consider the solidification of the diabase in the vicinity of the original contact surfaces. As mentioned previously in several connections, the olivine diabase of Satakunta normally forms chilled margins, 1—2 m. thick, against its country rocks. Bearing in mind that the rapakivi lens at point No. 1 in Fig. 8 is as much as 7—8 m. in thickness, it seems very probable that chilled margins were also formed against this lens at the very beginning of the diabasic intrusion. This is supported by the theoretical cooling curves Fig. 21 of an igneous sheet, 20 m. thick, after Bowen (1921). Fig. 21 shows that, in the vicinity of the contact margin of the intrusive sheet, cooling proceeds very rapidly with respect to the central part. On account of the character of the function of the thermal diffusion and the relatively small differences in the values of thermal conductivity, heat of fusion, and heat capacity of the different igneous rocks (Birch, 1942), it can be considered that, at the beginning of cooling, the cooling curves continued approximately symmetrically into the country rock, as shown by the dashed curves (not presented in the original figure by Bowen). Thus it is very probable that chilled margins, a few decimeters thick, were formed before the heat flows from the diabase sills have reached the center of the granite lens.

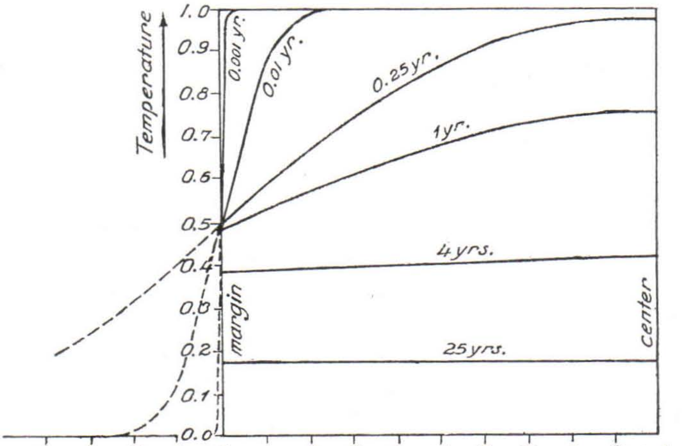

Fig. 21. Theoretical cooling curves of an igneous sheet, 20 m. in thickness, after Bowen (1921).

The temperature reached by the granite lens, lying between the diabase sills, depends upon the temperature of the diabasic magma as well as that of its surroundings, and above all upon the thickness of the diabase sills and that of the granite lens between them. As the lower contact in the drill hole lies at $Z = -10.4$ m. and the diabase is met at a depth of $Z = -23.9$ m., it is evident that the lower diabase is at least 13 m. thick, but taking into consideration that the lower diabase becomes coarser with increasing depth, being very coarse-grained at a depth of $-Z = 20 - 24$ m., it is probable that the thickness of the lower sill is twice that. On p. 65 the thickness of the upper diabase sill is shown to be at least 5—10 m. In addition, bearing in mind the symmetry of the density and concentration curves with respect to the straight line $Z = Z_E$, made from the drill hole, it is very probable that the thickness of the upper sill considerably exeeds 10 m. Thus a granite lens 7—8 m. thick has been situated between two diabase sills several tens of meters thick, and it is very probable that its temperature has been above the lower limit of the melting interval of the granite for a long time. This is clearly shown by the rapakivi hybrids, which contain, only in a narrow zone in the vicinity of the upper colder contact, partially assimilated potash feldspar ovoids as remnants of the original orthoclase ovoids of the granite.

Let us hereafter consider the changes in the contact margin of the diabase when granitic liquid had been formed in the granite lens. It is probable that there have been similar reactions, though of greater extent, than those described in connection with the palingenic dykes on pp. 20, 24. As a result of these reactions the fine-grained contact margin of the diabase were corroded away, while the diluted constituents of the diabase have migrated towards the center of the lens through the granitic liquid. It is important to know whether the granitic liquid came in contact with the uncrystallized diabasic magma, or with the medium-grained diabase, or perhaps with medium-grained diabase, containing some residual solution between the earlier crystallized grains. Bowen has stressed in his paper (1921, p. 309) that, when the constant of thermal diffusion of the rocks is about $10^4 - 10^5$ times that of the material diffusion, we cannot observe any considerable traces of material diffusion at the normal contacts of the intrusive rocks. The conditions at the southern hybrid contact, however, have been more suitable for material diffusion, but even here, on the basis of the aforementioned values, it is likely that thermal diffusion, and thus the crystallization of the diabase, has advanced before the hybridization »front». This is supported by the fact that the diabase hybrids contain, together with quartz and alkali feldspar grains, the minerals of the normal olivine diabase (p. 50); for example, olivine has been met within a distance of only 0.1 mm. from a mineral aggregate of quartz and alkali feldspar — — a fact not to be expected had the granitic liquid and diabasic magma mixed.

In view of the foregoing arguments, it is probable that at least the main part of the diabase had crystallized before hybridization began. How, then, could migration have taken place on the side of the olivine diabase? Did it happen in the solid state, or through the granitic, intergranular liquid situated between the partially corroded mineral grains of the olivine diabase, and containing material of the resorbed minerals as assumed in connection with the palingenic dykes on p. 38? As discussed on p. 72, it is certain that the granite has been in a liquid state during the hybridization, except for the remnants mentioned above. The laboratory experiments of Bowen (1921, p. 307) showed that the material diffusion constant in liquid diopside and plagioclase at a temperature of about 1 500°C and under normal pressure is of an order 10^{-6}—10^{-7} cm^2/sec (0.3—0.015 cm^2 per day). According to Rosenquist (1949) the maximum material diffusion constants for Ra^{++} in microperthite and albite under the pressure of one atmosphere and at temperature 1 063° and 1 073° K are $3.1 \cdot 10^{-8}$ and $1.1 \cdot 10^{-8}$ cm^2/sec respectively, while the diffusion constant for Pb^{++} in microperthite and albite under the pressure of one atmosphere and at a temperature of 1 038° K varies from 10^{-11} to 10^{-9} cm^2/sec. After Jagitsch (1949), the material diffusion constant of Na_2O in the solid system of Na_2O—Al_2O_3—SiO_2, under the pressure of one atmosphere and at a temperature of 760°C is about 10^{-9} cm^2/sec. It is to be noted, however, that the temperature in the determinations of Bowen was much higher than in the latter cases. If the constant of the material diffusion were 10—1 000 times greater on one side of the contact than the other, it would be visible in the unsymmetrical shape of the concentration curves, as is shown by the figures in Bowen's paper (see Fig. 20). Since this is not to be seen in the curves in Figs. 10 and 11, it is probable that migration on the side of the diabase has occurred in the liquid state, or else the migration abilities (see p. 69) must have been almost equal to that of the molten granite.

The former possibility is supported by the fact that in the upper part of the drill hole, especially, there are mineral aggregates and veinlets of quartz and alkali feldspars, with a micrographic texture similar to that of the palingenic dykes, and with fairly sharp boundaries against the original minerals of the diabase which are sometimes altered along the boundary. On the other hand, in the lower part of the drill hole, where the temperature has fallen more slowly, migration in the solid state might also have occurred at the same time or after the crystallization. This is shown by the scarcity of the micrographic aggregates and veinlets as well as by the more widely and evenly distributed alteration zones of the plagioclase grains.

On the basis of the data available, the author can not make any statement as to whether migration of ions or of oxide molecules has taken place. Examples of these both have been mentioned in literature as *e. g.*:

Eitel (1941), Jagitsch and Perlström (1946), Jagitsch and Bengtson (1946), and Bengtson and Jagitsch (1947). In this paper the author has used the oxides only because of easier calculations, the calculated positions of the contacts being independent of these assumptions.

On page 54 was mentioned that, on the basis of the statistical refractive index analyses, the upper limits of the labradoritic plagioclase intervals of the diabase hybrids are approximately equal to those of the normal olivine diabase. Thus the labradoritic plagioclase of the diabase hybrids is apparently the original plagioclase with which the intergranular granitic liquid from the granite lens has started to react, forming andesine. The refractive indices of the andesine and those of the quartz overlap, but in thin sections it can be seen that andesinic plagioclase is fairly abundant. The foregoing reactions apparently did not reach an equilibrium before the rock solidified, because together with the labradoritic and andesinic plagioclase alkali feldspars occur, increasing in amount towards the contacts. The fact that the rapakivi hybrids contain only plagioclase, rich in albite, is comprehensible, because the constituents which migrated from the diabase, crystallized simultaneously with the original constituents from the granitic liquid.

The great amount of anorthoclase in the hybrids may have originated, at least partially, from the relatively rapid cooling of the hybrids (see p. 38). The fact that, in accordance with the statistical refractive index analyses, the rapakivi hybrids contain less anorthoclase than the diabase hybrids, seems to show that the composition of the granitic melt (perhaps the water content) as well as the surrounding minerals have played an important part in the formation of anorthoclase, because the temperature and pressure conditions were probably almost the same in both these cases. As to the micrographic texture of the hybrids, the writer considers that it has been formed by the simultaneous crystallization of quartz and alkali feldspars from the residual solutions, as assumed in connection with the palingenic dykes p. 37.

As described on p. 55, the olivine and the gray-violet augite of the diabase become unstable, when approaching the contact. A part of the constituents of the disintegrated olivine and augite grains form serpentine, iddingsite, or hornblende and biotite in the place of the original minerals, while the rest of the constituents migrate into the rapakivi hybrids there to form new minerals as *e. g.* diopsidic pyroxene, amphibole, serpentine, chlorite, and biotite, which have been in equilibrium with their surroundings. The cooling of the hybrid formation, however, has proceeded so rapidly that even the dark minerals have not reached equilibrium. Thus, on the borders of the diopsidic pyroxene can be seen fibrous, yellow-brown and green hornblende, as well as serpentine and biotite as successive alteration products. In the middle of the long amphibole needles, characteristic of the rapakivi hybrids, there are minute, bright mineral cores which are probably pyroxene. It is likely that at the beginning of the hybridization process the magnesium, iron, and calcium ions (or oxides), which migrated from the diabase, formed together with the primary constituents of the granite long pyroxene needles, which have altered into amphibole at falling temperature.

Nockolds (1934, p. 31) has found the following reaction series at the contacts between acid magma and basic rocks:

—olivine → orthorhombic pyroxene → colorless amphibole → brown amphibole → green amphibole → biotite (green mica, chlorite)

—monoclinic pyroxene → new monoclinic pyroxene → brown amphibole → green amphibole → biotite → (green mica, chlorite).

Except for green mica, the latter series has been found in the hybrids of the Suontaka area. The gray-violet augite of the diabase, however, has not been observed to change directly into diopsidic augite. Contrary to the partially assimilated xenoliths of basalt in the rhyolite of the Katmai area, described by Fenner (1926), the hybrid formation of Suontaka contains many reaction minerals between the mineral composition of the granite and the diabase. For this reason the writer regards the use of the reaction principle of Bowen in this connection as justified.

On the basis of the statistical refractive index analyses, the indices of the amphibole and serpentine of the rapakivi hybrids area slightly lower than those in the diabase hybrids, probably due to their greater magnesium content. It is interesting to notice that the migration ability of MgO in Table X is slightly greater than that of FeO and, moreover, the values of mg (Table VI) of the rapakivi hybrids are distinctly higher than that of the normal rapakivi granite, which is consistent with the relation between the values of mg in the palingenic dykes and the parent rocks p. 38. On the other hand, the values of c/fm are considerably lower (0.2—0.27) than that of the rapakivi granite (0.39), which seems to show that DT/D_0T_0 of CaO is less than that of MgO or FeO.

The partially assimilated potash feldspar ovoids, as well as the quartz blebs, are considered to be remnants of the original texture of the rapakivi granite. The potash feldspar ovoids are restricted to a relatively narrow zone ($-Z = 4.5—5.5$), which lies in approximately the middle of the values of Z_u and Z_E. This can be understood in this way: the temperature in the vicinity of the more rapidly cooling, upper diabase sill did not rise as high as it did near the value of Z_E, where the influence of the hybridization effect, on the other hand, can be regarded as least. Although the quartz blebs which occur especially in the depth interval of $-Z = 4.0—6.5$, have been considered as remnants of original quartz grains of the rapakivi granite, their greater size (0.5—1.0 cm.) together with their rounded shape shows that much additional material has crystallized around the original grains. The idiomorphic quartz grains, very often surrounded by hornblende margins, show that quartz occurs in two generations in the rock. *viz.*, as idiomorphic drops which crystallized early, and as xenomorphic grains which together with alkali feldspars fill the interstices between minerals that had crystallized earlier.

Finally, let us try to understand the fine-grained granitic dykes that cut the rapakivi hybrid rock containing potash feldspar ovoids on the basis of the contact phenomena described in Parts III and IV. The author considers that these dykes represent the residual solution of the remelted and recrystallized granite lens. This residual solution has been intruded from the lower parts of the granite lens that had crystallized last into the overlaying rapakivi hybrid rocks that had crystallized earlier. This assumption is supported by the chemical composition of the dyke (No. 3 in Table VII), which deviates considerably from those of the palingenic dykes and the rapakivi hybrids. The dyke contains more K_2O and SiO_2 than the rapakivi hybrids. Perhaps the residual solution of the granitic material, on account of the enriched water content, even under the hypabyssal conditions of the diabase tends to be enriched in these components. If this is correct, it means that the remelting and recrystallizing phenomena are not reversible under the conditions just described.

HYBRIDIZATION PHENOMENA IN OTHER AREAS

In addition to the hybridization phenomena of the Suontaka diabase area, similar phenomena are also encountered in other parts of the area investigated. The disappearance of the sharp boundary between the diabase and sandstone xenoliths is described on p. 23; the hybridization phenomena of the »old contact of Heikkilä» is mentioned on p. 24.

On the basis of the geological map it has previously been assumed that the diabase of the Lappi area would also have a sill-like character. During field work in the summer of 1938 the writer found a new contact between the diabase and normal rapakivi granite in the northern part of the diabase area (No. 5 on map Pl. V). As usual, the gently sloping diabase has an aphanitic contact against the granite on which it lies.

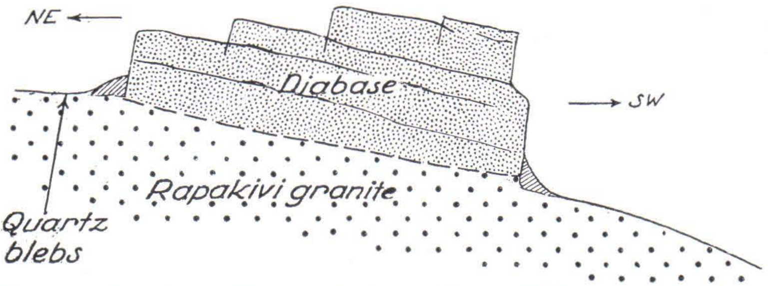

Fig. 22. Sketch profile of a diabase ridge in SW part of the Lappi diabase area.

The rapakivi granite is quite normal up to the contact and no contact influence can be observed megascopically. In the southern part of the Lappi diabase area (No. 6 on map. Pl. V), on the other hand, quartz blebs or worms, 0.5—1.0 cm. in diameter, were found in the rapakivi granite situated on the NE side of the diabase ridge (see Fig. 22). Margins of brown-green hornblende and dark, strongly pleochroic biotite are found round the quartz blebs, making the rock slightly darker than the normal rapakivi granite. The quartz blebs and the worms greatly resemble those described from the Suontaka diabase area (p. 56). The diabase is a medium-grained type on top of the ridge, but on approaching the granite on the NE and SW sides of the ridge, it becomes finer-grained, the contact itself not being exposed. The fact that the variation in grain size takes place only in a vertical direction, but not horizontally, shows that the contact between the diabase and the rapakivi granite is most probably situated parallel to the main joint plane (see Fig. 22 and p. 10) of the diabase. Thus the granite containing quartz blebs has probably been situated immediately below the diabase sill and the writer regards the quartz blebs as a result of the weak contact influence of the diabase.

Some hundred meters east of this place the writer found another exposure of rapakivi granite, containing orthoclase ovoids and quartz blebs. Here are thin diabase remnants, aphanitic against the contact with the rapakivi granite, and cut by small palingenic dykes from the granite. Thus at the lower contacts of the Lappi diabase sill (or sills) remelting of the country rock and probably also slight hybridization have taken place.

Corresponding rocks have been also found in the diabase area of Vaimaroinen (No. 11 on map, Pl. V), but in the absence of detailed mapping the relation of this rock to the contacts of the diabase is not known at present.

Many examples of contact phenomena between basic and acidic rocks, influenced either by basic or acidic magmas are described in literature. Sobral (1913, p. 107—114) describes monzonites which occur at Ulfön in the Nordingrå area in Sweden and which pass through several transitional rocks into the normal olivine diabase. Sobral assumes that the monzonites have been formed by assimilation of rapakivi granite xenoliths by the diabasic magma. The monzonites greatly resemble in mineral composition and texture the diabase hybrids described above. The chemical composition of the fayalite-monzonite lies between analyses Nos. 3 and 4 in Table VI, but its Na_2O content is distinctly greater than that in the corresponding diabase hybrids of the Suontaka area. This is easily explained as the rapakivi granite of Ulfö contains considerably more Na_2O than that of Suontaka.

H. von Eckermann (1936, p. 315—317) describes similar monzonites, which gradually change into doleritic diabase. In addition to some andesine, these rocks contain orthoclase, anorthoclase and long prisms of pyroxene, the latter of which have been partly altered into amphibole, as in the hybrids in the Suontaka area. Eckermann, however, »considers them, in this case, to be normal members of the differentiation sequence of the doleritic magma, or, maybe, a hybrid rock originated at greater depths». It would be interesting to know the contact relations of the doleritic diabase in the vicinity of the monzonites. Would it be possible to explain their origin in the same way as the hybrid formation in Satakunta?

In Gävle region, Asklund (1934, p. 34) has encountered a reddish pegmatitic zone, a few centimeters thick, between the gneissous-granite and Hohällan diabase. Small dykes extend from this zone into the diabase. Asklund regards these dykes as well as the zone itself as the result of refusion or palingenesis of the wall rock.

Krokström has explained the epidolerite of Breven (1932, p. 309) as well as the altered contact zone of the mottled dolerite of the Hällefors dolerite dyke (1936a, p. 138) as a result of assimilation of the acid country rock by the doleritic magma. The kersantite dykes at Island Halsaren, too, have been explained by Åhman (1947) as the product of partial assimilation of Jotnian sandstone by diabasic magma.

Wager and Deer (1939) describe in the olivine gabbro of the Skaergaard intrusion granophyre inclusions, which they regard as compleatly refused blocks of acid gneiss from the surrounding metamorphic complex. Between these inclusions and the surrounding olivine gabbro there are zones of variable thickness consisting of extremely coarse quartz gabbro, which is assumed to be a product of hybridization between the refused inclusions and the surrounding basic magma.

According to Walker and Poldervaart (1949), the doleritic magma of the Karroo System in South Africa has also been »estremely active toward the associated sedimentary rocks causing widespread rheomorphic and syntectic phenomena. Many of the rocks previously described as 'diorite'or'granophyre' were found to be transfused siltstones».

In her paper (1950) on the rocks of the Slieve Gullion area, Reynolds describes how the Caledonian granodiorite changes through transitional rocks to typical Tertiary granophyre, containing micrographic textures similar to palingenic dykes and rapakivi hybrids of the Suontaka area. Like the authors of the aforementioned papers, Reynolds also regards the heat of the adjacent basaltic magma flow (situated in the vicinity of the granophyres) as responsible for this transformation. While deferring some important genetical conclusions to later publications, she assumes, however, that the transformation of the granodiorite to granophyre has taken place through selective migrations of the components in the crystalline state and not as a result of (more or less) complete remelting of the granodiorite, as assumed by Geijer and Eskola in the discussion (*op. cit.* p. 30) and by the author in the present paper. As the author has not visited the area in question and thus does not know all the facts available it is preferable to postpone comments untill the investigations of the Slieve Gullion area are completed and the final conclusions concerning the genesis — especially the source of the potash, necessary for the transformation, the destiny of the displaced Fe, Mg, and Ca, as well as a description of the process in more detail—are at hand.

The investigations of Fenner (1938) and Sahama (1945) may be mentioned as examples of the assimilative influence of an acid magma. According to the former, the rhyolite on Gardiner River has deeply penetrated the basalt as complex networks of veins, and has had a corrosive action upon the basalt giving rise to a series of hybrid rocks, the composition of which lie on straight lines between basalts and rhyolite (when the different oxides are presented as a function of the SiO_2-content). In Fig. 12 we can ascertain that the Niggli numbers of the hybrids at Suontaka, when presented as a function of the value of si, deviate considerably from straight lines, which seems to show that the mechanism of hybridization is different in this case. Fenner has tried (p. 1482) to explain the hybridization by assuming gaseous emmanations from the rhyolite as the solvent and transporting medium, but this assumption does not solve (as he pointed out on p. 1483) the problem of the rectilinear variation of composition of the modified basalt. As the rhyolite contains many basalt xenoliths, would it be possible, perhaps, to explain the hybrid rock as a mechanical mixture of the liquid rhyolite with an increasing number of small basalt xenoliths, which have been assimilated by the rhyolite, thus giving rise to a fairly uniform rock?

Sahama (*op. cit.*) describes the contamination phenomena at the contact between the mica gneiss and the younger rapakivi granite at Ihovaara. On the basis of five analyses, rubidium, fluorine and lithium seem to have been enriched into the contaminated rock, while the other components are between the amounts of the mica gneiss and the granite.

In addition to the aforementioned papers be it mentioned the investigations of Dennen (1950) and Hotz (1950), who, according to the concise abstracts available at present, have had almost the same problems and, to some extent have also employed methods of investigation in their work similar to the authors'.

SUMMARY

This paper deals with the contact phenomena of the olivine diabase which is the youngest rock of the Jotnian formation of Satakunta in SW Finland. The chemical composition of the olivine diabase is nearly that of the plateau basalts, and there is reason to believe that the diabase formation represents the hypabyssal eruption channels and their horizontal extensions of one or more basaltic extrusions. The contact phenomena can be divided into three groups, *viz.*, low-grade contact influences, partial remelting of the country rock, and the hybridization phenomena between the olivine diabase and its country rock.

The induration of the sandstone in the vicinity of the diabase contacts represents the lowest grade of contact metamorphism. Near the contact with the olivine diabase, the rounded quartz grains have become toothed, thus rendering the constituents of the sandstone more coherent than usual.

The fine-grained dykes, called palingenic dykes, are regarded as the result of the partial remelting of the country rock. These dykes proceed from the various kinds of acidic country rock (or parent rock) for 2—3 m., at the most, into the aphanitic or fine-grained contact mantle of the olivine diabase.

Palingenic dykes contain mainly quartz and alkali feldspars, the latter being mostly either anorthoclase or plagioclase rich in potash; in addition there is some biotite and chlorite, and especially near the diabase contact also hornblende. A micrographic texture is characteristic of all the palingenic dykes. In the vicinity of the palingenic dykes the plagioclase of the diabase has been corroded, and at the same time the olivine and augite have disintegrated and changed into serpentine, hornblende and iron ore.

Ten chemical analyses of the palingenic dykes and the parent rocks are presented, and these analyses have been plotted on the equilibrium diagram of dry $NaAlSiO_4$—$KAlSiO_4$—SiO_2 after Schairer and Bowen.

Despite the great differences in composition of the parent rocks, the composition of the corresponding palingenic dykes occurs in a fairly limited field near the boundary curve between tridymite and alkali feldspar. It is to be noted that all palingenic dykes from the rapakivi granites which are rich in potash contain more sodium than their corresponding parent rocks.

The difference in the composition between the parent rocks and their palingenic dykes is explained as the result of the contact influence of the diabase. The constituents of the parent rocks have been only partially remelted, forming intergranular liquids, the composition of which has been situated near the eutectic composition of the quartz and alkali feldspars under the prevailing conditions of pressure and temperature.

In the Suontaka diabase area there is a hybrid formation about 20—30 m. thick situated between two diabase sills, and the hybridization phenomena here are described in more detail. The density determinations, chemical analyses and the microscopical investigations of samples from a drill hole, made for the present investigation, and specimens from the surface are presented. Accordingly, the olivine diabase on the upper and lower sides of the formation is found to change gradually into a rock that, in the middle of the formation, has almost the same density and chemical composition as the surrounding rapakivi granite. The texture is micrographic, but the medium-grained rock contains, in addition, large partially assimilated ovoids of potash feldspar and quartz blebs.

The formation is explained as the result of almost complete remelting of a granite lens, about 7—8 m. thick, by the heating influence of the two diabase sills, intruded contemporaneously on both sides of the granite lens, together with reactions between this granitic liquid and the solidified diabase. The reactions between the remelted granite and the diabase have been explained by the reaction principle after Bowen. With the aid of the density and concentration curves of the different oxides, an attempt is made to estimate the position of the original contacts between the granite lens and the surrounding diabase sills.

On the basis of these calculated contact positions and the concentration curves, the migration of the components from the granite to the diabase (K_2O, SiO_2) is found to follow approximately Fick's second law of material diffusion. Moreover, with the aid of the theory of material diffusion and the concentration curves, the relative migration abilities (that is, the diffusion constant multiplied by the time of diffusion) have been calculated for some oxides with respect to K_2O. The main results obtained are;

—the relative migration abilities of all the oxides considered, *viz.*, K_2O, SiO_2, MgO, FeO, FeO_t (total iron), TiO_2 and MgO are of the same order of magnitude, varying from 0.35 to 1.04, and approximately equal on both sides of the contacts,

—the migration ability of K_2O seems to be greater than that of the SiO_2 and the migration ability of MgO almost equal to that of FeO and perhaps slightly greater than that of FeO_t.

The method as well as the results obtained are discussed. Finally a more detailed conception of the hybridization and some comparisons with corresponding phenomena in other areas are presented.

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EXPLANATIONS TO THE PLATES

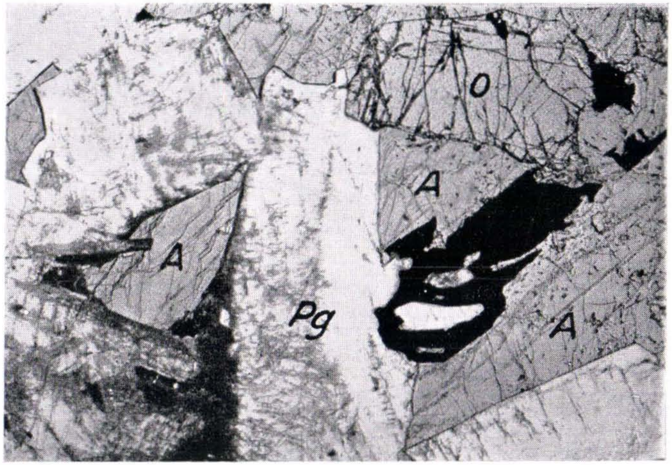
Plate I.
Fig. 1. The jointing of the diabase in Suontaka. The arrows show the upper contact of the diabase.
Fig. 2. Olivine diabase. Suontaka. Grains of olivine (O), plagioclase (Pg), augite (A). x16.
Fig. 3. Normal arkosic sandstone. From a well near the Kauttua factory. x34.
Fig. 4. Toothed quartz grains of the sandstone at the diabase contact of Kiperjärvenoja. x28.

Plate II.
Fig. 5. Palingenic dyke from sandstone. Matomäenkallio, Tuiskula. x16.
Fig. 6. Palingenic dykes from sandstone. Eskonkallio, Tuiskula.
Fig. 7. Palingenic dykes from sandstone. Eskonkallio, Tuiskula. x16.
Fig. 8. Palingenic dyke from Tarkki granite, 0.5—1 cm in thickness, cutting a diabase apophysis. The new contact of Heikkilä, Eurajoki. Phot. R. Kern.

Plate III.
Fig. 9. Sinuous palingenic dykes from Tarkki granite, cutting a diabase apophysis. The ordinary arrows show the palingenic dykes in the diabase, the broken arrow the vaguer extention of a dyke in the Tarkki granite. The new contact of Heikkilä, Eurajoki.
Fig. 10. The contact between the palingenic dyke from the Tarkki granite and the fine-grained diabase. The new contact of Heikkilä, Eurajoki. x34.
Fig. 11. Diabase hybrid from the upper part of the drill hole. Suontaka, Laitila. x16.
Fig. 12. Long amphibole needles in the rapakivi hybrid from the drill hole. Suontaka. x16.

Plate IV.
Fig. 13. Quartz bleb in the rapakivi hybrid near the drill hole. Suontaka. x17.
Fig. 14. Partially assimilated rapakivi granite. Suontaka.
Fig. 15. Normal rapakivi granite. Honkilahti.
Fig. 16. Haukkavuori granite, a rapakivi variety. Honkilahti.

Fig. 1



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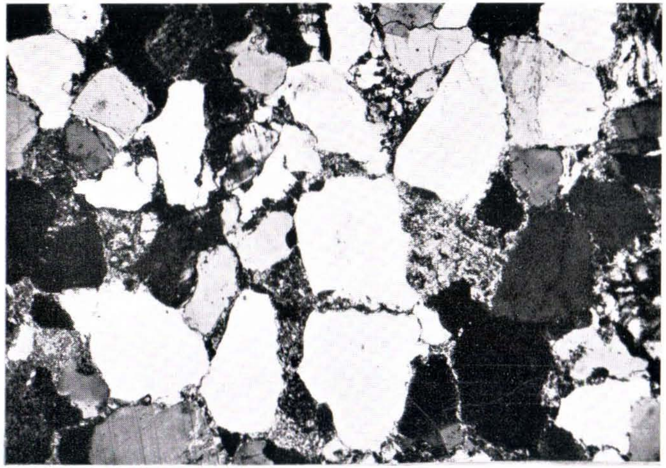

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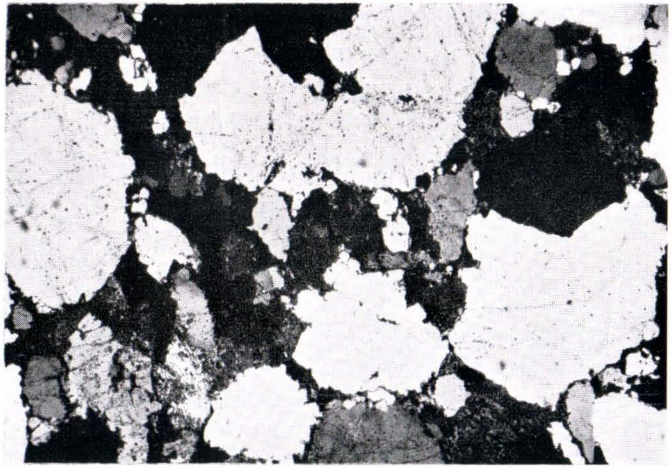
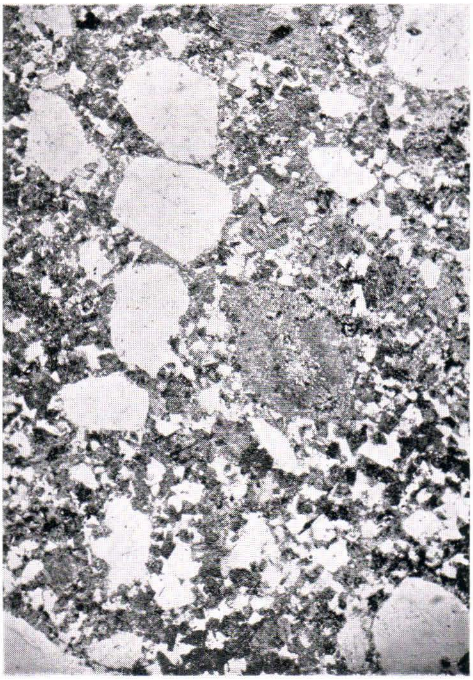


Fig. 4


Fig. 5


Fig. 6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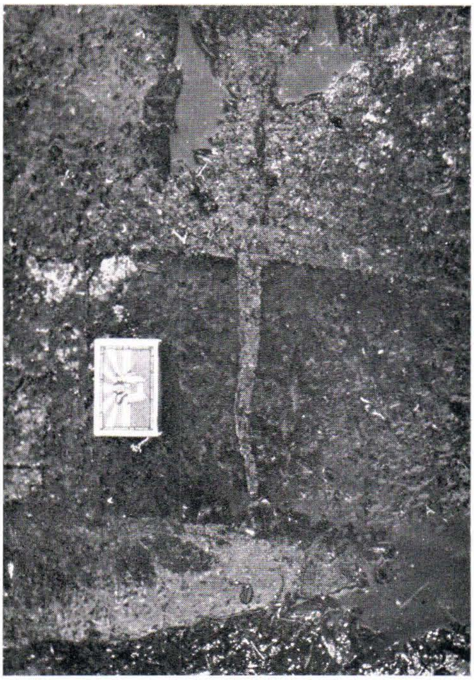
Fig. 8

Fig. 5

Fig. 6

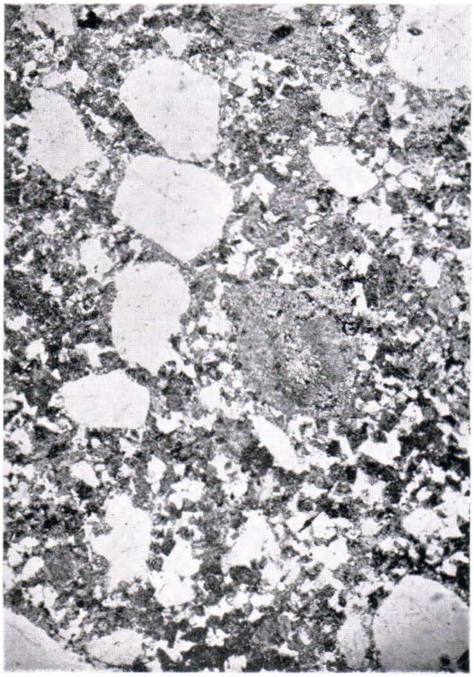

Fig. 7

Fig. 8

PLATE III.

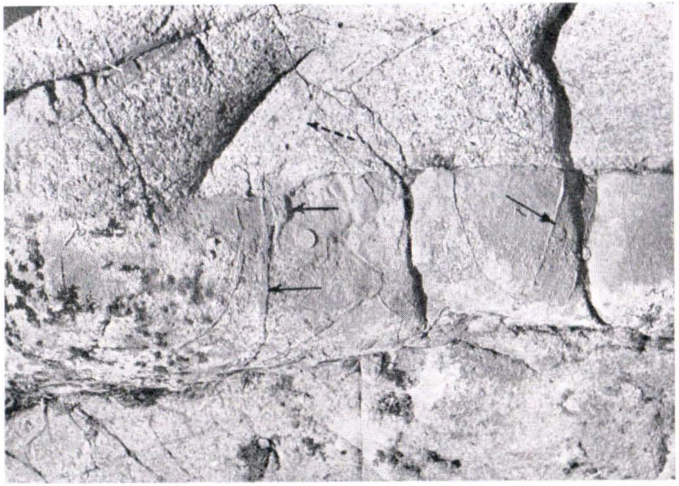

Fig. 9

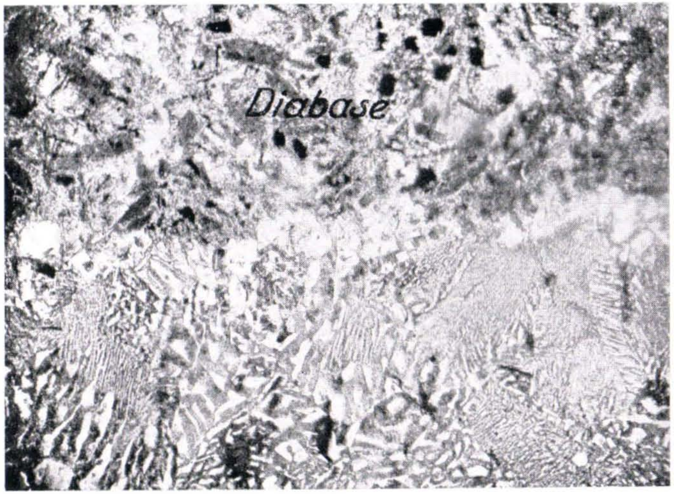

Fig. 10

Fig. 11

Fig. 12

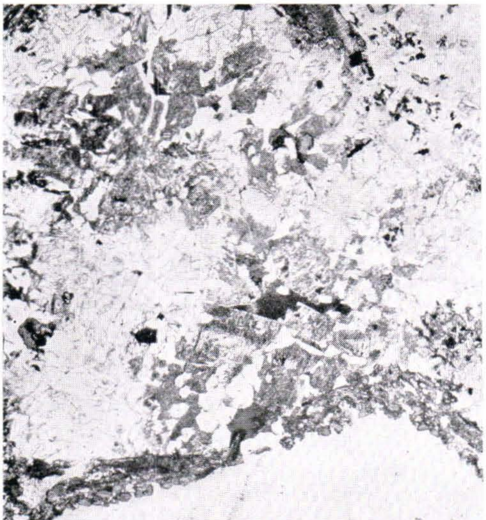

Fig.13

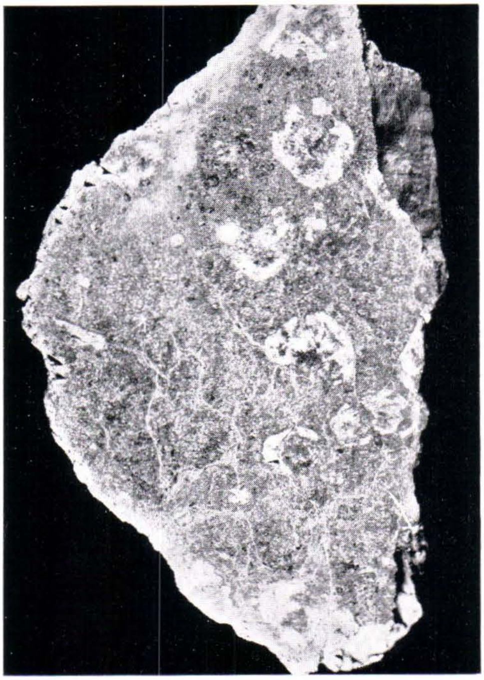

Fig.14

Fig.15

Fig.16

PETROLOGICAL MAP OF THE ALA-SATAKUNTA-REGION

by Aarno Kahma

Bulletin de la Commission géologique de Finlande.

N:o 1.	Ramsay, Wilhelm und Nyholm, E. T. Cancrinitsyenit und einige verwandte Gesteine aus Kuolajärvi. S. 1—12. 4 Fig. 1895	60: —
*N:o 2.	Sederholm, J. J. Ueber einen metamorphosirten praecambrischen Quarzporphyr von Karvia in der Provinz Åbo. S. 1—16. 12 fig. 1895	—
N:o 3.	Ramsay, Wilhelm, jemte Bihang 1 af Hackman, Victor och 2 af Sederholm, J. J. Till frågan om det senglaciala hafvets utbredning i Södra Finland. S. 1—44. 1 karta. Résumé en français: La transgression de l'ancienne mer glaciaire sur la Finlande méridionale. 1896	100: —
*N:o 4.	Frosterus, Benj. Ueber einen neuen Kugelgranit von Kangasniemi in Finland. S. 1—38. 11 Fig. 2 Taf. 1896	—
*N:o 5.	Berghell, Hugo. Bidrag till kännedomen om Södra Finlands kvartära nivåförändringar. S. 1—64. 16 fig. 1 plansch. 1 karta. Deutsches Referat: Beiträge zur Kenntniss der quartären Niveauschwankungen Süd-Finlands. 1896	—
*N:o 6.	Sederholm, J. J. Über eine archäische Sedimentformation im südwestlichen Finland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. S. 1—254. 97 Fig. 5 Taf. 2 Karten. 1897	—
*N:o 7.	Ailio, Julius. Über Strandbildungen des Litorinameeres auf der Insel Mantsinsaari. S. 1—43. 8 Fig. 1898	—
*N:o 8.	Andersson, Gunnar. Studier öfver Finlands torfmossar och fossila kvartärflora. S. 1—210. 21 fig. 4 tafl. Deutsches Referat: Studien über die Torfmoore und die fossile Quartärflora Finlands. 1898	—
N:o 9.	Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—17. 1 carte. 1899	100: —
N:o 10.	Sederholm, J. J. Les dépôts quaternaires en Finlande. P. 1—28. 2 fig. 1 carte. 1899	100: —
*N:o 11.	Hackman, Victor. Neue Mitteilungen über das Ijolithmassiv in Kuusamo. S. 1—45. 7 Fig. 1 Taf. 2 Karten. 1899	—
*N:o 12.	Ramsay, Wilhelm und Borgström, L. H. Der Meteorit von Bjurböle bei Borgå. S. 1—28. 20 Fig. 1902	—
*N:o 13.	Frosterus, Benj. Bergbyggnaden i sydöstra Finland. S. 1—168. 18 fig. 8 tafl. 1 karta. Deutsches Referat: Der Gesteinsaufbau des südöstlichen Finland. 1902	—
*N:o 14.	Borgström, Leon. H. Die Meteoriten von Hvittis und Marjalahti. S. 1—80. 8 Taf. 1903	—
N:o 15.	Hackman, Victor. Die chemische Beschaffenheit von Eruptivgesteinen Finlands und der Halbinsel Kola im Lichte des neuen amerikanischen Systemes. S. 1—143. 3 Tab. 1905	120: —
*N:o 16.	Sundell, I. G. On the Cancrinite-Syenite from Kuolajärvi and a Related Dike Rock. P. 1—20. 1 plate. 1905	—
N:o 17.	Fircks, Curt. On the Occurrence of Gold in Finnish Lapland. P. 1—35. Frontispiece. 15 fig. 1 map. 1906	80: —
N:o 18.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. I. Till frågan om Ost-Finmarkens glaciation och nivåförändringar. S. 1—165. 23 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. I. Sur la glaciation et les changements de niveau du Finmark oriental. 1906	200: —

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*N:o 19.	**Trüstedt, Otto.** Die Erzlagerstätten von Pitkäranta am Ladoga-See. S. 1—333. 80 Fig. 19 Taf. 1 Karte. 1907	—
N:o 20.	**Tanner, V.** Zur geologischen Geschichte des Kilpisjärvi-Sees in Lappland. S. 1—23. 3 Fig. 2 Taf. 1 Karte. 1907	60: —
N:o 21.	**Tanner, V.** Studier öfver kvartärsystemet i Fennoskandias nordliga delar. II. Nya bidrag till frågan om Finmarkens glaciation och nivåförändringar. S. 1—127. 10 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. II. Nouvelles recherches sur la glaciation et les changements de niveau du Finmark. 1907	200: —
N:o 22.	**Borgström, L. H.** Granitporphyr von Östersundom. S. 1—20. 3 Fig. 1 Taf. 1907	60: —
*N:o 23.	**Sederholm, J. J.** Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia. S. 1—110. 11 fig. 8 tafl. 1 planteckn. 1 karta. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. 1907	—
*N:o 24.	**Sederholm, J. J.** Les roches préquaternaires de la Fennoscandia. P. 1—39. 20 fig. 1 carte. 1910	—
N:o 25.	**Tanner, V.** Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-öjen im Kirchspiel Saltvik, Åland-Inseln. S. 1—13. 5 Fig. 2 Taf. 1911	60: —
*N:o 26.	**Mäkinen, Eero.** Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium. S. 1—8. 1911	—
N:o 27.	**Sederholm, J. J.** Esquisse hypsométrique de la Finlande. P. 1—21. 5 fig. 1 carte. 1911	80: —
*N:o 28.	**Sederholm, J. J.** Les roches préquaternaires de la Finlande. P. 1—27. 1 carte. 1911	—
N:o 29.	**Sederholm, J. J.** Les dépôts quaternaires de la Finlande. P. 1—23. 5 fig. 1 carte. 1911	80: —
*N:o 30.	**Sederholm, J. J.** Sur la géologie quaternaire et la géomorphologie de la Fennoscandia. P. 1—66. 13 fig. 6 cartes. 1911	—
N:o 31.	**Hausen, H.** Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar. S. 1—34. 9 fig. Deutsches Referat. 1912	80: —
N:o 32.	**Hausen, H.** Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor. S. 1—32. Deutsches Referat. 1912	80: —
N:o 33.	**Wilkman, W. W.** Kvartära nivåförändringar i östra Finland. S. 1—40. 9 fig. Deutsches Referat. 1912	100: —
N:o 34.	**Borgström, L. H.** Der Meteorit von St. Michel. S. 1—49. 1 Fig. 3 Taf. 1912	100: —
N:o 35.	**Mäkinen, Eero.** Die Granitpegmatite von Tammela in Finnland und ihre Minerale. S. 1—101. 23 Fig. 1913	120: —
N:o 36.	**Eskola, Pentti.** On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities. P. 1—50. 15 fig. 1913	100: —
N:o 37.	**Sederholm, J. J.** Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia. S. 1—66. 27 Fig. 1 Taf. 1913	140: —
N:o 38.	**Tanner, V.** Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. S. 1—815. 139 fig. 16 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. 1915	600: —
N:o 39.	**Hackman, Victor.** Der gemischte Gang von Tuutijärvi im nördlichen Finnland. S. 1—41. 9 Fig. 1914	80: —
*N:o 40.	**Eskola, Pentti.** On the Petrology of the Orijärvi region in Southwestern Finland. P. 1—277. 55 fig. 6 plates. 2 maps. 1914	—
N:o 41.	**Borgström, L. H.** Die Skapolithlagerstätte von Laurinkari. S. 1—30. 7 Fig. 1913	60: —

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N:o 42.	Hackman, Victor. Über Camptonitgänge im mittleren Finnland. S. 1—18. 3 Fig. 1914	60: —
N:o 43.	Wilkman, W. W. Kaleviska bottenbildningar vid Mölönjärvi. S. 1—36. 11 fig. Résumé en français. 1915	80: —
N:o 44.	Eskola, Pentti. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. S. 1—145. 5 fig. English Summary of the Contents. 1915	120: —
N:o 45.	Ailio, Julius. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung. S. 1—158. 51 Abb. 2 Karten. 1915	200: —
N:o 46.	Laitakari, Aarne. Le gisement de calcaire cristallin de Kirmonniemi à Korpo en Finlande. P. 1—39. 14 fig. 1916	80: —
N:o 47.	Mäkinen, Eero. Översikt av de prekambriska bildningarna i mellersta Österbotten i Finland. S. 1—152. 25 fig. 1 karta. English Summary of the Contents. 1916	200: —
N:o 48.	Sederholm, J. J. On Synantetic Minerals and Related Phenomena (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, &c.). P. 1—148. 14 fig. in the text and 48 fig. on 8 plates. 1916	240: —
N:o 49.	Wilkman, W. W. Om en prekalevisk kvartsitformation i norra delen af Kuopio socken. S. 1—18. 7 fig. Résumé en français. 1916	60: —
N:o 50.	Sauramo, Matti. Geochronologische Studien über die spätglaziale Zeit in Südfinnland. S. 1—44. 5 Abb. 4 Taf. 1918	120: —
N:o 51.	Laitakari, Aarne. Einige Albitepidotgesteine von Südfinnland. S. 1—13. 5 Abb. 1918	60: —
N:o 52.	Brenner, Th. Über Theralit und Ijolit von Umptek auf der Halbinsel Kola. S. 1—30. 4 Fig. 1920	60: —
N:o 53.	Hackman, Victor. Einige kritische Bemerkungen zu Iddings' Classifikation der Eruptivgesteine. S. 1—21. 1920	60: —
N:o 54.	Laitakari, Aarne. Über die Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas). S. 1—113. 40 Abb. 3 Taf. 1921	120: —
N:o 55.	Eskola, Pentti. On Volcanic Necks in Lake Jänisjärvi in Eastern Finland. P. 1—13. 1 fig. 1921	60: —
N:o 56.	Metzger, Adolf A. Th. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet. S. 1—8. 3 Abb. 1922	60: —
*N:o 57.	Väyrynen, Heikki. Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens. S. 1—78. 20 Fig. 1 Karte. 1923	—
*N:o 58.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part I. The Pellinge Region. P. 1—153. 64 fig. 8 plates. 1 map. 1923	—
N:o 59.	Berghell, Hugo und Hackman, Victor. Über den Quartzit von Kallinkangas, seine Wellenfurchen und Trockenrisse. Nach hinterlassenen Aufzeichnungen von Hugo Berghell zusammengestellt und ergänzt von Victor Hackman. S. 1—19. 19 Fig. 1923	60: —
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N:o 61.	Hackman, Victor. Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikationen. S. 1—23. 2 Fig. 1 Karte. 1923	60: —
N:o 62.	Wilkman, W. W. Tohmajärvi-konglomeratet och dess förhållande till kaleviska skifferformationen. S. 1—43. 15 fig. 1 karta. Deutsches Referat. 1923	80: —
N:o 63.	Hackman, Victor. Über einen Quartzsyenitporhyr von Saariselkä im finnischen Lappland. S. 1—10. 2 Fig. 1923	60: —
N:o 64.	Metzger, Adolf A. Th. Die jatulischen Bildungen von Suojärvi in Ostfinnland. S. 1—86. 38 Abb. 1 Taf. 1 Karte. 1924	120: —
N:o 65.	Saxén, Martti. Über die Petrologie des Otravaaragebietes im östlichen Finnland. S. 1—63. 13 Abb. 5 Fig. auf 1 Taf. 2 Karten. 1923	120: —
N:o 66.	Ramsay, Wilhelm. On Relations between Crustal Movements and Variations of Sea-Level during the Late Quaternary Time, especially in Fennoscandia. P. 1—39. 10 fig. 1924	80: —

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N:o 67.	Sauramo, Matti. Tracing of Glacial Boulders and its Application in Prospecting. P. 1—37. 12 fig. 1924	80: —
N:o 68.	Tanner, V. Jordskredet i Jaarila. S. 1—18. 2 fig. 10 bild. Résumé en français. 1924	60: —
N:o 69.	Auer, Väinö. Die postglaziale Geschichte des Vanajavesisees. S. 1—132. 10 Fig. 10 Taf. 11 Beil. 1924	200: —
N:o 70.	Sederholm, J. J. The Average Composition of the Earth's Crust in Finland. P. 1—20. 1925	80: —
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N:o 72.	Hackman, Victor. Das Gebiet der Alkaligesteine von Kuolajärvi in Nordfinnland. S. 1—62. 6 Fig. 1 Taf. 1925	120: —
N:o 73.	Laitakari, Aarne. Über das jotnische Gebiet von Satakunta. S. 1—43. 14 Abb. 1 Karte. 1925	120: —
N:o 74.	Metzger, Adolf A. Th. Die Kalksteinlagerstätten von Ruskeala in Ostfinnland. S. 1—24. 9 Abb. 2 Karten. 1925	80: —
N:o 75.	Frosterus, Benj. Ueber die kambrischen Sedimente der karelischen Landenge. S. 1—52. 1 Fig. 1925	120: —
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N:o 77.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part II. The Region around the Barösundsfjärd W. of Helsingfors and Neighbouring Areas. P. 1—143. 57 fig. in the text and 44 fig. on 9 plates. 1 map. 1926	240: —
N:o 78.	Väyrynen, Heikki. Geologische und petrographische Untersuchungen im Kainuugebiete. S. 1—127. 37 Fig. 2 Taf. 2 Karten. 1928	160: —
N:o 79.	Hackman, Victor. Studien über den Gesteinsaufbau der Kittilä-Lappmark. S. 1—105. 23 Fig. 2 Taf. 2 Karten. 1927	160: —
N:o 80.	Sauramo, Matti. Über die spätglazialen Niveauverschiebungen in Nordkarelien, Finnland. S. 1—41. 8 Fig. im Text. 11 Fig., 1 Karte und 1 Profildiagr. auf 7 Taf. 1928	60: —
N:o 81.	Sauramo, Matti and Auer, Väinö. On the Development of Lake Höytiäinen in Carelia and its Ancient Flora. P. 1—42. 20 fig. 4 plates. 1928	60: —
N:o 82.	Lokka, Lauri. Über Wiikit. S. 1—68. 12 Abb. 1928	120: —
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N:o 88.	Tanner, V. Studier över kvartärsystemet i Fennoskandias nordliga delar. IV. Om nivåförändringarna och grunddragen av den geografiska utvecklingen efter istiden i Ishavsfinland samt om homotaxin av Fennoskandias kvartära marina avlagringar. S. 1—589. 84 fig. 4 tavl. 1 karta. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandie. IV. Sur les changements de niveau et les traits fondamentaux du développement géographique de la Finlande aux confins de l'océan Arctique après l'époque glaciaire et sur l'homotaxie du quaternaire marin en Fennoscandie. 1930	600: —
N:o 89.	Wegmann, C. E. und Kranck, E. H. Beiträge zur Kenntnis der Svecofenniden in Finnland. I. Übersicht über die Geologie des Felsgrundes im Küstengebiete zwischen Helsingfors und Onas. II. Petrologische Übersicht des Küstengebietes E von Helsingfors. S. 1—107. 4 Fig. 16 Taf. mit 32 Fig. 1 Übersichtskarte. 1931	160: —

N:o 90.	Hausen, H. Geologie des Soanlahti-Gebietes im südlichen Karelien. Ein Beitrag zur Kenntnis der Stratigraphie und tektonischen Verhältnisse der Jatulformation. S. 1—105. 23 Fig. im Text und 12 Fig. auf 4 Taf. 1930	200: —
N:o 91.	Sederholm, J. J. Pre-Quaternary Rocks of Finland. Explanatory Notes to accompany a General Geological Map of Finland. P. 1—47. 40 fig. 1 map. 1930	120: —
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N:o 93.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, IV. P. 1—68. 12 fig. 6 planches. 1931	160: —
N:o 94.	Brenner, Thord. Mineraljordarternas fysikaliska egenskaper. S. 1—159. 22 fig. Deutsches Referat. 1931	280: —
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N:o 96.	Mikkola, Erkki. On the Physiography and Late-Glacial Deposits in Northern Lapland. P. 1—88. 25 fig. 5 plates. 1932	200: —
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N:o 99.	Tanner, V. The Problems of the Eskers. The Esker-like Gravel Ridge of Čahpatoaiv, Lapland. P. 1—13. 2 plates. 1 map. 1932 ..	60: —
N:o 100.	Sederholm, J. J. Über die Bodenkonfiguration des Päijänne-Sees. S. 1—23. 3 Fig. 1 Karte. 1932	200: —
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N:o 102.	Wegmann, C. E., Kranck, E. H. et Sederholm, J. J. Compte rendu de la Réunion internationale pour l'étude du Précambrien et des vieilles chaînes de montagnes. P. 1—46. 1933	120: —
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N:o 106.	Hackman, Victor. Das Rapakiwirandgebiet der Gegend von Lappeenranta (Willmanstrand). S. 1—82. 15 Fig. 2 Taf. 1 Analysentab. 1 Karte. 1934	140: —
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N:o 108.	Laitakari, Aarne. Geologische Bibliographie Finnlands 1555—1933. S. 1—224. 1934	200: —
N:o 109.	Väyrynen, Heikki. Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. S. 1—24. 7 Fig. 1 Karte. 1935	80: —
N:o 110.	Saksela, Martti. Über den geologischen Bau Süd-Ostbothniens. S. 1—35. 11 Fig. 1 Titelbild. 1 Taf. 1 Karte. 1935	100: —
N:o 111.	Lokka, Lauri. Über den Chemismus der Minerale (Orthit, Biotit u. a.) eines Feldspatbruches in Kangasala, SW-Finnland. S. 1—39. 2 Abb. 1 Taf. 1935	100: —
N:o 112.	Hackman, Victor. J. J. Sederholm. Biographic Notes and Bibliography. P. 1—29. With a vignette. 1935	80: —
N:o 113.	Sahama (Sahlstein), Th. G. Die Regelung von Quarz und Glimmer in den Gesteinen der finnisch-lappländischen Granulitformation. S. 1—110. 5 Fig. 80 Diagr. 3 Taf. 1936	160: —
N:o 114.	Haapala, Paavo. On Serpentine Rocks in Northern Karelia. P. 1—83. 21 fig. 2 maps. 1936	120: —

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N:o 116.	Väyrynen, Heikki. Petrologie des Nickelerzfeldes Kaulatunturi—Kammikivitunturi in Petsamo. S. 1—198. 71 Abb. 36 Tab. 1 Karte. 1938	200: —
N:o 117.	Kilpi, Sampo. Das Sotkamo-Gebiet in spätglazialer Zeit. S. 1—118. 36 Abb. 3 Beil. 1937	200: —
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N:o 122.	Hietanen, Anna. On the Petrology of Finnish Quartzites. P. 1—118. 20 fig. 8 plates. 3 maps. 1938	200: —
N:o 123.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XII. P. 1—107. 20 fig. 3 planches. 1938	200: —
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N:o 126.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIV. P. 1—140. 60 fig. 4 planches. 1941	150: —
N:o 127.	Mölder, Karl. Studien über die Ökologie und Geologie der Bodendiatomeen in der Pojo-Bucht. P. 1—204. 7 Abb. 1 Karte. 14 Diagr. 14 Tab. 1943	200: —
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N:o 141.	Simonen, Ahti. On the Petrochemistry of the Infracrustal Rocks in the Svecofennidic Territory of Southwestern Finland. P. 1—18. 7 tabl. 5 fig. 1948	25: —
N:o 142.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXI. P. 1—129. 45 fig. 1 planche. 4 tabl. 3 cartes 1948	200: —
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N:o 145.	Salmi, Martti. Physical and Chemical Peat Investigations on the Pinomäensuo Bog, SW. Finland. P. 1—31. 12 fig. 1 table. 1949	50: —
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